

**TOWARDS A MODEL FOR ARTIFICIAL AESTHETICS**

*Contributions to the Study of Creative Practices  
in Procedural and Computational Systems*



Universidade do Porto  
Faculdade de Belas Artes

# TOWARDS A MODEL FOR ARTIFICIAL AESTHETICS

*Contributions to the Study of Creative Practices  
in Procedural and Computational Systems*

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## ABSTRACT

This work proposes the development of an analytical model and associated terminology for computational aesthetic artifacts. Faced with the growing presence and widespread usage of computational media, we start by studying how they quantitatively transform previous media through remediation, and the qualitative transformations induced by their procedural and computational properties. To grasp the creative potential and uniqueness of computational media we develop a framework for their practice, critique and analysis.

We resort to Espen Aarseth's typology for cybertexts as a starting point for the work, studying its adequacy for the analysis of ergodic visual and audiovisual pieces, adapting and expanding it with three variables and associated possible values. The model is tested in a set of samples that represent diverse approaches to procedural creation and contemporary clusters of activity. A control analysis is developed to assert the usability and usefulness of the model, its capability for objective classification and the rigor of the analysis.

We demonstrate the partial adequacy of Aarseth's model for the study of artifacts beyond text-based systems and expand it to better suit the objects in study. We conclude that the model we present produces a good description of the pieces, clustering them logically, reflecting stylistic and procedural affinities between systems that, if studied from their physical or sensorial properties or from their surface structures alone would probably not be found to be similar. The similitudes revealed by the model are structural and procedural, attesting the importance of computational characteristics in the aesthetic appreciation of the pieces. We verify our initial conjecture about the importance of procedurality not only in the development and implementation stages of the works but also as conceptual grounding and aesthetic focus in artistic creation and appreciation, as an aesthetic pleasure in itself.

Keywords: *Algorithmic, Art, Design, Digital, Ergodic, Generative, Media, Procedural.*

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## RESUMO

Este trabalho propõe o desenvolvimento de um modelo analítico e da terminologia a ele associada para o estudo de artefactos estéticos computacionais. Reconhecendo a presença e uso crescentes dos media computacionais, começamos por estudar como através da mediação eles transformam quantitativamente os media precedentes, e como as suas propriedades procedimentais e computacionais os afectam qualitativamente. Para perceber o potencial criativo e a especificidade dos media computacionais, desenvolvemos um modelo para a sua prática, crítica e análise.

Como ponto de partida recorreremos à tipologia desenvolvida por Espen Aarseth para o estudo de cibertextos, avaliando a sua adequação à análise de peças ergódicas visuais e audiovisuais, adaptando-a e expandindo-a com novas variáveis e respectivos valores. O modelo é testado através da análise de um conjunto de peças que representam diversas abordagens à criação procedimental e diversas áreas de actividade criativa contemporânea. É posteriormente desenvolvida uma análise de controlo para avaliar a usabilidade e utilidade do modelo, a sua capacidade para a elaboração de classificações objectivas e o rigor da análise.

Demonstramos a adequação parcial do modelo de Aarseth para o estudo de artefactos não textuais e expandimo-lo para melhor descrever as peças estudadas. Concluimos que o modelo apresentado produz boas descrições das peças, agrupando-as logicamente, reflectindo afinidades estilísticas e procedimentais entre sistemas que, se estudados com base nas suas propriedades sensoriais ou nas suas estruturas de superfície provavelmente não revelariam muitas semelhanças. As afinidades reveladas pelo modelo são estruturais e procedimentais, e atestam a importância das características computacionais para a apreciação estética das obras. Verificamos a nossa conjectura inicial sobre a importância da procedimentalidade não só nas fases de desenvolvimento e implementação das obras mas também como base conceptual e estética na criação e apreciação artísticas, como um prazer estético.

Palavras-chave: *Algorítmico, Arte, Design, Digital, Ergódico, Generativo, Media, Procedimental.*

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## INTRODUCTION

### The Ubiquity of Digital Media

Over the course of the last decades we have witnessed a growing presence of computational media and tools in many areas of contemporary life,<sup>1</sup> ranging from those aspects that were traditionally associated with technologies to the more mundane details of everyday routine. As artists or designers, we are particularly aware of this in all that is closer to our activities, not because the phenomenon is especially prevalent there but perhaps because that is where we deal with it more frequently, where we witness that many media, as well as the mainstream communication channels, are taken over by computational systems. From being used as tools to becoming the media themselves, computational devices have been growing to be nearly ubiquitous parts of our lives and their presence is doing much more than just altering the vehicles for communication: it is fundamentally changing the media and the work produced *in, with* and *to* them.

Technological, social or cultural changes in a medium alter what one can do with or for it by imposing different constraints and affordances on the designer or artist, therefore necessarily influencing the products of their work and eventually trans-

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<sup>1</sup> We should note that we are particularly mentioning Western life, but these technologies have touched a majority of the world's population, both in Western countries as in the so-called developing economies. Not everyone has equal opportunities of access to computers, to the Internet or to the latest technologies, but computational media and technologies assume many different forms and exist in a complex gradient that surpasses the newest products and overnight builds.

forming the medium into something altogether different.<sup>2</sup> The changes brought about by computational media are however very different from previous transformations, not only quantitatively — as we will see, computational media are excellent remediators and their resolution has been steadily increasing — but especially qualitatively — as we are for the first time able to program our media, to create artifacts that are autonomous from their creators and users and that, are ultimately also able to create themselves, to generate new messages and artifacts on their own.

Because computational media are still somewhat recent, we have not yet had the time to experiment and develop them into coherent and mature tools and technologies of communication. We are in a continuous process of learning and shaping these media, a process that is balanced by the dialectics between the so-called traditional, or precomputational forms of media — those that for the most part shape our historic experience, our knowledge, skills, training and lexicon — and the new forms — those that inherit much from them but that sometimes also transform the established media almost beyond recognition. We are in the era of computational *incunabula*, where experimentation abounds and its products slowly help the new media to be defined, a time where older media are updated by new technologies, new media are developed and sometimes become obsolete<sup>3</sup> as part of a continuous process of change. We are not only in the era of transformation but rather in the era where we realize that transformation is not only inevitable as it is permanent, that the media will perhaps never crystallize and become reliable, uniform and standardizable.

In the most diverse areas of artistic activity we discover creators that use computational tools and media in the development of their work, sometimes integrating them in noncomputational processes or devices, sometimes making them become the sole objects and instruments of work. Even if one disregards those artists and designers that turn to computational media because their analog counterparts become too expensive or otherwise inconvenient to use, and look solely for those that, to put

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<sup>2</sup> These should not be interpreted as being negative constraints or limitations, as they can very often represent new possibilities and open new territories for exploration. They are, nevertheless, always constraints, more or less long lists of dos and don'ts, of possibilities and impossibilities.

<sup>3</sup> See, as an example, the now defunct interactive CD-ROM, that once promised to change the cultural landscape and already seems to be a bygone archaeological artifact. This is far from being the only example, at a time when besides the so-called 'planned obsolescence' of platforms, the media cycles seem to become continuously shorter.

it simply, use what is *new* in the *new* media, there is a wealth of examples to be found in literature, music, visual or performing arts, communication and industrial design, architecture and fashion, of practitioners that devote their time and resources to the exploration of computational media and arts and that have been discovering a fertile ground for creation with computational systems. And there are, besides these more easily classifiable genres, entirely new fields of work that emerged from these tools and media, as for example computer games. The ubiquity of tools and the similarity of working methods, media and processes across artists and designers with diverse backgrounds, leads to a blurring of boundaries between practitioners and many of the fields where they are active. Therefore, it becomes increasingly difficult to classify the practices or their products as belonging to well-defined fields or genres. Furthermore, even if they do belong to what one may recognize as specific genres or fields, the commonalities of tools and processes may lead to the sharing of common traits among otherwise very diverse artifacts.

### **The Necessity of a Terminology**

As we will see, the lack of an established and rigorous terminology for computational media is a serious disadvantage in their practice and study. Practitioners bring with them terminologies that were inherited from the most diverse fields of visual arts, design, aesthetics, computer sciences, mathematics or life sciences, terminologies that are not always compatible and whose normalization becomes essential. A normalized terminology should contain a nomenclature that is rich enough to describe new and unprecedented phenomena with no clear references in other fields of work, while dealing with authorial, technical, narrative and dramatic issues, as well as with aspects from cognition, interaction and agency, and it should recognize computational aesthetic artifacts as being a heterogeneous set of objects and systems. It should not be dependent on ad hoc perspectives or on particular contexts of implementation or usage of the pieces but rather recognize the history and diversity of computational practices. It should also not be focused in the physical strata of the artifacts, that are not only very assorted as they are often volatile and described by other terminologies that can coexist within their specificities, but rather in their computational properties, where one can find the most relevant shared traits. Computational aesthetic artifacts need a theory, a criticism and a terminology with fuzzier boundaries between “human and machine, creative and automatic, interested and disinterested” (Aarseth 1997, 134) and that are able to offer a “distinctive power

as well as unproblematic connotations” (59) when faced with the inherent instability of both traditional as well as ‘new’ media forms. Finally, this terminology would benefit from being functional and phenomenological, not dependent of (or describing) code, but rather of the actions and effects of the code.

### **Starting Point**

The model developed by Espen Aarseth (1997) proposes a typology of textual communication that is able to describe what he terms of ‘cybertexts’, characterized by their mode of traversal, i.e. by the ‘non-trivial effort’ that a reader needs to develop in their experimentation. His model synthesizes the most prominent characteristics of these works through seven variables, each with a range of two to four possible values, creating a “multidimensional space of 576 unique media positions” (64) where each text’s profile is defined. Because of the similarities between cybertexts and the computational aesthetic artifacts in which we will focus our study, we find this model to be a solid and interesting starting point on which to base the development of a model that is able to describe a broader scope of aesthetic computational artifacts, that strives to find the common characteristics among a big diversity of systems. For this endeavour we will need to assert the suitability of Aarseth’s model and to adequate or expand it with further variables if that proves to be necessary, but we will always keep in mind that it is essential to arrive to a model that is as simple and manageable as possible, a definitive requisite for its universality.

### **A Survey of the Clusters of Activity**

As an introduction to this work we will sample some of the current clusters of activity of computational artists and designers, where one discovers artifacts that not only express their computational nature as well as that of the tools used in their creation, artifacts that besides and beyond their classic aesthetic properties also encode and embody processes and appeal to a sense of procedurality. We will look at some fields that can perhaps be classified as being in the fringes of mainstream activity, and will not delve into other fields that although being more popular or more commonly perceived as making use of digital tools are nevertheless using them mainly as simulators, not as generators.<sup>4</sup> This does not mean that the contemporary us-

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<sup>4</sup> Such is for example the case in photography and cinema, by altogether different reasons. In photography, the optical appropriation of the visible (external, real) world is generally agreed as being the central

age of computational aesthetic systems is only to be marginally found in art and design practices, much on the contrary. We can find several international festivals and awards dedicated to media and computer arts, some of them happening for over thirty years — like the *Ars Electronica* festival in Linz — some of them more recent — *Transmediale* in Berlin, *Offf* in Barcelona, then Lisbon and now Paris, *Pixelache* in Helsinki, *File*, *Festival Internacional de Linguagem Eletrônica* in São Paulo or *Future Places* in Porto, among several others — that have been bringing computational arts to wider audiences and endowing them with institutional recognition and specialized venues. Several museums have been dedicating shows to computational arts and studying the phenomena through associated critical and historical publications. Recent examples are *El Proceso Como Paradigma*,<sup>5</sup> *Decode: Digital Design Sensations*,<sup>6</sup> *See this Sound*,<sup>7</sup> or *Design and the Elastic Mind*,<sup>8</sup> to name just a few. Artists, designers, festivals and museums alike, not always strive for a differentiation or to underline the specificity of computational (or digital, or generative) practices, but often intend to affirm them as an integral part of the respective preexisting areas of work, looking at computational practices as something that although deeply transforming *how* things are done and *what* is done, does not however affect *why* things are done. As we shall see, this should not be taken as an a priori axiom. Computational media and tools are not simply just a new way to do what was done with traditional resources, and much as they affect the practice and the surface structures of the artifacts, they also transform the most fundamental aspects of art and design, leading us to question their essence and our roles as human participants.

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defining trait of the discipline. Digital technologies have for a long time been used in photography and the digital manipulation of analog or digital captured stills is nowadays commonplace. Retouching, enhancing and editing images with digital tools is as commonplace as any other step in the work process of a photographer but the link with physical reality, however tenuous, cannot be breached, if one is still to talk about photography as a genre and not amend our classification and use photography simply as a classifier for a technical resource used in the production of something else. When considering cinema, and understanding it as the deeply narrative art form that has been developed for well over a century now, it is also very rare to find digital technologies used in the production of works that are not deeply linked with the human experience of reality, no matter how spectacular and otherworldly may the special effects be — or, conversely, how discreet and omnipresent may digital manipulation be in a given film. In a sense, nothing can ever be truly new in narrative film because if it is, it will cross the genre border and probably start to be classified as something different: visual art, visual music, animation or ‘experimental’ film, the adjective usefully distinguishing it from the mainstream and preparing the viewer for something that shares properties with a familiar medium but that does not follow some of its conventions.

5 Curated by Susanne Jaschko and Lucas Evers at Laboral in Gijón, April 23 to August 30, 2010.

6 At the Victoria & Albert Museum in London, December 8, 2009 to April 11, 2010.

7 At the Lentos Art Museum in Linz, August 28, 2009 to January 10, 2010.

8 Curated by Paola Antonelli and Patricia Juncosa Vecchierini at the Museum of Modern Art in New York, February 24 to May 12, 2008.

## Literature

Literature was one of the fields where computational media were first explored in creation. The relative simplicity of the resources needed for writing and for the encoding of text allowed literature and text-based media to explore the creative potential of these tools earlier than other fields that demanded higher resolution, bandwidth or processing power. Electronic texts, hypertexts or other types of text-based systems — collectively referred to as ‘cybertexts’ by Aarseth — have been produced in or with computers since the mid-twentieth century and many authors have since studied literary production with computers.<sup>9</sup>

Being as they are deeply linked to language, literature and text-based communication have also been fields of interest for computer scientists working in artificial intelligence and creativity. Software and language are “intrinsically related, since software may process language, and is constructed in language” (Cramer 2008, 168) but naturally, research on artificial intelligence goes far beyond and has many other concerns besides natural language systems.

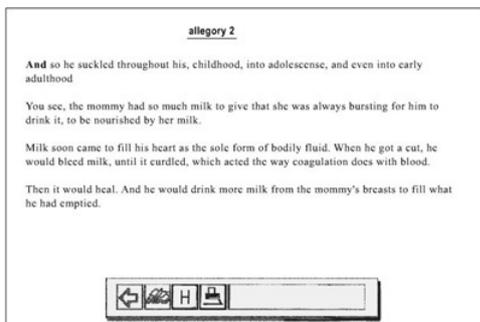


Fig. 1: *Afternoon, a Story* (Joyce 1990).

<sup>9</sup> One of the first creation-oriented pieces of software was the word processor, a “medium for the creation and modification of linguistic structures that play a role in human communication” (Winograd 1990, 5) and a tool that is “empty of information” (Ullman 1997, 79) and that waits “patiently and passively for their human owners to put something interesting into [it]”. Although its relevant domain, in the user’s perspective, is not a computational one, it turned the activity of writing into a computational activity and added to it new levels of abstraction and new affordances. Starting as a simulator of a typewriter, the word processor evolved into something much more complex, even while it was physically attached to a typewriter. “We cannot take the activity of writing as an independent phenomenon. Writing is an instrument — a tool we use in our interactions with other people. The computer, like any other medium, must be understood in the context of communication and the larger network of equipment and practices in which it is situated. A person who sits down at a word processor is not just creating a document, but is writing a letter or a memo or a book. There is a complex social network in which these activities make sense. The significance of a new invention lies in how it fits into and changes this network.” (Winograd 1990, 5-6)

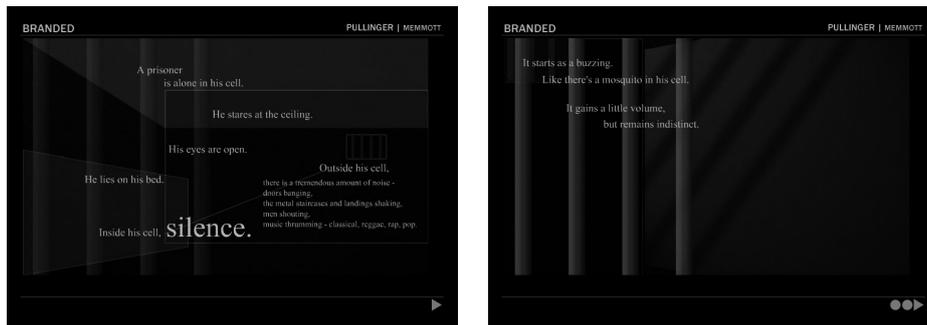


Fig. 2: *Branded* (Pullinger and Memmott 2003).

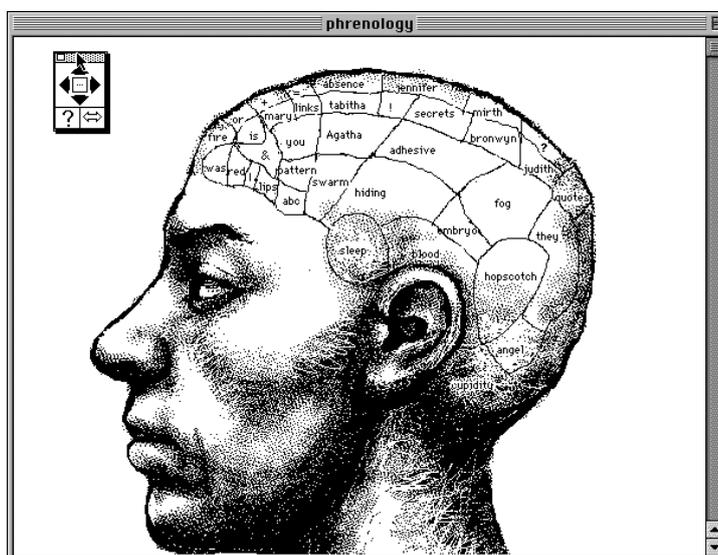


Fig. 3: *Patchwork Girl* (Jackson, 1995).

Language is not only words and sentences. It is a type of semiotic activity that provides us with insights into the vaster domain of communication, but that does not serve as its general model (Wilden 1987, 124). Human natural languages are symbol systems and these are the root of human communication, regardless if they are organized into what we may recognize as a human language or if they take any other form.<sup>10</sup> Art is one of those forms, one that can be understood as a complex collection of symbol systems (Lee 2006, 30), but naturally, not all symbol systems have the same capacity to encode and transmit information, or to communicate, to refer to or to represent things in the world. They depend, as we will see, on their capacity to be notational.

<sup>10</sup> "Let it be emphasized that the communication of information does not necessarily imply the use of (human) language, nor consciously perceived sending or receiving, nor consciously intended communication, nor consciously noted understanding." (Wilden 1987, 124)

## Music

Western music depended on notational written languages for centuries before computers were developed and eventually started to be used in composition and later on music recording and performance. Nowadays it is becoming hard to picture how contemporary music can be produced, performed and recorded without the assistance of digital tools, but most of the times these tools are still used as replacements and simulators of their analog forerunners. We can however find several fields of music creation that came into existence due to the development of computational tools and media or that explore a particular interest in the computational aspects of music creation — from academic composers to computer musicians and sound artists — and this has been one of the areas of artistic production where a steady production of conceptually interesting work has been recorded since the early 1950s. There is not only a large corpus of theory published on computation and music (and the use of computers in music), as there are several journals, academic publications and conferences dedicated to this field.

The image displays a complex handwritten musical score for the piece *ST/10-1, 080262* by Iannis Xenakis. The score is written on multiple staves, each labeled with an instrument or voice part: Clarinet (Cl), Bassoon (Bt), Cor Anglais (Cor), Horn (Cor II), Harpe (Harp), Comp (Computer), Trompe (Trumpet), Violoncello (Vc), and Violon (Violin). The notation is dense and includes various musical symbols such as notes, rests, and dynamic markings. At the top left, there is a box containing the text 'J=4' and 'd = 40 ← 60 ← 80 MM'. The score is organized into measures, with some measures containing multiple notes and rests, indicating a complex rhythmic structure. The overall appearance is that of a detailed and intricate musical manuscript.

Fig. 4: Bars 1-5 of the score of *ST/10-1, 080262* (Xenakis 1956-62), computed in an IBM-7090 (1992, 154).



Fig. 5: View from Florian Hecker's 2010 show at the Ikon gallery, Birmingham.

This work will not focus exclusively in the fields of literature and music, rather it will study the usage of computational tools in the creation of visual arts and design, mentioning however several examples from both areas whenever they are necessary, aware that textual and sonic communication are indispensable components of many contemporary artistic and design practices.

### Visual Arts and Communication Design



Fig. 6: *Hummingbird* (Csuri and Schaffer 1967).

Visual arts have been a fertile ground for experimentation with computational systems. Later in this work we will develop a brief historical survey of pre- and early computational systems used by visual artists, and many of the works cited as examples during this text will be drawn from contemporary arts.

Not only because of a necessity for absolute innovation (or originality) that is instituted in the practice of visual arts but also because more often than not contemporary artistic production focuses on the construction of singular objects rather than multiples or mass-produced copies — not necessarily subjected to requirements of compatibility with existing media, platforms or conventions, or of ease of use and familiarity of users with tools and media<sup>11</sup> — this is often a field where there is a great capacity for experimentation and innovation, along with the possibility to develop prototypes of systems and processes that can then be posteriorly redeveloped in other fields.

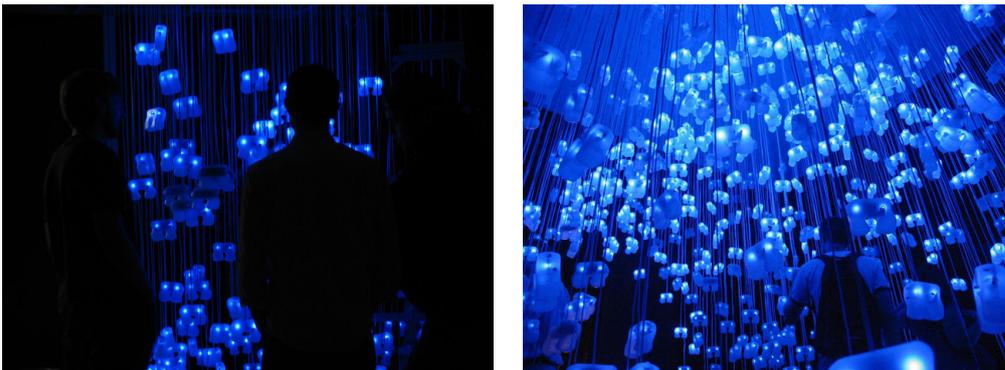


Fig. 7: *Bion* (Brown and Fagg 2006).

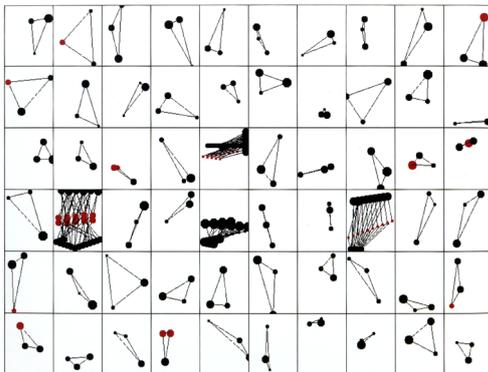


Fig. 8: *CodedocII* (Simon 2003).

<sup>11</sup> Actually, often productively exploring the effects of strangeness or misfit with conventions as part of the artwork's conceptual schema.

Communication design is one of the fields where we traditionally witness the redeveloping of formal and technical research originating from visual arts.<sup>12</sup> It is also, somewhat conversely, an area where it is difficult to avoid or choose the media and technologies, as they are often specified by clients or audiences. Although it may be somewhat common to find that communication designers tend to develop a more conservative approach than visual artists, it is nevertheless possible to find several designers that are in the forefront of contemporary procedural creation — often working across the borders that split commercial design and artistic practice and possible to be classified as artists, designers or programmers.

Since the popularization of desktop publishing in the late 1980s there were successive waves of digitally influenced styles<sup>13</sup> in communication design, exploring the possibilities that were opened by digital typography, typesetting, photography and by all the various tools of the trade that were computerized or created from computers. By and large, however, during most of the later years of the twentieth century, the media to which communication design catered were analog or, using a definition that is more useful and accurate in the context of this work, noncomputational. Even if designers were working with digital tools, the outputs of their work were ultimately converted to analog tokens and even when the work process involved proceduralism (in the sense we will define it here) the final artifacts that were produced could not, in most cases, support it. As digitalization of the media became more pervasive, the opportunities to develop design works as processes have therefore grown.

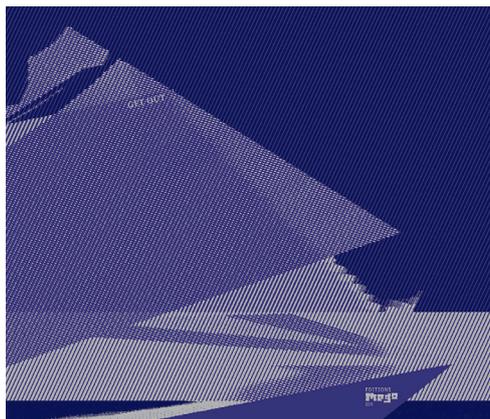


Fig. 9: Cover for *Get Out* (Frank 1999).

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<sup>12</sup> Communication design's entanglement with visual arts in general and this redevelopment in particular are in themselves broad subjects, that although fascinating, we cannot pursue in this work.

<sup>13</sup> Or trends, or fads, sometimes leading to almost baroque excesses.

The idea of developing works as processes is in itself nothing new in communication design. In various ways it is present in many corporate identity projects, and in book or magazine design for example, should one choose to view them in this perspective. Systems and rules for variation and derivation in design projects are an integral part of design work, as is the necessity to develop artifacts that will ultimately become independent from their creators or contexts of creation: e.g. logos, brands and corporate identities, typefaces or layout projects for periodical publications. Still, before computational media these systems had to be deployed and explored by other artists or designers, and could not be autopoietic, that is, could not develop themselves, in autonomous or semi-autonomous ways.

Newer computational media allow designers to create digital tokens that incorporate processes and that *are* processes, to create works that are not static media messages but that are as complex and diverse as the audiences with whom designers communicate. Identity projects become more than sets of rules aimed at designers and start to be able to dynamically interpret those rules and to generate variable outputs adjusted to particular contexts or media.<sup>14</sup> This can of course be done at a superficial formal level, creating multiple variations of a design or multiple designs based in the same set of formal rules but can also be taken further, massively customizing designs to provide individuals with unique artifacts, tailored to their own needs, requests or contexts of usage.<sup>15</sup>

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<sup>14</sup> One of the earliest procedural identity projects was developed for an online medium: the rhizome.org logo (Weisbeck and Hauschild 2001) was generated on the fly from the IP addresses of the last four visitors to the website, keeping the same typographic structure but recomposing the remaining graphic elements in the logo. At the time of the writing, the logo has already been redesigned, eliminating the procedural component.

<sup>15</sup> An example of which is the so-called adaptive design of interfaces, an approach to website design that instead of composing layouts as fixed pages rather searches for optimal strategies to vary compositions across different devices and display aspect-ratios and resolutions, in order to provide a consistent user-experience and platform identity across a range of possible alternatives.

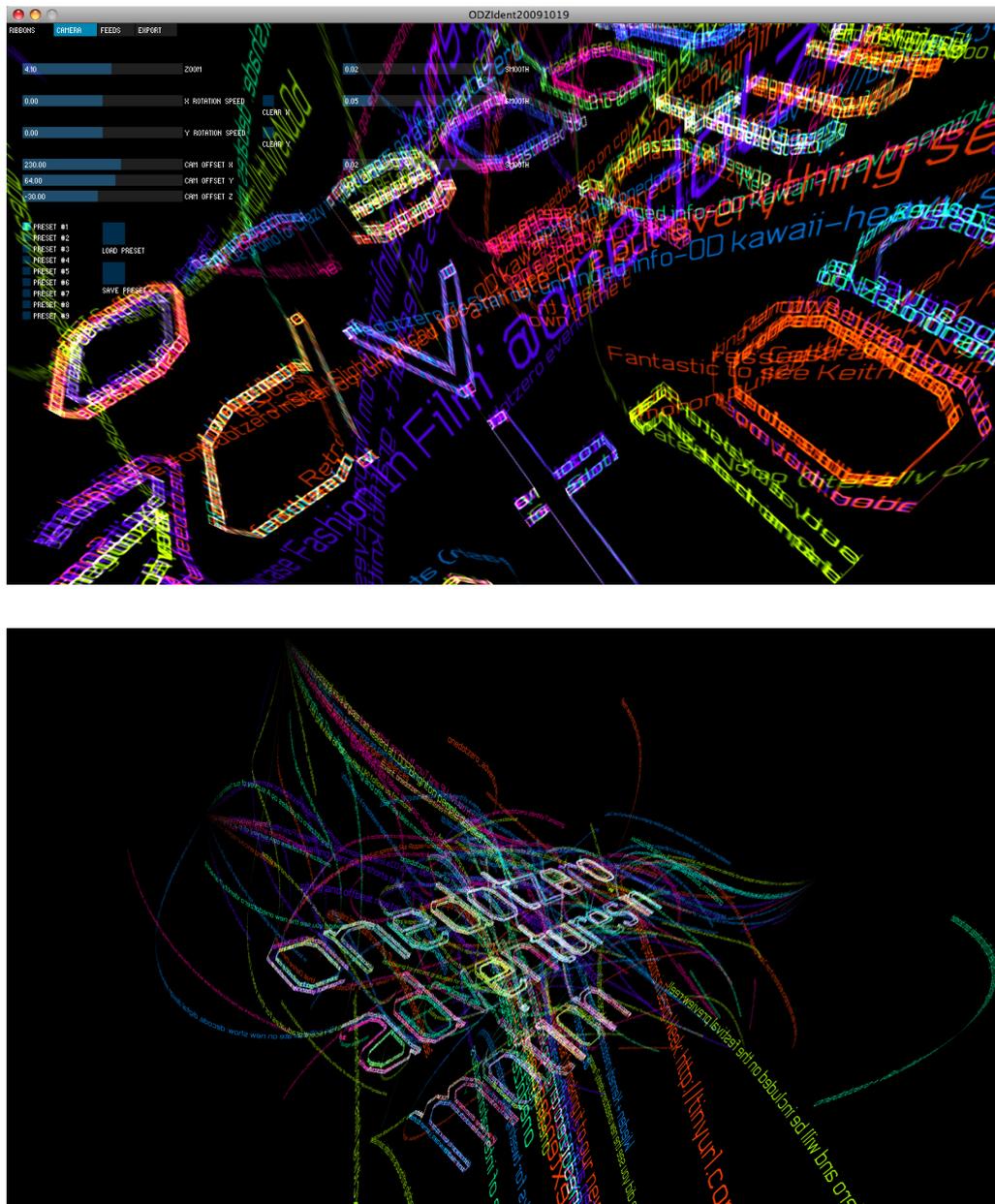


Fig. 10: Visual identity of the *onedotzero* festival (Wieden + Kennedy London and Schmidt 2009).

Digital printing frees the designer from the forced repetition of mechanical reproduction and allows the development of a variety of outputs even in print form, not congealing one analog token from a process but rather representing the process through a vast number of tokens that are articulated in a project. Unlike paper-based hypertexts,<sup>16</sup> identical printed tokens that can be read differently by each read-

<sup>16</sup> That some would perhaps prefer to call 'prohypertexts' in an attempt to distinguish electronic texts from paper-based texts with paths or similar devices (Aarseth, 1997, 75).

er, these artifacts provide different readings because they can, quite literally, be created different from each other.<sup>17</sup>

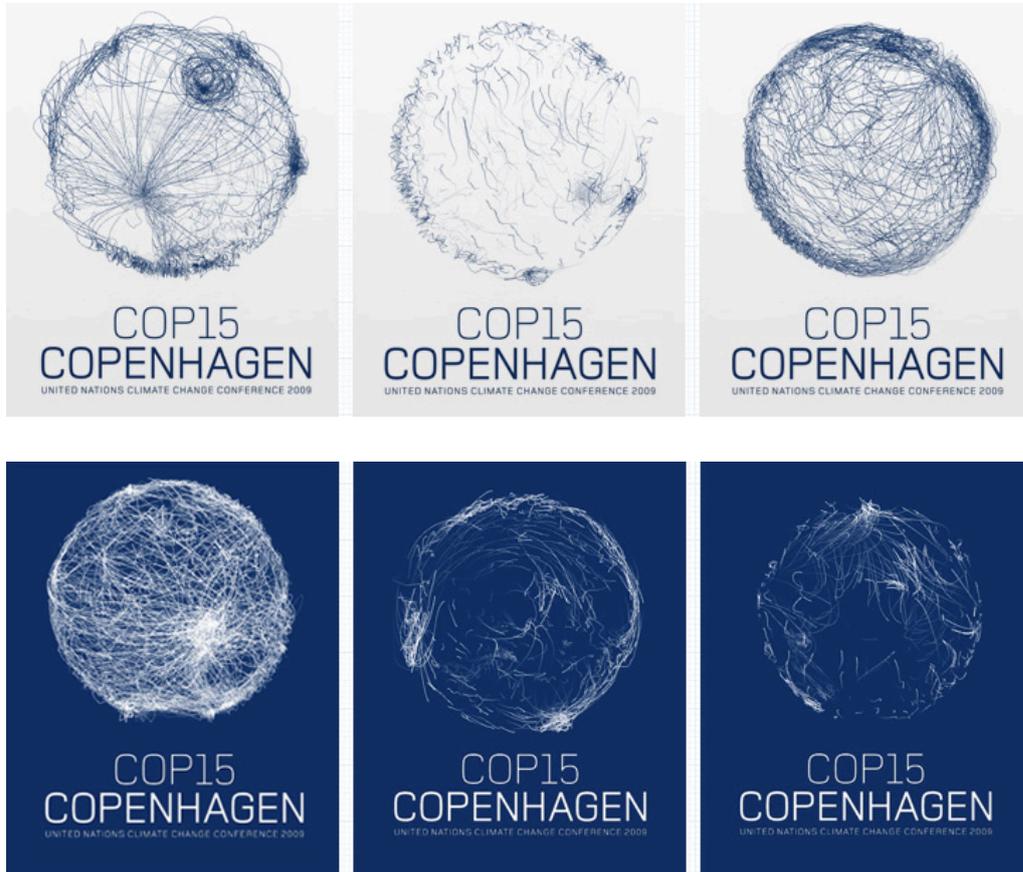


Fig. 11: Identity for the *United Nations Climate Change Conference* (NR2154 and Shiftcontrol 2009).



Fig. 12: Books from the *Faber Finds* collection (Wall and Schmidt 2008).

<sup>17</sup> An interesting example is the work-in-progress book *Written Images*, edited by Martin Fuchs, created from programmed images, with each print calculated individually, each book a unique token.

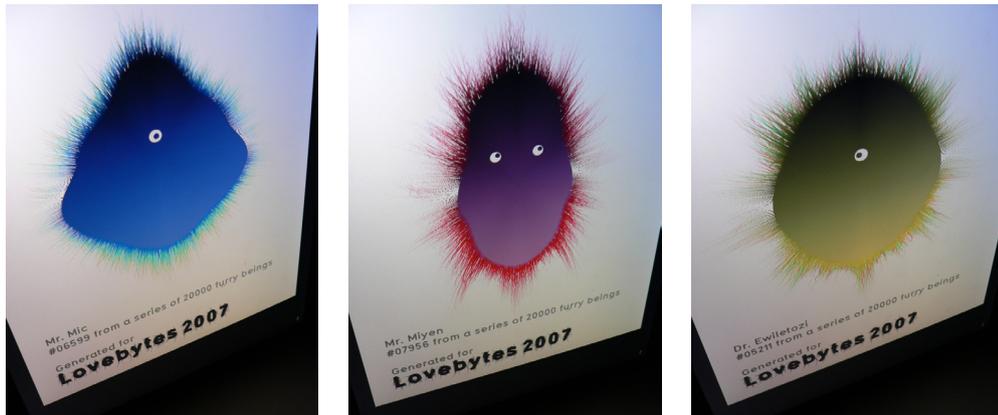


Fig. 13: Three postcards for the *Lovebytes Festival* (Universal Everything 2007).

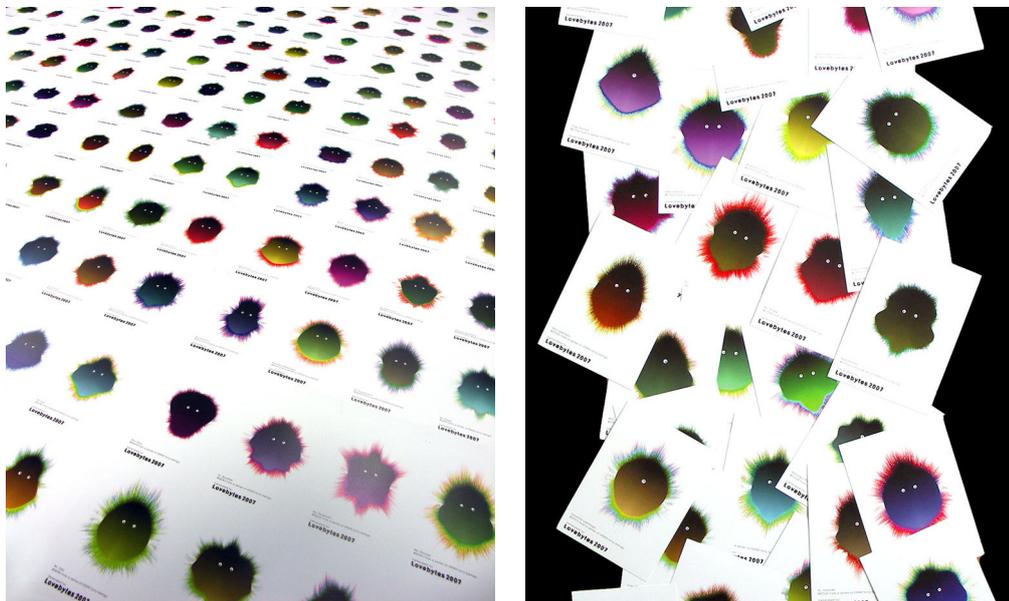


Fig. 14: Postcards for the *Lovebytes Festival* (Universal Everything 2007).

An area of communication design that has been particularly affected by computational technologies is that of information visualization. The visual display of quantitative information<sup>18</sup> has for a long time been a part of communication design, helping authors and readers to assimilate and interpret large volumes of data. Interactive visualization has been developed practically since the first capable computer systems allowed it and have since been used in science and engineering.<sup>19</sup> The mass media-

<sup>18</sup> To borrow Tufte's title (2006).

<sup>19</sup> It is not surprising to discover that Charles Babbage, whose *Analytical Engine* we will discuss later, worked in the recording and visualization of information concerning vibrations and motions of railway carriages drawn by locomotives at known velocities (Tomas 2004, 37).

tion of interactive information visualization has been growing along (or with) digital technologies, media and networks. As digital data becomes more abundant and accessible and the infrastructure to communicate and visualize it becomes more powerful, the visualization tools need to not only allow the mapping of a particular (and closed) dataset as to be able to update and filter the data according to the user's needs, something that cannot be done without an understanding of the data, of visualization techniques and of the computational processes involved in these.

### Audiovisuals, Performance Arts

Digital capture, editing and manipulation has radically transformed several areas of the audiovisual industry, turning much of contemporary film into a melting-pot of analog and digital processes.<sup>20</sup> A clear growth of the weight of digital processes is noticeable, extending to all areas, including television production, newscasting,<sup>21</sup> fiction, entertainment, set design, etc.



Fig. 15: *Pixilation* (Schwartz and Knowlton 1970).

Film was among the first media to be used in computer art — if a process could be output as a sequence of frames, independently of the rendering time necessary for each frame, an output to film would allow the creation of animated sequences out of otherwise static outputs — but the ongoing increase in processing speed of computational media allowed digital animations to start to be created in real-time<sup>22</sup> and for artists to develop visual pieces that were not film- or video-based (neither in capture or archival media) but were rather displayed as the system processed its program. This created the potential for the creation of ever-changing dynamic artworks, that were in a sense close to traditional visual arts but different from anything ever pre-

<sup>20</sup> The capture of image or performance — which includes motion-capture — is still normally involved, even with computer-generated imagery, when the actual images of the actors are not used. To be exact, the capture itself is a digital process so, as we will see in chapter 1, it is not *analog* but rather *somatic*.

<sup>21</sup> An area where information visualization is also of particular importance.

<sup>22</sup> Or in some cases, faster than real-time.

viously developed. John Maeda refers to these non-interactive dynamic visual compositions as ‘motion paintings’, other artists, as for example C.E.B. Reas, prefer to define them as installations. Regardless of the semantic distinction, the exhibition of computational animations has become common over the last decades.



Fig. 16: *Amber Waves* (Maeda 2003).

Whenever audiovisual articulation may be an issue, when the animations develop a defined narrative or whenever there are constraints with the archival and diffusion media, computational animation is often offset to digital video, thus losing the potential for variability but gaining in ease of access. When not only created in real-time but also performed to an audience<sup>23</sup> (with or without music) and taking

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<sup>23</sup> The concept of performance generally implies, as we will see, a coprocessing with a human performer. This is a topic that in itself would justify a longer discussion but that very often can be defined by the presence of a human interactor or performer that controls or collaborates with the computational system, in a performative context — that is, a context where the actions of the performer as well as the outputs of the performance are both visible and presented as the artistic act. If the human performer is not present or if the performative act is not readable (i.e. not necessarily visible, but somehow perceivable) by the audience (however complex and strenuous it may be) then the audience will often tend to perceive the presentation as a ‘reproduction’ (as in cinema) or ‘diffusion’ (as in *electronische musik*) and not as a performance.

the center role in the performance, we can speak about *real-time visual performance*, *live visuals*, *video-jockeying*<sup>24</sup> or *visual music*.



Fig. 17: Live visuals performed at the Hugo Wolf festival (Lia 2010).

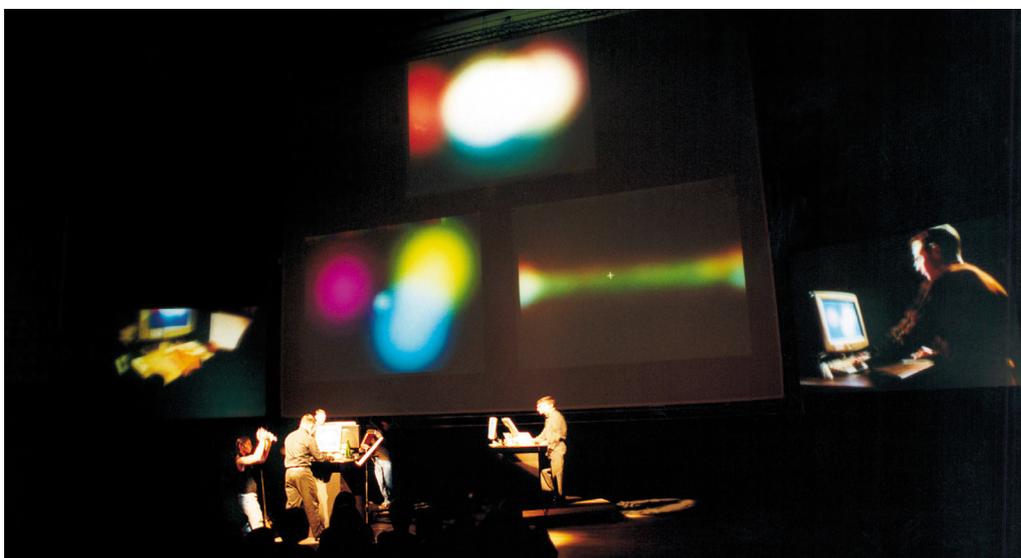


Fig. 18: Performance of *Scribble* (Levin, Shakar and Gibbons 2000) at the Ars Electronica Festival.

<sup>24</sup> Or vj, a term that although understandable for historical origins, is somewhat dubious when used to refer to artists that develop generative images and do not use video sources (i.e. captured video) in their work. Regardless of the techniques and resources used, it is still a common designation for live visual performance artists, especially when coupled with disc-jockeys, or DJs.

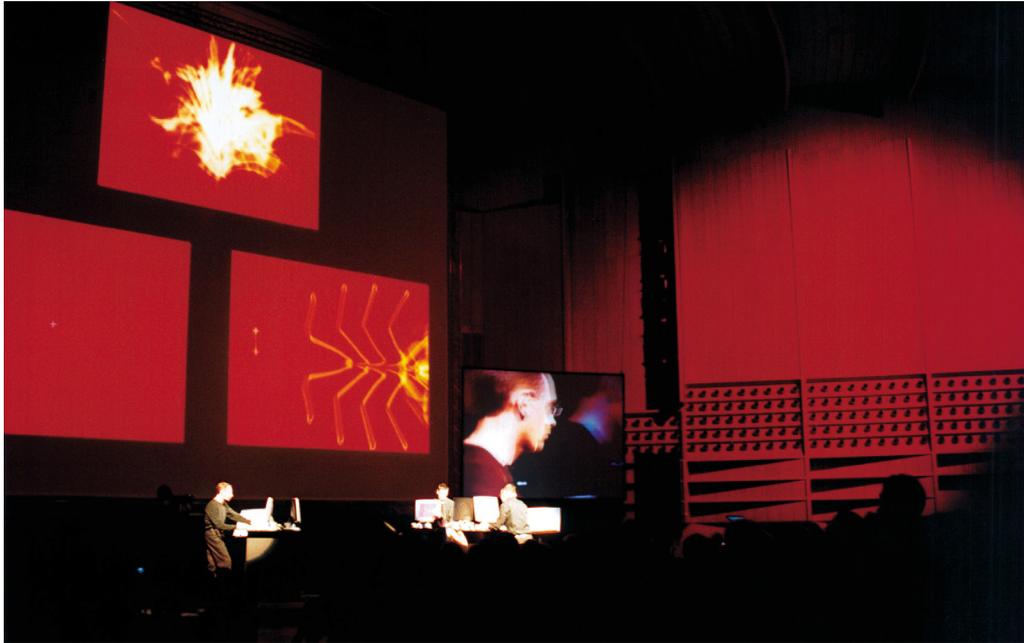


Fig. 19: Performance of *Scribble* (Levin, Shakar and Gibbons 2000) at the Ars Electronica Festival.

Other performance arts, such as theater or dance, have incorporated live computation as part of the set design or as performance resources, with varying degrees of process intensity<sup>25</sup> or of human/computer performance ratio. If at times the computational systems are used as secondary elements in the performance — as backgrounds or other scenic elements that even when transient play minor roles in the show — there are also many cases where the computational systems are brought to the fore to act with human performers or to even replace them on stage altogether and be presented as *the* performance. *Messa di Voce* (Tmema, Blonk and La Barbara 2003) is an example of an interplay between human and computational performances. In this piece both singers and computational systems form a performing unit, either of which unable to take the central role alone. Granular Synthesis's<sup>26</sup> performances *Modell 3* (1992) and *Modell 5* (1994), by eliminating humans altogether from the stage (although keeping their representations) are examples of the later, as is Ryoji Ikeda's *Datamatic [Prototype-Ver.2.0]* (2006), a live performance presented through a single-channel projection and stereo sound, resources more commonly used for cinema than for live performance.

<sup>25</sup> A concept we will later elaborate on.

<sup>26</sup> A project by Kurt Hentschläger and Ulf Langheinrich.



Fig. 20: Stage design for *Rua! Cenas de Música para Teatro* (Tudela 2003).



Fig. 21: *Modell 3* (Granular Synthesis 1992).

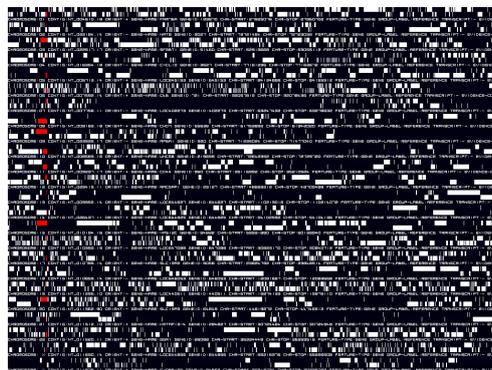
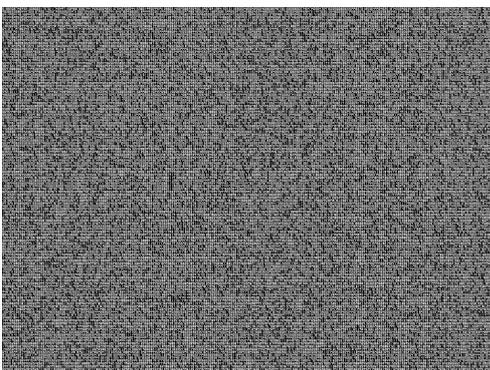


Fig. 22: *Datamatic [Prototype-Ver.2.0]* (Ikeda 2006).

Sharing venues and contexts with music or audiovisual performances we find several artists that bring into the performance not only the computational tools but also the act of programming sound, images or both, in what has been commonly referred to as ‘live coding’. These artists not only regard coding as a craft, as they see it as a performative act (Magnusson 2008, 240) and thus present its elaboration and manipulation as an integral part of the performances, writing programs in real-time, without restarting processes, with every adjustment to the code reflected in the audio or video output.<sup>27</sup>

They program in conversation with their machine, playing with instructions while a computer follows them. Here, there is no distinction between creating and running a piece of software — programs run while they are being created, gaining complexity via source code edits. We can think of coding live in the sense of working on electricity live, re-routing the flows of control around a program with the real danger that a faulty loop will get activated, causing the program to crash in sparks of logic. (...) It is not only the relationship between programmer and code that defines live coding, but also that between programmer and audience. Live coding can be a performance art, where an audience watches an artist write code while enjoying the output. As with all improvisations some preparation is necessary, but for many the aim is to begin with an empty text editor and live code their performance from scratch. (McLean 2008, 224)

If similar resources for the creation and projection of images are used outside conventional performance contexts and venues, particularly in outdoors urban public space, they may fall into what is referred to as ‘digital graffiti’, the attempt to bring computational technologies into the field of work for graffiti artists, or, as the Graffiti Research Lab puts it in their mission statement, to outfit “graffiti artists with (...) technologies for urban communication.” (Roth and Powderly 2006)

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<sup>27</sup> “Outside of the context of time based arts, live coding is generally termed dynamic programming. It began in the form of bit twiddling — modifications of low level machine instructions while they were being followed. This was done for debugging, experimentation, and hackerly fun, although in the early days of computing, hands-on access to computers was hard to come by.” (McLean 2008, 227)



Fig. 23: Digital graffiti from the EyeWriter initiative (Quan et al. 2009).



Fig. 24: Graffiti Research Lab activities in Barcelona (Roth and Powderly 2007).



Fig. 25: Projections in The Hague (Lia 2008b).



Fig. 26: Projections in The Hague (Watz 2008a).

### Games, Game Art

Interactive gaming is one of the largest entertainment industries to arise from computational media and a growing area of work for digital artists and designers, as well as a very active and fertile area for research — either on action and gaming (or research in *ludology*) or in their narrative aspects (*narratology*).<sup>28</sup> Digital games are native computational forms that are developed through interaction and sensorial outputs. As such they share properties and characteristics with several of the systems we will study in this work but they will not be our primary focus. We should however note that some game systems allow the creation of user-generated content and the transformation of the game or its engine into new and different games or game variations,<sup>29</sup> and as such can be used as media for the creation of new artworks. Several artists have explored the possibilities offered by customizable game engines or by their hacking and deconstruction, as Joan Leandre,<sup>30</sup> JODI<sup>31</sup> and Brody Condon, sometimes developing new narratives from the altered game space but often exploring glitch, obfuscation and lack of control and altering the illusions originally meant to be created by the games, revealing the artificiality of the representational spaces in a form of media hacking.

<sup>28</sup> Bogost chooses these two terms as a convenient shorthand for identifying the study of rule-based systems and story-based systems in games (2006, 68).

<sup>29</sup> Also called game ‘mods’.

<sup>30</sup> Also known as Retroyou.

<sup>31</sup> The collaboration of Joan Heemskerk and Dirk Paesmans.

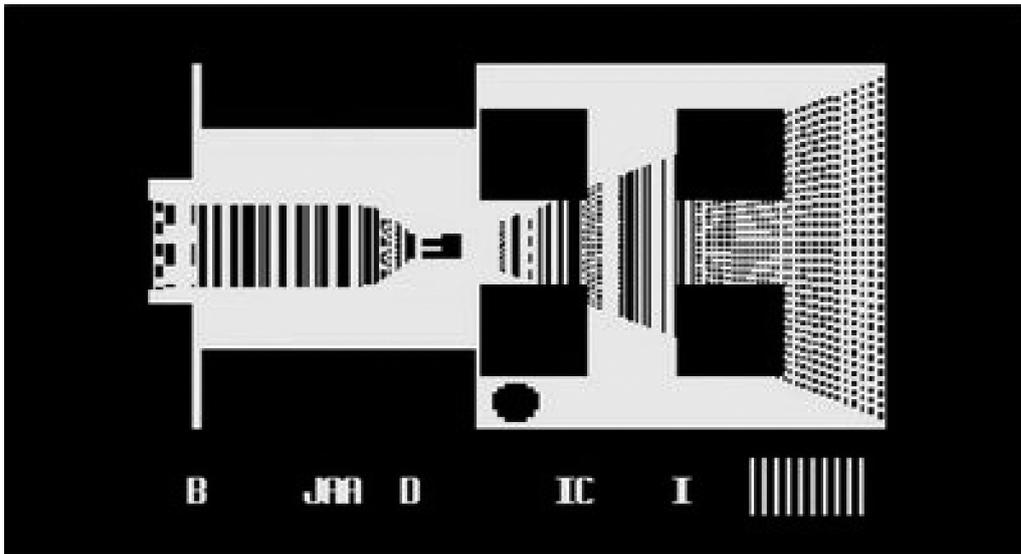


Fig. 27: *SOD* (JODI 1999).



Fig. 28: *Untitled Game* (JODI 2001).

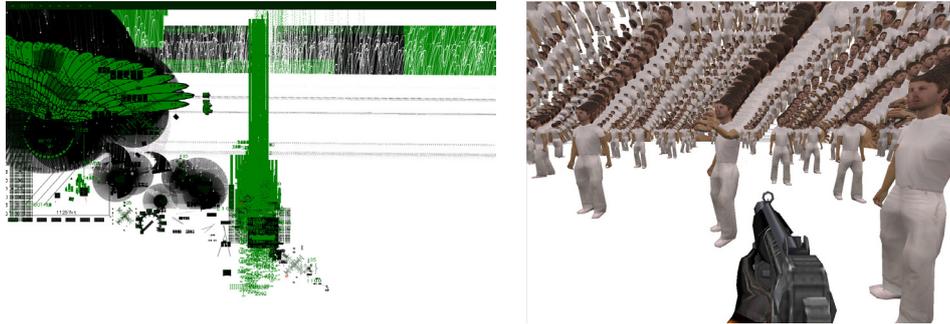


Fig. 29: *Nostal(G) \_ Phoenix West* (Leandre 2003) and *Adam Killer* (Condon 1999).

Naturally, several other authors choose to develop games from scratch, following models from well-established games or developing original concepts that can alternatively be presented as games or art, and are often both, realizing not only narrative and interactive, as well as a complex aesthetic experience that “can be enthralling. Not only can it arouse emotion, but its emotional power is one of its strengths and a major factor in its appeal.” (Lopes 2010, 116)



Fig. 30: *Sleep is Death (Geisterfahrer)* (Rohrer 2010).

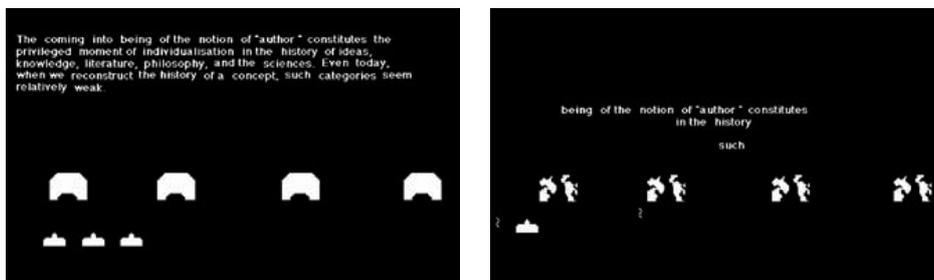


Fig. 31: *Triggerhappy* (Thompson and Craighead 1998).



Fig. 32: *The Graveyard* (Harvey and Samyn 2008).

Games and game systems are also used in the creation of *machinima*,<sup>32</sup> a cinematic appropriation of the systems to create linear narratives using the resources provided by the games instead of traditional camera capture or other animation techniques.



Fig. 33: *Red vs. Blue* (Rooster Teeth Productions, 2003-2010) a machinima series created in *Halo*.

### Architecture, Industrial Design

A survey of the applications of aesthetic computing in the realm of three-dimensional production may start with architecture, where generative or evolutionary design models have been used by several architects<sup>33</sup> in the creation of architectural drawings and building plans and where a considerable amount of theoretical work has been developed. But computational technologies applied to architecture can reach much further than the design, project and planning stages of a building, they can be used in the fabrication or construction stages and can later be used in (or by) the building itself.<sup>34</sup>

<sup>32</sup> From the misspelled portmanteau of ‘machine cinema’.

<sup>33</sup> Such as Zaha Hadid, Frank Gehry, Herzog & de Meuron or Will Alsop, to mention just a few.

<sup>34</sup> Creating what is sometimes referred to as ‘intelligent’ buildings. That however extends to far more than the mere development of amenities like self-regulating window-shades or air conditioning.

Similarly, areas as industrial and fashion design have been increasingly using computational technologies, not only for design, prototyping and simulation but, as in architecture and as the technologies allow it, also for the embedding of computational power in the objects themselves. The majority of objects produced are still, however, classic objects,<sup>35</sup> in the sense that they do not themselves develop computational processes, although they are created through them or make them visible<sup>36</sup> and although they can contain computational elements or parts.<sup>37</sup> The non-classic objects<sup>38</sup> are those where processes are not only visible but actually deployed by the objects themselves, as we will see.



Fig. 34: Computationally generated knitted patterns (Kurbak and Yavuz 2007).



Fig. 35: Computationally generated tissue prints (Reas and Reas 2008).

<sup>35</sup> ‘Artifacts’, ‘machines’ or ‘products’, according to Sterling (2005).

<sup>36</sup> To create the patterns shown in the example the designers tap into raw news data, automating the creative process and “turning semantics into aesthetics. The metaphorical process of weaving draws from, and relies on, the internet’s densely connected web of current, topical information.” (Klanten et al. 2008)

<sup>37</sup> In this sense we can consider that most ‘intelligent’ buildings simply contain some computational elements and cannot be regarded as *being* or *developing* a computational system.

<sup>38</sup> ‘Gizmos’ or ‘spimes’ according to Sterling (2005).

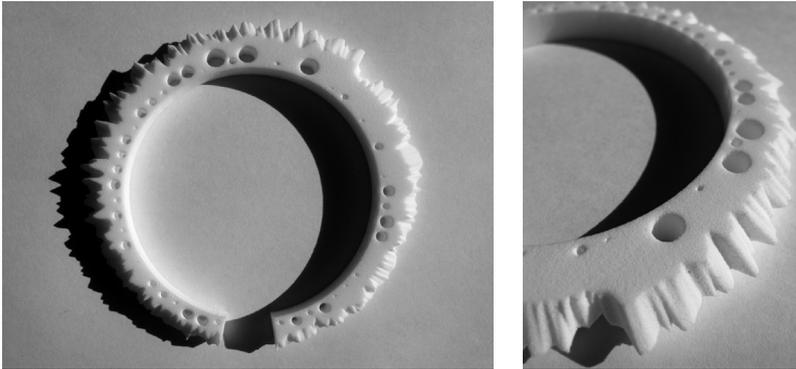


Fig. 36: *Weather Bracelet* (Whitelaw 2009).

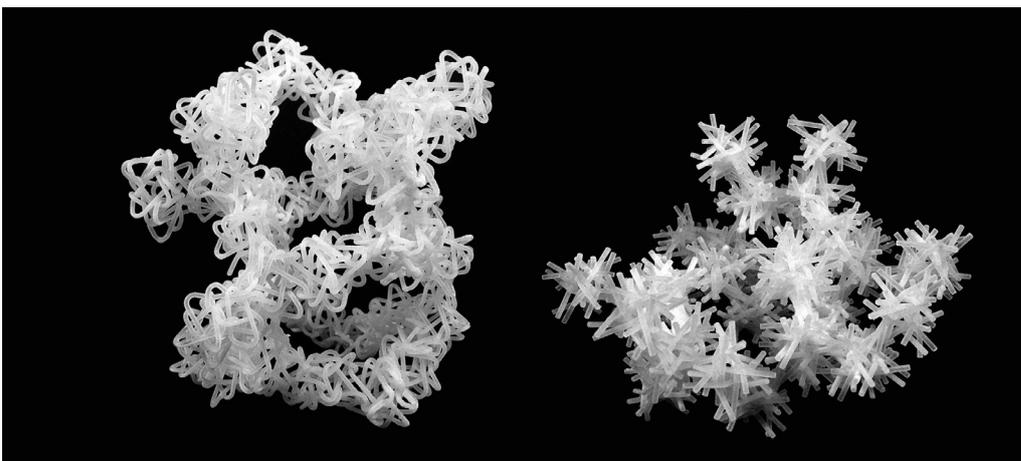


Fig. 37: *Baskets* (2006), a collaboration between architects Aranda/Lasch and Native-American basket weaver Terrol Dew Johnson.

All computational artifacts, whether physically embodied, whether virtual and immaterial, share a substantial number of common properties and traits, overcoming differences that were very clear (and almost natural) in noncomputational artifacts. These differences are not only to be found in how the artifacts are conceived and produced but also in how they *are*, how they *work* and how they *communicate* — either with humans or with other systems. This work will focus in the study of aesthetic artifacts — regardless of whether they are produced as artistic or as communicational devices — that is, in media, tools or other devices that achieve their goals and fulfill their purposes through their aesthetic properties.



## COMPUTATION, MEDIA AND CREATIVITY

### 1.1 Media and Computation

#### 1.1.1 From Somatic to Digital Media

The human body was the earliest asset for communication and artistic expression. Its presence and energy were put to use in the production of signs, creating messages to which Pierre Lévy calls *somatic*, because they imply the effective presence, commitment, energy, and sensibility of the body in the production of signs, as in the living performance of speech, dance, song, or music in general (Lévy 1997, 45). Outside and beyond somatic technology, traditional media for art and design have been material technologies for the fixation and transmission of those somatic messages. The human body was the connection to the earth, it was the originator and the receptor of signs and when these were for the first time transferred to other physical media — to carved bones or painted cave walls, to papyrus, clay or stone, to paper and metal — the originally multimodal somatic messages became unimodal *media* messages. The original (and inescapable) physical relation that was an essential characteristic of somatic messages was transferred to these artifacts, as they became their containers and the preservers of their integrity. Media technologies focused on reproducing signs in ways that somatic technology never managed, inseparable as it was from the ever-changing contexts of production and communication, and they also ensured that they would travel farther, improving their “distribution through space and time” (46). As Walter Ong<sup>39</sup> puts it, the thought of *media* or *medium* of

39 1912-2003.

communication suggests that communication is a pipeline transfer of units of material called *information* from one place to another: “My mind is a box. I take a unit of ‘information’ out of it, encode the unit (that is, fit it to the size and shape of the pipe it will go through), and put it into one end of the pipe (the medium, something in the middle between two other things). From the one end of the pipe the ‘information’ proceeds to the other end, where someone decodes it (restores its proper size and shape) and puts it in his or her own boxlike container called a mind.” (1982, 172)

Although always affecting message production in one way or the other, most conventional media tried to accurately represent the fixed messages, focusing on (and almost obsessing with at times) the ideal of fidelity, of the precise preservation and reproduction of signs, or the precise notation of instructions for the recreation of signs. As Cornelius Cardew<sup>40</sup> wrote, “notation is a way of making people move” (qtd. on Yuill 2008, 74). Time could not be recorded by conventional media, only sets of instructions to be performed or repeated in time could. It follows that “conventional media are not, as a first approximation, technologies for sign creation” (Lévy 1997, 46). They record gestures, vocalized sounds, material situations. They fix signs without, for the most part, creating them. This physical relation between man and media only started to fundamentally change with the development and widespread use of electric media in the nineteenth century, and with the subsequent revolution in communications during the first half of the twentieth century.

Electric media were ethereal, disembodied and transient. Classic media were static, material and permanent. Electricity encoded time, classic media kept space. Classic media sometimes encoded actions but never actually registered them. Electric media, perhaps starting from the telegraph and continuing with the radio, phonograph, cinema and television, were able to record and communicate time, and thus actions were for the first time fixed. Even photography,<sup>41</sup> by freezing the time in front of the camera to a two-dimensional still was already in a way recording time, albeit only a single slice per photo.

Temporal media were the first to go beyond the recording of somatic signs. They were the first to allow the creation of new signs, becoming “manufactured temporal

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<sup>40</sup> 1936-1981.

<sup>41</sup> Photography is of course a chemical medium, but contemporary to electric media and with the exception of some fringe techniques, almost impossible or at least very difficult to realize without electricity.

items” (Moles 1966, 106). In the early twentieth century, after a period of fifteen or twenty years of early movies that were little less than ‘photoplays’ or documental moving pictures created by pointing cameras at sets with actors, pioneer directors like Edwin Porter,<sup>42</sup> Edward H. Griffith<sup>43</sup> or Sergei Eisenstein<sup>44</sup> started to develop artifacts that presented a revolutionizing new cinematic language (Deutsch 2003, 28), artifacts that explicitly contested the “simplistic division between original and reproduction” (Lévy 1997, 46). They discovered how montage allowed the establishment of larger horizons for action and storytelling and how it allowed the creation of new signs besides the playback of those that were somatically produced and directly registered in the film (Murray 1997, 66).<sup>45</sup> They started to turn the medium of cinema into an “act of imagination and construction, not an act of recording or transmission.” (Sherman 2006)

If traditional media and somatic messages are material entities, electric media are for the first time manifestations of energy, manifestations of what Manuel De Landa (1991, 68) calls the ‘machinic paradigm’ of the motor. This paradigm is historically preceded by that of the clockwork, of a strictly mechanical device that works by deriving all motion from an external source as a spring or a pendulum, and is unable to produce motion on its own, as the motor does, internally. When studying communication technologies, we can apply this paradigm to how the information is handled by different media. Clockwork media are unable to produce any information, being limited to convey information that is supplied by external sources, while motor media, being able to preserve and transmit external information also have the capacity to internally produce new information.

Electric media start to coexist with material media at a time when the mechanical seeds of what would later become information media were being developed.

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<sup>42</sup> 1870-1941.

<sup>43</sup> 1894-1975.

<sup>44</sup> 1898-1948.

<sup>45</sup> Wilden places the birth of montage in 1902, when Porter, a director at the Thomas Edison’s company, directed the ten-minute film *The Life of an American Fireman*. Trying to make the best of his tight budget, Porter started with a dream sequence created by double exposure of the film, he then dissolved to a close-up of the fire alarm and cut to stock footage of the firemen preparing for the action in the firehouse, then to an external shot of the fire engine in motion and ended the sequence with the fireman rescuing a mother and child about to be overcome by smoke. This edited sequence, as trivial as it may seem nowadays, excited and delighted contemporary audiences, that had never witnessed anything similar before (1987, 269-70).

Around 1833 Charles Babbage<sup>46</sup> designed the Analytical Engine, a general-purpose, programmable computer (Huff 1976).<sup>47</sup> This device already pointed to the next machinic paradigm, the organizational form of our days, the network. The Analytical Engine would have been something completely new and revolutionary, as Babbage noted when he described it as “a Locomotive that lays down its own railway” (qtd. in Tomas 2004, 103). We would nevertheless have to wait until the middle of the twentieth century to actually find the first realizations of this machinic paradigm, as the Analytical Engine was never built during Babbage’s lifetime.<sup>48</sup>

The organizational form of the network, as defined by De Landa (1991) and Manuel Castells (2001) is a system of organized chaos, characteristic for its self-organizing and emergent properties. Contemporary digital media, incorporating information besides energy and matter are characteristic of this polylogic essence (Joyce 1995), they are part of the knowledge space of signification and freedom that Lévy presents, a space that “doesn’t produce only a knowledge of chaos and fractals,” but “also fabricates a chaotic, fragmented knowledge.” (1997, 213)

The physical, electric and digital layers in the network are additive. Electric media do not dispense material technologies and material support, they actually are an “operation of matter on itself” (Fuller 2005, 19). Digital media do not dispense energy and matter, either to work, to be incorporated on or to convey their outputs to humans and machines, uniting the three layers in an effective synergistic whole.

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<sup>46</sup> 1791-1871.

<sup>47</sup> According to De Landa (1991, 159), the roots of software can even be traced to some years earlier, when in the early years of the nineteenth century Joseph Marie Jacquard (1752-1834) introduced his control mechanism for pattern-weaving looms, coding the weaving process into punchcards, in an elaboration of earlier ideas of his countrymen Basile Bouchon, Jean-Baptiste Falcon and Jacques Vaucanson (1709-1782), and as the result of about a century of experimentation. De Landa argues that the Jacquard Loom transferred control and structure from the “human body to the machine in the form of a primitive program stored as punched holes in paper cards, the earliest form of software: a rigid sequence of steps to be followed sequentially in an unbroken chain.” Babbage himself, a student of the labor process, saw the idea of the instruction cards controlling the weaving process as a form of abstract assembly line and understood the importance of the Loom for the future of mechanical computation, appropriating the idea in the designs of his Analytical Engine.

<sup>48</sup> Maybe the Analytical Engine was conceived too much ahead of its time, as Bolter suggests when we says that Babbage “was trying to fashion out of clockwork a device that really belongs to the age of electronics” (1984, 33).

The processes of montage that were first discovered and developed with cinema and subsequently explored in many of the electric media became central to digital media (Manovich 2001). Montage was a natural language of electric media and it was remediated by their historical successors, which by encoding all the information in what is fundamentally the same digital ‘alphabet’, regardless of its original textual, visual or temporal nature (Noble 1997, 88), facilitated the transcoding of information. Transcoding is digital media’s tendency to computerize even those aspects of life that are not digital and due to this influence, contemporary artistic expression is therefore affected by computerization even when digital media themselves are not used in production.

Transcoding is akin to what Anthony Wilden defines as ‘mapping’, a fundamental act in the process of abstraction or pattern recognition, not necessarily a means of visual representation, but a way of structuring information (1987, 107). To Wilden a mapping is a translation from code to code, “a translation of selected features of a ‘territory’ into another medium or another code of representation, or the translation of one kind or level of mapping into another kind”. It is one of the most important activities of systems that depend on information.<sup>49</sup> At one or several levels, mapping is developed in the simplest of mechanical simplicities like a thermostat or a steam engine governor (Robinson 2008, 26) as in the still relative simplicity of the mapping of patterns of numbers in a computer, and also in the complexity of an organism’s environment or in the “high complexity of the many maps of many territories at many levels characteristic of human beings” (Wilden 1987, 109).

We can find examples of transcoding in several artistic and cultural fields. Transcoding in science, arts or culture means leveling all sources of information. It gives us the ability to cross-reference and to use information from any field in whatever particular work is being developed. As in *musique concrète*, every sound and every sonic object, independently of its source or original context, is valid as a piece in the assemblage of a sequence that is sufficiently ordered to be intelligible (Moles 1966, 169). In the contemporary transcoding culture, every information and every data is usable, reusable and possible to remediate in multiple contexts, being freely copied and mass distributed (Parikka 2008, 70). In the transcoding culture, digital

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<sup>49</sup> Systems that according to Wilden include (in order of increasing diversity and complexity) cybernetic machines (including robots, with feedback), computers, organisms, persons, corporations, armies, and societies (1987, 107-9).

technologies become a “universal representational medium for describing structure and process” (Mateas 2005), they become the primal vehicle for remediation (Bolter and Grusin 1999). As Lawrence Lessig (2008) shows, digital media reintroduce a read/write culture to the read-only landscape of the twentieth century industrial society, maybe ending it (Cooper, Reimann and Cronin 2007) or maybe just adding to it and increasing its intensity (Thackara 2005), but in any case transforming it almost beyond recognition. Transcoding virtually interconnects all digitized messages (Lévy 1997, 49) and helps to create a cybersphere of contemporary culture. It operationalizes Pierre Teilhard de Chardin’s<sup>50</sup> proposed noosphere (1959), that “emergence of an informational membrane enveloping our planet and unifying the human mind” (Flichy 2007, 111) and collectivizing human thought (Morowitz 2002, 175). Louis Rossetto sums it up by emphasizing the communicational properties of digital media: “The more minds that connect, the more powerful this consciousness will be. For me, this is the real digital revolution — not computers, not networks, but brains connecting to brains.” (qtd. in Flichy 2007, 112)

So as this transcoding culture<sup>51</sup> accelerates, information technologies are developed and massively adopted<sup>52</sup> and the place that electric media occupy shrinks. As Alvin Toffler predicted, “the demassification of the media demassifies our minds as well... This, in part explains why opinions on everything (...) are becoming less uniform [, why] consensus shatters.” (1980)

### 1.1.2 Three Types of Information

Nature can be interpreted as matter, energy, and information (Campbell 1982, 16). Energy is a system’s capacity to do physical work, to “set matter in motion” (Wilden 1987, 71) and although the term is commonly put to different uses, its scientific meaning is precise. Every process, every movement or change in the real world involves the conversion of energy from one form to another (Ball 2004, 19). Information, on the other hand, is the capacity of a system to do logical or structural work, it is its capacity to organize matter, energy and/or information (Wilden 1987, 71). If matter has been studied at least since Aristotle and Plato, energy only started to be ex-

<sup>50</sup> 1881-1955.

<sup>51</sup> Or ‘convergence culture’, if we prefer to use Jenkins’s term (2006).

<sup>52</sup> At least in the developed world, but also in many of the developing countries albeit maybe in a not so clearly visible way.

plored during the nineteenth century, and information became a scientific concept much more recently, during the first half of the twentieth century when scientists as Claude Shannon<sup>53</sup> “fashioned it into a theory, provided it with laws, festooned it with equations, and, as is their practice, wrung as much of the vagueness and mystery out of it as they could” (Campbell 1982, 16). In much the same way as scientific laws for matter and energy were in principle not restricted to specific contexts and were devised as being universal, so were Shannon’s laws for information (1949), urging one to confront the fact that information is as universal as matter and energy (Campbell 1982, 17).

Matter-energy and information, however universal, are nevertheless distinct. When Rudolf Clausius<sup>54</sup> established the laws of thermodynamics he concluded that the energy of the universe was a constant, while the entropy of the universe tended to a maximum (Campbell 1982, 37). The first of these statements concerned energy, while in the second Clausius was already talking about information (Lloyd 2006, 66). We are able to transform, exchange and use both matter and energy, but we cannot create or destroy any of them, while information is continually created and destroyed in ordinary human, biological or physical activities (Wilden 1987, 71). According to Wilden, matter and energy are real and do not depend for their existence on being perceived by living creatures or human minds or senses, information on the other hand, may be symbolic, imaginary, or real, and does depend for its existence on being perceived by living creatures or human minds or senses (72) (or, somewhat simplifying things, information depends on being perceived by any system that may be aware of it).

On a more common reading, and at a human communicational level, information is usually not defined in this primary sense from the natural sciences, as a fundamental property that can be measured. Information refers to data that we perceive from the environment, data that may be relevant to decisions, however mundane these may be. As Paul Starr notes, ‘information’ is not synonymous with ‘knowledge’, because the later refers to abstract concepts and judgments, it provides a basis for the understanding of the world and of the actions one may undertake in it. Information “carries the connotation of being more precise, yet also more fragmentary, than knowledge” (2004, 17).

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53 1916-2001.

54 1822-1888.

Thinking about this human perception of information, and not so much about its mechanical codification, Wilden (1987) proposed a classification of information in three types: *analog*, *digital* and *iconic*. The three types of media previously discussed — physical, electric and digital — are able to convey any of the three types of information despite what may at first be suggested by their designations. Analog information, like analog technologies, is based on difference and is continuous; digital information, based on distinction, is discrete, while iconic information is defined by Wilden as being based on both difference and distinction and as being simultaneously continuous and discrete. Analog differences are more-or-less differences and are related by continuity, while digital distinctions are either/or, or, more often than not all-or-none, and are separated by gaps (1987, 222).

As obvious examples of analog information, Wilden presents time and space as we perceive them on the middle scale of our organisms, almost in the middle of the size of the universe.<sup>55</sup> Time and space can be measured and divided, but always along a continuum that forces our measurements to be relative, never absolute. The alphabet, the whole numbers, money, the genetic code or the pieces in a game of chess are equally obvious examples of digital information, consisting as they do of discrete units separated by distinct gaps, in a way that makes the gap itself become an integral part of the syntax or of the ordering principles of the system. If the infinite sequence of the whole numbers is digital, each integer separated from the next by a distinct, unfillable and regular gap, the infinite sequence of the real numbers is purely analog, because of the continuum of infinitely many differences between every other difference in the system (223). Analog information lacks the syntax to communicate the fundamental logical operation of identity and cannot represent zero, and while it can express the *and* function, it is unable to express the other three truth functions of analytic logic, *either/or*, *if... then* and *not*, functions that require a digital syntax based on identity and contradiction, and the capability to distinguish logical types (224).

By pointing out how humans perceive space, Wilden also suggests how analog coding can be a fundamentally human construction. The continuities that we identify as analog are either human intellectual constructions, like the infinite series of real numbers or time itself (Spengler 1962, 77), or are caused by the fundamental limits of

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<sup>55</sup> “The smallest things we know about are approximately 30 orders of magnitude smaller than ourselves, and the largest structures in the universe are about 30 orders of magnitude bigger.” (Kelly 2009a).

our perception at the meso scale, where all of the quantum phenomena are impossible to detect. Having evolved in what Richard Dawkins calls the ‘middle world’ of our scale, our senses and intuitions have grown to deal with objects much larger than individual atoms (Lloyd 2006, 5) or the even smaller subatomic particles at which scales quantum ‘weirdness’ happens. We perceive the world as being continuous, although to the best of our knowledge we know it to be discrete and discontinuous. Along our history, we discovered digital coding and, after the fact, produced the concept of the analog to describe the way the world seems to work for us (Wark 2007, 089).

The discovery of *zero* may well be one of the first occurrences of digital coding. Zero was a product of the calculation through positional numbers and it was originally *the gap* that made the syntax of the system work (McLuhan 1964, 125). Originally discovered in India about two thousand years ago (Seife 2001), and with written records dated around 800 CE, it was introduced in Europe in the tenth century CE (Wilden 1987, 104). In the thirteenth century the Arab word for ‘gap’ or ‘empty’, *رفص*, (*şifr*), was Latinized as ‘cipher’ (*zephyrum*) and eventually became the Italian *zero* (McLuhan 1964, 125). Incidentally, it was also around this time that the space between words started to be used as a punctuation mark, a fact that is hard to dissociate from the discovery of zero (Levy 2001, 14) and that turned the alphabet into a real digital system.<sup>56</sup>

Zero was a difficult abstract concept, rejected by ancient Greeks<sup>57</sup> but it was made visible and somewhat clearer by one of the earliest devices to perform digital encoding, the abacus (Lloyd 2006, 12). By turning every whole number into a discrete digital unit, the abacus created the space to the possibility, or rather the reality, of the zero to become clear.

The terms ‘analog’ and ‘digital’ were originally derived from the distinction between analog computers (computing by means of variations in continuous quantities, such as volume, potential, or length) and digital computers (computing by means of the selection and combination of discrete elements). ‘Iconic’, meaning ‘form’ or ‘image’, is derived from the visual and plastic arts, but may

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<sup>56</sup> We could argue that without the spaces and the vowels, as in Semitic writing systems, alphabets are still a very analog system, as they create a continuum of information to be interpreted in sometimes very arbitrary ways.

<sup>57</sup> To whom, according to Wilden, even the numeral 1 was reluctantly called a number, because as Aristotle said, numbers measure pluralities and the numeral 1 is the measuring unit, not a plurality (1987, 253).

equally well be applied to dreams, music, meaning, ideas, any distinct bodily sensation, and so on. (Wilden 1987, 222)

Curiously, since analog devices employ digital coding in computation and control — the divisions in the dial of a clock, the distances marked on a ruler — strictly speaking they are both analog and digital, they are iconic devices (223). The same could perhaps be said of those digital devices that simulate analog devices. Analog and digital coding can be found in all communication systems, where the digital is instrumental to the analog communication of context and relationship, from where it follows that the two codings do not oppose but rather complement each other and make each other possible (225).

From here Wilden identifies three levels of knowledge: *sensing*, where the analog continuity dominates the digital discontinuity; *meaning*, where analog and digital combine to form iconic coding; and *signification*, where digital coding dominates its analog counterpart. From a definition of information as coded variety, “sensing can be defined as coded information, meaning as coded sensing; and signification as coded meaning.” (225)

## 1.2 The Computer

### 1.2.1 As a Tool

If writing is a medium of thought, then software is an agent of will. (Levin 2004, 140)

Since its invention, the computer<sup>58</sup> has been used as a tool. Initially it was uniquely a tool for the mind (McCullough 1998, 17), accelerating and expanding it, and producing symbols: not mechanical artifacts nor physical power, but abstract information and mathematical power. Tools are machines, and machines automate and replace work that was originally done by humans, and so did computers, named after the workers whose job they were designed to replace (Turing 1950). Machines process and alter materials according to standardized processes. In this sense the computer, as a machine and a tool, acts on and modifies information (Schubiger 2005, 343).

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<sup>58</sup> Unless otherwise noted, whenever we write *computer* we will be referring to a *digital computer*, not to *analog computers*.

It is useful to set a distinction between two different uses of computers, the first being the use of *programmed* computers, when hardware and software are taken as the tool to use, and the second being that of *programmable* computers, when both physical and logical components can be freely manipulated by the user. This classification does not propose to rank the usages, or the goals pursued by the users of computers, but simply to describe two alternative ways of operation, that many users occasionally intersect. In the sake of simplicity let us call these two modes after the nomenclature proposed by Michael Joyce (1995, 41) and define them as *exploratory* and *constructive* uses of the computer.

Exploratory usage approaches the computer and ready-made software as a multi-tool that can perform very complex tasks in a short time, outperforming the human abilities to manipulate symbols in formal languages by several orders of magnitude (Dorin 2008, 290). Through exploratory use a computer can be made to work in calculations, algorithmic simulations or other operations on information for which it was programmed, and aid humans with complex operations, or even replace them in some cases. A constructive usage, on the other hand, goes beyond ready-made software and creates its own, allowing users far more than just disposing of a very fast and effective tool but rather opening up the possibility for them to also become toolmakers, to create tools that will in turn generate or operate the solutions for the problems at hand.

Exploratory use of computers allows users to perform sets of predefined functions in a given work process or design. Ready-made software is intended for specific kinds of usage and will consequently tend to impose models of operation that with few exceptions must be followed by the user. Programmable computers may however also become tools that allow completely different approaches to the task of design, that allow new modes of usage, by not “functioning as graphic translators or organizers, but by requiring input in the form of rules, gestures, goals and parameters, and a defining *grammar* which governs the combination thereof.” (Ceccato 2001, 4) The first mode of usage represents what Harold Cohen called “the use of the computer as a tool in the sense that a camera is a tool”, it is “the antithesis of autonomy” (1973b) and therefore although useful, it doesn’t focus on one of the “most fundamental and radical concepts associated with digital computers: that of computation itself” (Manovich 2002).

If you hold a hammer in your hand, everything in the world begins to resemble a nail. (Small 1999)

Through exploratory use, computers and software, much like any other tool, recreate the world in their own image. They are projections of slim parts of ourselves, models of processes that need to be used in predefined ways and that simulate and stimulate the realities of the original designers of the software. Through constructive use, however, users are able to go several steps further in the positive investigation of the potential of the technology, not only extending the mind but also the hand in ways that were not necessarily foreseen by others and that may approach design problems in idiosyncratic and truly original ways.

Dave Griffiths (2008, 250-51) describes how it is possible to break down the development of software into three broad categories based on intent, or on the nature of the goals that it is designed to fulfill.<sup>59</sup> ‘Classical tools’ embody the conventional idea of a software that is designed to achieve some clear and simple goal. The simplicity of the goals does not derive from their inherent low complexity, because there may be several goals to achieve and their resolution can be highly complex from a software design point of view, but rather from the fact that all the goals are clear and defined a priori. As examples of classical tools, Griffiths points the ‘ls’ command in Unix systems or a web server as Apache. Any computer user could add to this list dozens or hundreds of other classical software tools used daily in personal computers, from media players to calendars, task managers, etc.

The second of Griffiths’s categories is that of ‘environments for working in’, software developed when the nature of the goals is more complicated, and involves more human issues. Environments for working in offer the user a series of functionalities through a framework, usually a text-based or a graphical user interface. More complex goals are harder to predict and define a priori, therefore the solutions need more flexibility so that they can be useful in the long run. Finally, the third category is what Griffiths terms of ‘artistic’, software designed to achieve very complex goals, difficult to define in any way, let alone to predict. Goals that are ambiguous, that sometimes are expressed merely by existing, using software as the only way to express something. In art, design and communication, this is the domain *par excel-*

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<sup>59</sup> Three gross simplifications, according to Griffiths, as most software typically consist of a blend of these types.

*lence* for the constructive use of computers, it is the domain of designers that create their own tools as an artistic process of research and investigation (251). The first two of Griffiths's domains are typically the field of the exploratory use of computers, of work processes that, we could argue, regard the computer and its software (in a somewhat simplistic view) as not much more than traditional mechanical tools.

But digital technologies are more than tools. As Caroline Schubiger notes, if with a tool there must be some difference between input and output, between pre- and post-usage states, otherwise the tool would have served no real purpose, in a medium, the alterations to the conveyed messages should be kept to a minimum or otherwise the medium will be poor or noisy. "Input must be as similar as possible to output, or else the medium will have defeated its purpose." (2005, 343) Digital technologies can be used to store, reproduce and communicate information, they are communication paths that in Lévy's perspective are media, carrying messages that were originated elsewhere.

### 1.2.2 As a Medium

Defining media, Henry Jenkins turns to historian Lisa Gitelman and to her model that describes media on two levels, in the first place as technologies that enable communication and then as sets of associated protocols or social and cultural practices that grow around those technologies. This points to a coexistence between what Jenkins calls 'delivery technologies', simply and only technologies, and 'cultural systems', that persist as layers within the complex information and entertainment stratum after the technologies die or become obsolete (2006, 13-14). Marshall McLuhan<sup>60</sup> would identify these as the figure and ground of a medium, the ground being the situation that gives rise to it, the technology, and the figure the "whole environment of services and disservices that it brings into play" (1988).

Agreeing with this view, Schubiger reminds that media have a 'double-nature' that is on the one hand tied to their communicational potential, and on the other to the social systems that form around the technologies (2005, 343). She develops this idea by pointing to how mass media produce and disseminate information, presenting a single view of authority and offering no feedback option. Two-way media differ by the existence of a counterpart that permits reciprocity, by a bidirectional transmis-

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60 1911-1980.

sion and reception of information. Two-way media transform those that in mass media were just recipients into de facto participants. Therefore, Schubiger concludes, if “we take a closer look at the computer, we see that it, too, can be considered a two-way medium that sends and receives information. The computer is a medium. It stores information. The computer is a two-way medium that allows for an exchange of information between man and machine.” (343)

Nicholas Negroponte followed the same line of thought when in *Being Digital* he chose the broadcast television as an example of a medium in which all the intelligence is at the point of origin, and he suggested that an evolutionary step in television would eventually be “a change in the distribution of intelligence — or, more precisely, the movement of some intelligence, from the transmitter to the receiver” (1995, 19). This was what pioneers like Douglas Engelbart (2003) and J.C.R. Licklider<sup>61</sup> (1960), or Roy Ascott (2003) perceived in the 1960s: how big was the social potential of computer-mediated communication (Lévy 1997, xx), how digitally controlled cognitive prostheses could transform our intellectual capabilities as clearly as, according to Lévy, “the mutations of our genetic heritage” (xxiv).

Looking to Jenkins’s delivery technologies, in his view old media never die or fade away. What dies are the tools that are used to access media content, like Floppy disks, Beta tapes, VHS tapes, Compact Cassettes, DATs, Mini Discs and many, many others. These are delivery technologies and they are what becomes obsolete and gets replaced while media, on the other hand, persist and evolve. “Recorded sound is the medium. CDs, MP3 files, and 8-track cassettes are delivery technologies” (Jenkins 2006, 13) or, in the words of Donald Byrd, “print is the content, not the form, of electronic media” (qtd. in Joyce 1995, 21). As an example, the medium of cinema keeps moving away from its material delivery technologies, and nowadays most ‘film’ is captured by charged coupled devices, the editing is digital, as is much of the distribution and projection. As bits take over, we find that if we look at delivery technologies alone, as Tom Sherman said, ‘film’ has become just another word for video (2006). Better still, ‘film’ is increasingly being transcoded as digital video, abstracted as bits. But cinema is a medium that shows no signs of being at risk of disappearance.

Computers were embraced by every presentational medium (Nelson 2003, 306) and as a consequence the current delivery technologies are bits, bandwidth, file formats

61 1915-1990.

and communication protocols. Early computer engineers regarded bits as resources for mathematical processing, missing the part they played as a universal medium (Hofstadter 2007, 244). Today our culture keeps failing to see bits in this way, but for an altogether different reason, actually, according to Douglas Hofstadter, for the opposite reason: as all those numbers are hidden behind screens, computers and networks, we utterly forget they are there. Aarseth identifies a breaking into two independent technological levels: the ‘interface’ and the ‘storage medium’, leading to a divorce between the surface of reading and the information stored behind it (1997, 10). Following similar lines of thought, and fundamentally disagreeing with McLuhan’s understanding of ‘media’, both Wilden and Negroponte propose a break with his most famous axiom, that “the medium is the message” (1964). Wilden notes that if energy is the capacity of a system to set matter in motion and information is its capacity to do logical or structural work, its capacity to organize matter, energy and/or information in ways not found in ordinary physical systems, matter-energy and information should thus be understood as functionally distinct. It then follows that the medium is not the message but rather the means of communication (1987, 71). In Negroponte’s view, in the digital world the medium is no longer a message but rather an embodiment of it, and any given message may have multiple embodiments that are automatically delivered from the same data (1995, 71).

In *Technologies of Freedom* (1983), Ithiel de Sola Pool<sup>62</sup> enunciated the concept of convergence in media. Understanding the role of electronic and digital technologies, he foresaw a revolution in communication that would have effects as profound as those of the printing revolution:

For untold millennia humans, unlike any other animal, could talk. Then for four thousand years or so their uniqueness was not only that they could move air to express themselves to those immediately around them but also that they could embody speech in writing, to be preserved over time and transported over space. With Gutenberg a third era began, in which written texts could be disseminated in multiple copies. In the last stage of that era phonographs and photographs made it possible to circulate sound and pictures, as well as text, in multiple copies. Now a fourth era has been ushered in by an innovation of at least as much historical significance as the mass production of print and other media. Pulses of electromagnetic energy embody and convey messages that up

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62 1917-1984.

to now have been sent by sound, pictures, and text. All media are becoming electronic. (Pool, 1983, 24)

This convergence blurs the borders between media, the two-way, point-to-point communications, and mass communications, when a single device or a limited group of devices is able to carry services that in the past were provided separately. At the same time, those services that in the past were provided by one medium, like telephony, broadcast or press, are now provided in concurrent ways, eroding the one-to-one relationship that used to exist between a medium and its use (Jenkins 2006, 10).

Today, all media collapse into digital technologies. Analog media do not disappear in the process, but they are transformed. If according to McLuhan (1964), the content of a medium is its predecessor, and every medium therefore remediates those that preceded it (Bolter and Grusin 1999), digital technologies contain and remediate all of their predecessors. We do not live anymore in *Gutenberg's Galaxy* (McLuhan 1962), we live in *Turing's Galaxy* (Grassmuck 1994).

### 1.2.3 As a Metamedium

The double role of the computer as tool and medium has originated several discussions among those that used it in artistic practice. Already in 1976 Edward Ihnatowicz<sup>63</sup> mentioned that the distinction, as arbitrary as it seemed, was in fact very important because “it distinguishes those artists whose inspiration comes from outside the world of computing and who use the computer simply for convenience from those whose ideas have originated as a result of computing experience” (1976). Frieder Nake described the computer as a “medium that we use instrumentally as a tool while communicating with it as a medium, thus it is both machine and mediation simultaneously” (qtd. in Pold 2008a, 32), a statement that led Søren Pold to conclude that in this new kind of media-machine, the instrumental is mediated as the representational medium is functionalized. In other words, function is mediated and the mediated representation becomes functional (2008a, 33). As David Tomas notes, we can identify the ‘newness’ of digital media from their development as ideas that are amplified and transformed again and again through space and time — and culture, we might add — “the distant past to potential and possible futures since each

63 1926-1988.

of these transformations would engender their own mental systems and associated perceptual spaces” (2004, 186).

More than just accelerating cognitive functions and mathematical capacity, computers also expand the human mind by simultaneously working as media and by remediating multiple other media. They contribute to the remembrance of particular pieces of information, to the safe-keeping, the search and the retrieval of memories, and they create a new repository for our collective memory and new forms of instrument-based identity (158). And the effect they have in individual humans and in humanity is nothing short of remarkable, altering our view of the world and transforming our intellectual capabilities, as Lévy puts it, sharply accelerating ‘hominization’, or the process of the emergence of the human species (1997, xxiv). In *Understanding Media*, McLuhan cited Stéphane Mallarmé,<sup>64</sup> who thought that the world existed to end in a book, while emphasizing that we were not in a position to already go beyond that idea and to transfer “the entire show” to the memory of a computer (1964, 65). Nowadays, more than forty years after he wrote that, we are at a moment in history when much of the ‘show’ can already be transferred to the memory of computers, to networks, databases, wikis, websites and e-books. Man, McLuhan added, is not like merely biological creatures, for he possesses something more than his genetic heritage: he possesses apparatus of transmission and transformation that are based on the power to store experience and to draw from it, apparatus that expand human nature.

The feeling of being expanded by digital technologies can be strong to the point of leading a writer as Michael Joyce to describe himself as being “possessed of two minds: my own and its augmented silicon” (1995, 2). The prosthetic expansion, the merging of artificial and biological intelligences (Rosenberg 1994, 268), turn humans into something of a cyborg<sup>65</sup> in the sense proposed by Donna Haraway (2004). They make “the difference between natural and artificial, mind and body, self-developing and externally designed, and many other distinctions that used to apply to organ-

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<sup>64</sup> 1842-1898.

<sup>65</sup> The word *cyborg* was coined by Manfred Clynes, a neurologist working in the field of space medicine, from the words *cybernetic organism*. Clynes used it to describe how a new symbiotic entity results from an alliance between humans and their technology (Aarseth 1997, 53). If this alliance was originally thought to exist in closed artificial environments such as space capsules or space stations, the miniaturization of technology and, above all, the ubiquitous and facilitated access to digital technologies allowed the term to be applied to a series of other relations.

isms and machines” become thoroughly ambiguous, and lead us to conceptualize both machines and organisms as “coded texts through which we engage in the play of writing and reading the world” (11). They lead us to see our personal computers as cybernetic mirrors (Pold 2008b, 220) and to develop a computational view of ourselves and of the world.

Alan Kay observed that computers are representation machines that can emulate any known medium: “The protean nature of the computer is such that it can act like a machine or like a language to be shaped and exploited. It is a medium that can dynamically simulate the details of any other medium, including media that cannot exist physically. It is not a tool, although it can act like many tools. It is the first metamedium, and as such it has degrees of freedom for representation and expression never before encountered and as yet barely investigated.” (1984, qtd. in Laurel 1993, 32-33)

Michael van Schaik warns us against mistakenly regarding the computer as a medium that just reproduces all earlier media without changing them (2008, 182). If in the early stages of any medium there usually is a tendency to use it to emulate previous and better established media, developing incunabula that simultaneously try to prove the medium’s value and search for its fundamental traits, it is not until a medium reaches some maturity in its contact with the public and in its use by content creators and communicators that it begins to take a life of its own and to display its uniqueness (Lansdown 1997, 13). This is what happened with cinema, what happened with books in Gutenberg’s time (Murray 1997, 28) and what happened with many other technologies (Starr 2004; Zielinski 2006). According to van Schaik, many metaphors still in use in digital media are tied to previous media and restrict its actual hyper-qualities and its nature as a metamedium (2008, 183), a point of view with which Lev Manovich concurs when he proposes that instead of “digital multimedia”, of designs that simply combine elements from different media, we see “metamedia”, i.e., the remixing of working methods and techniques of different media within a single project (2008, 123). Manovich identifies two major consequences of the production workflows that digital technologies currently allow: a hybridity of the media language we see in the contemporary design universe and a similarity of techniques and strategies used, regardless of the output media or the type of project. He elaborates: “Like an object built from Lego blocks, today’s typical design combines techniques coming from multiple media. It uses the results of the operations

specific to different software programs that were originally created to imitate work with different physical media”, and “while these techniques continue to be used in relation to their original media, most of them are now also used as part of the workflow on any design job” (124). Once again we find transcoding, not of information or data, but now of languages and ways to communicate.

After digital technologies are introduced to human activities they can no longer be factored out. The introduction is, according to Joseph Weizenbaum,<sup>66</sup> an irreversible commitment (1976, 28), because the plasticity and polyvalence of the metamedium means that it is thoroughly integrated with the structure and deeply enmeshed with vital substructures of any domain where it can act. Thus, according to Norbert Bolz, media theory is confronted with its transformation into computer theory, in what will certainly become the metatheory in the area of communication, connecting the electronic media and the metamedium that is the computer (2004, 25).

#### 1.2.4 As a Simulator of Media

As we have seen, digital technologies sample analog and iconic information into bits, sometimes reducing the amount of information to the point where it can be described in a finite (and adequate) number of words. With digitalization come the advantages of a better signal-to-noise ratio, of the reduction of the power required to transmit signals, of the ease of interpolating boundaries and of storing the information in digital memory (Wilden 1987, 223) and also the power to remediate and simulate other media. Following the work of McLuhan, and specifically his proposal of how each medium contains its historical antecedents, Jay David Bolter and Richard Grusin (1999) proposed that all media fundamentally work by remediating other media, that is, by translating, refashioning, and reforming other media, both on the levels of content and form. Print, photography, radio, film, and television have always borrowed from other media, not only their antecedents but also their concurrents, in a process of cultural competition between or among technologies (Bolter 2001, 23-24), where new media forms always claim to be improving or reforming earlier forms, even when they are in fact simply paying homage to them (2003, 28). Manovich draws from examples in human-computer interfacing to argue that the history and present development of digital media fit Bolter and Grusin's thesis, because there is no shortage of examples of borrowing, reformatting and combining

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66 1923-2008.

other media, those media's conventions and even those from human-made physical artifacts (2001, 95).

If remediation pays homage to and shifts media, it also creates opportunities to their development. Bolter exemplified this by going back to as far as the invention of writing and by showing how writing “remediated oral communication by involving the eye as well as the ear and so giving the words a different claim to reality” (2001, 23). He also elaborated on how ancient Greeks and Romans conceived of alphabetic writing in a dialectic tension between the oral tradition that it only partially replaced: “prose, even philosophy and history, was often highly rhetorical, as if the writing were still trying to imitate and improve on oral presentation” (24). After discussing several other examples, he concludes that digital technology is turning out to be one of the most traumatic remediations in the history of Western writing, because of the way it fundamentally changes the ‘look and feel’ of writing and reading.

But although they are largely based in text, and largely used to communicate text, digital technologies remediate several other media and they do it so well as to become their ultimate simulations. In *Simulacra and Simulation* (1994), Jean Baudrillard<sup>67</sup> defines simulacra as the ways in which a heterogeneous system of symbols is used in diverse strategies of communication, and he classifies them in three categories according to the technologies used in their creation: counterfeits, replicas and simulations. Counterfeits are traced to technologies that were intended to create illusions that would pass for reality, to images that imitated life to the point of becoming virtually indistinguishable from it.<sup>68</sup> De Landa cites painting, sculpture and stagecraft as the three main forms of imaging reality during the late sixteenth century, when they were used to visually codify passages of the Bible, imposing an unambiguous interpretation on them and fixating a real, or better said, an ‘official’ meaning (1991, 188). Siegfried Zielinski (2006) cites examples from Ignatius de Loyola,<sup>69</sup> Giovanni Battista della Porta,<sup>70</sup> Robert Fludd<sup>71</sup> and especially Athanasius Kircher<sup>72</sup> and his mechanical exhibits of elaborate contraptions that functioned like audiovisual automata (125) and created a “perfect mise en scène of God as omnipres-

<sup>67</sup> 1929-2007.

<sup>68</sup> At least at the light of the time when they were produced.

<sup>69</sup> 1491-1556.

<sup>70</sup> 1535-1615.

<sup>71</sup> 1574-1637.

<sup>72</sup> 1601/2-1680.

ent watcher and prompter,” with sculpted heads that would “begin to speak whenever anyone passed by, and no one knew where the voices came from” (127). It is also in Kircher’s work that we find early examples of the magic lantern, used in his own lectures or for theatrical productions, and of optical “metamorphosis apparatus for the allegorical transformation of an observer” that allowed to position mirrors so that the observer could view the image of an object but not his own reflection (136). This device had such a powerful dramatic effect that Kircher eventually added a second observer to the setup, in a position where he would be capable to watch the first observer’s interaction with the illusion machine and its images (138).<sup>73</sup>

When photography was invented a new kind of image began to populate the world: mechanical replicas. When the first movie was shown to amazed audiences in 1895, the ability of photography to replicate the arrangement of objects in space was supplemented with film’s ability to replicate a pattern of events in time. These technologies created new possibilities for the development of simulacra, perhaps first truly exploited in World War II by Goebbels and his Reich Ministry of Public Enlightenment and Propaganda. In his hands newsreels and documentaries (like those of Leni Riefenstahl) became part of the spiritual currency of the Nazi state.

Finally, the advent of computers has made possible a new breed of image, and the possibility of a third kind of simulacrum. Reality ceased to be imitated or replicated, and began to be simulated: the new breed of image was generated through computers, using mathematical models of real physical phenomena. The best-known example of this kind of image is perhaps the flight simulator, the machine used to train pilots to expensive warplanes by confronting them with real-time graphic models of the landscapes through which they will eventually have to fly. (De Landa 1991, 188-89)

Returning to Bolter, in *Writing Space* (2001) we find how he identifies two apparently contradictory expectations for media that have been developing in our culture since the Renaissance (25). On one hand, in line with Baudrillard, the goal of representation has been to achieve transparent depictions where the medium is supposed to

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<sup>73</sup> We can find a parallelism with how contemporary interactive systems are sometimes enjoyed through direct interaction but sometimes also become enjoyable to watch as a shared performance between a system and an interactor.

function as a window through which the viewer can see the actual objects that are represented. Artists and audiences have generally treated media as being transparent<sup>74</sup> but transparency is not always what artists and audiences desire. Sometimes they are both likely to prefer to be made conscious of and even surrounded by the media, an effect that Bolter names hypermediacy and that he describes as “an intense awareness of and even reveling in the medium” (25). Television is the most common example of a medium that at times can function transparently but that most of the times is highly hypermediated.<sup>75</sup> Among digital media, Bolter mentions the World Wide Web as being the most often characterized by hypermediacy, nevertheless pointing that it is common to find the same medium striving for transparency on one case and for hypermediacy in another, and that today “we swing back and forth between a desire for transparent contact with the ostensibly real (unmediated) world and a fascination with the possibilities that media offer us. Because the number of old and new, analog and digital, media available to us today is very great, we live in an environment that is conducive to hypermediacy. Yet the desire for a transparent medium remains strong” (25).

The computer therefore mediates messages and remediates media messages, doing it mostly through transcoding and simulation. The computer is a mimetic medium, in the sense proposed by Aristotle and Plato (Kamper 2004, 14), and is capable of greatly extending the range of systems whose behavior can be imitated, due to its abstract character and symbol-manipulating generality (Simon 1969, 14). The computer simultaneously operates in what Weizenbaum calls ‘performance’ and ‘simulation’ modes (1976, 164), creating what is certainly an hypermediated medium, but also bringing authenticity and simulation together in a new, and revealing, transparency. When properly programmed, a computer can simulate any medium, allowing us to draw inferences from the simulation, and to directly translate them into inferences applicable to the media (145). Furthermore, as even electric media have progressively been digitized over the years, what we once regarded as simulations are nowadays the media themselves, the simulations and models have become the reality. We no

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74 As a series of historical accounts and anecdotes attest to, one of the most famous (and probably apocryphal) being the telling of the terror that audiences felt when watched the projection of Lumière’s 1895 short-film *L’arrivée d’un train en gare de La Ciotat* (The Arrival of a Train at La Ciotat Station). This film showed the entry of a train pulled by a steam locomotive into a train station in the French town of La Ciotat. It is a single, unedited real-time shot lasting approximately 50 seconds.

75 In many contemporary television fictions, the breaking of the fourth wall has become rather common and somewhat of a trend.

longer use computers to simulate media but rather build the media with computers, sometimes leaving a physical distribution technology, as with newspapers or books, sometimes still using an electric or electromagnetic distribution technology, as with radio, but more often than not, converting all of the medium's infrastructure to the digital realm.

As Iannis Xenakis<sup>76</sup> summarizes, creative thought gives birth to mental mechanisms, a process that takes place in all realms of thought, including the arts; some of these mechanism can be expressed mathematically and can be mechanized, thus possible to simulate by computers (1992, 131).

### 1.2.5 Four Essential Properties

In *Hamlet on the Holodeck* (1997), Janet Murray tries to understand how the computer and computer networks will affect the production of narratives and the production and consumption of aesthetic artifacts and communication. She maps the “continued loosening of the traditional boundaries between games and stories, between films and rides, between broadcast media (like television and radio) and archival media (like books and videotape), between narrative forms (like books) and dramatic forms (like theater or film), and even between the audience and the author” (64), and she presents what she identifies as four essential properties of digital environments. In this order, Murray states that digital environments are *procedural*, *participatory*, *spatial* and *encyclopedic*, adding that “[t]he first two properties make up most of what we mean by the vaguely used word interactive; the remaining two properties help to make digital creations seem as explorable and extensive as the actual world, making up much of what we mean when we say that cyberspace is immersive” (71).

Encyclopedism, the fourth of the properties is, according to Murray, more a difference in degree than a difference in kind. Due to the enormous (and ever increasing) storage capacity of computers and computer networks and the relatively small footprint of digitally encoded information, the storage and retrieval of vast quantities of information becomes possible and we are able to virtually extend the human memory. Technologies like hypertext and search engines help to expand, connect and organize these resources while at the same time establishing a topological space

<sup>76</sup> 1922-2001.

within them. Although some conceptualize it as a non-space (Morse 1996, 195), when confronted with the vastness of the information that is accessible through computers and digital networks, most of the times we cannot escape a “sense of spatial immensity, in greatness and smallness, disarticulating and spacing out” (de Chardin 1959, 33). This is accentuated by the visual presentation of the information, displayed in computer screens that are not only physical devices *per se* but are also understood as boards for transient and impermanent information, read as stages and interpreted as *places*. Screens are like *supermatter*, “once switched on, all attention turns to them, and their material qualities are demoted to the status of package or container as the viewer searches for the real content, information. Unlike sound, which can be nondirectional, screens tend to give a space a specific orientation.” (Dunne 2005, 125) The sense of vision is responsible for the acquisition of more raw data than all the other human senses combined (Hall 2008), Zielinski reminds us that “ever since Aristotle the faculty of vision has been privileged over all the other human senses with which we perceive the world” (2006, 84) and vision also allows us to perceive spaces, to locate ourselves in spaces, even if they’re abstract constructs and not concrete physical realities. We conceptualize the digital domain as a cyberspace,<sup>77</sup> “an environment with its own geography in which we experience a change of documents on our screen as a visit to a distant site on a world wide web” (Murray 1997, 80) and we use all sorts of spatial and physical metaphors to describe our digital experiences ‘there’, from ‘pages’ to ‘maps’, from ‘landscapes’ to ‘navigation’, to ‘topography’, and the like. These metaphors emphasize the immersive quality of our experiences within it. Even more than with any other technology or medium, “one gets *inside*. While cinema permits an illusion of participation, cyberspace is predicated on it. From the very first computer games, the graphical *Spacewar*<sup>78</sup> and the text-based *Adventure*,<sup>79</sup>

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77 Lévy (1997, 118) notes the origin of the word ‘cyberspace’: of American origin, it was used for the first time in 1984 by the science-fiction writer William Gibson in his novel *Neuromancer* (1984).

78 *Spacewar!* was programmed by Steve Russel, Martin Graetz and Wayne Witaenem on a DEC PDP-1 computer at the MIT in 1962. In *Spacewar!* the players navigated two spaceships around the (circular) screen, while shooting torpedoes at one another. They would also have to be careful enough not to let either of the ships get too close to the star in the center of the screen which pulled them towards it. Therefore, the players not only interacted with the ships but with the space itself. Although this space was not navigable — one could not move through it — the simulation of gravity made it a truly active presence, and just as the player had to engage with the spaceships, he had to engage with space (Manovich 2001, 219).

79 *Adventure* or *Colossal Cave Adventure* was programmed by William Crowther and Don Woods (1976) for the DEC PDP-10 computer. It was the first game of its kind and defined an entire genre of computer games. *Adventure* was strictly text-based, describing all the spaces where the player could move and all the actions performed by this and other non-playing characters as text, “YOU ARE STANDING AT THE END OF A ROAD BEFORE A SMALL BRICK BUILDING. AROUND YOU IS A FOREST. A SMALL STREAM FLOWS OUT OF

the model of the disembodied, simulated subject moving through Cartesian space, [...] the cybersubject, was already in place” (Bailey 1996, 34).

We have allowed cyberspace to become a set of real spaces where we can meet and interact with others (Reville 2009), but cyberspace is less the new media for the transmission of information than it is all the new and original modes of information exchange, creation and navigation of knowledge. As Lévy reminds us, cyberspace is the social relations that the new media bring about (1997, 118), once everyone is equipped with a screen from where to access the world’s digital libraries (Flichy 2007, 61).

Hence, digital environments are also participatory. They allow unprecedented forms of communication, starting with the two-way exchange of information between man and machine that we normally call interaction (Schubiger 2005, 343), ever since the internal actions of the computer were conveyed to its exterior in a pace close to real-time, representing actions in which humans could participate (Laurel 1993), which humans could change (Nake and Grabowski 2006, 53) or influence through their somatic actions (Joyce 1995). Digital environments turn passive spectators into active participants (Zajec 1976) and assemble humans and machines into a synergistic whole (De Landa 1991, 193) by providing the user with the ability to modify system parameters through interactive devices that (for the most part) do not force them to ever think about numbers or about the internal processes that are being developed, thus reducing the demands on the users’ prior knowledge about the system or the models it runs (Csuri 1976). This was regarded by Licklider as a fundamental shift in computing, a shift from problem-solving to problem-finding or problem-exploring through vast spaces of possibilities (qtd. in Murtaugh 2008, 144). Interaction with the users not only allows them to retrieve information from the computer in a variety of ways as, and perhaps most importantly, allows the computer to get information about the human (Lloyd 2006, 108) thus turning her into a real participant in the developing digital processes.

The space of the computer screen then becomes more than a stage where information is presented or where data patterns emerge and is converted into “a place where the very workings of the computer could be controlled, a surface of contact between

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THE BUILDING AND DOWN A GULLY.”, and requiring player commands to be input as text strings, as for example “GO IN”.

humans and machines where their evolutionary paths could be joined symbiotically” (De Landa 1991, 193). In this space we could for the first time witness a series of feedbacks between users and systems, feedbacks that turn the clean inner space of the algorithms into an unpredictable space of very real contact with the external world and the user’s senses, feedbacks that turn it into a dynamic and shared space (Murtaugh 2008, 147), feedbacks that opened the way to the development of strange loops (Hofstadter 1999) in the user-system cooperation and forced the exploration of the outer environment as a prerequisite for the realization of the system’s functionality. As De Landa says, the work of Licklider, Engelbart and others transformed the surface of the computer screen into a place where the partnership between two machinic species could be achieved, where the evolutionary paths of humans and computers could be linked symbiotically, but it also made the computer interface become a surface of contact between people (1991, 221).

Participatory systems create responsive machines that acknowledge their own incompleteness and pursue “experiences that are playful, insightful, and potentially surprising” (Murtaugh 2008, 148). For Joyce the true index of interaction is coauthorship (1995, 193), when the participatory nature of digital environments not only makes it possible as it makes it commonplace to experience a complex sense of co-creation with digital systems. Peter Bøgh Andersen gives us a semiotic definition: “An interactive work is a work where the reader can physically change the discourse in a way that is interpretable and produces meaning within the discourse itself. An interactive work is a work where the reader’s interaction is an integrated part of the sign production of the work, in which the interaction is an object-sign indicating the same theme as the other signs, not a meta-sign that indicates the signs of the discourse.” (qtd. in Aarseth 1997, 49) Murray sums it up by stating that in participatory environments it is not only the human that programs the computer but also the computer that has the opportunity to program the user (1997, 77). All interactors, human, machine, individual or collective become agents in the processes (Thackara 2005, 132).

In *Computers as Theatre*, Brenda Laurel (1993) elects these participative properties as the most interesting feature of computers, but Murray classifies them as second in a list of four properties, that, as Ian Bogost defends, are hardly equivalent (2006, 13). The procedural properties of the computer are what allow participatory properties to be created and developed in the first place, what allow the systems to interact with

their users, what create the possibility for spatial properties to emerge in digital environments and ultimately also what make their encyclopedic nature possible. This view is shared by Manovich, for whom it is “computation itself” that is really fundamental in computers, more than interactivity, networking or multimedia (2002).

Murray defines procedurality as the “ability to execute a series of rules” by a device that is not “fundamentally a wire or a pathway but an *engine* (...) designed not to carry static information but to embody complex, contingent behaviors” (1997, 72), later adding that “[t]he most important element the new medium adds to our repertoire of representational powers is its procedural nature, its ability to capture experience as systems of interrelated actions.” (274)

As Kenneth Knowlton points, the possibility to define or execute complex processes exists independently of the computer (1976). Günter Bachelier mentions how William Latham produced evolutionary artworks on paper long before he started working with computers (2008, 252), defining his process as non-computerized, although in our view it was computational, as John R. Searle’s *Chinese Room Thought Experiment* (1981) reminds. In Searle’s experiment, we are led through the description of how a human placed in a black box, performs by hand all the algorithmic operations that a computer would realize in a complex procedure for the decoding and interpretation of Chinese texts. The human is unable to understand the meaning of the Chinese symbols she manipulates and only comprehends the set of English instructions that are presented to her. Nevertheless, because the human is able to manipulate the information in ways that, to external observers, seem to demonstrate an actual understanding of the original texts, the system as a whole works as a computer. In fact, we could say that the system as a whole *is* a computer. But the *Chinese Room Thought Experiment* also reminds us, as Hofstadter underlines in his reflections about Searle’s text, that the illusion “Searle hopes to induce in readers (...) depends on his managing to make readers overlook a tremendous difference in complexity between two systems at different conceptual levels” (1981, 373), and to neglect how arduous, boring and extremely long any simulation of an artificial intelligence system (or for that matter most of even the simplest computational processes) would be if manually realized by a human. However fast and effective the human could be, the computer would nevertheless outperform her by many orders of magnitude (Dorin 2008, 290). What the computer effectively makes possible is to execute these complex processes fast enough to conclude them in a humanly reason-

able amount of time, accurately enough to avoid the mistakes that would be expectable if a human computed the algorithm, and cheaply enough to afford plenty of time and resources for experimentation.

In digital environments work is quantified, abstracted and established as procedures that are independent of the particular person or device carrying out the tasks. When a programmer writes code, in the words of Kay, he “generates processes” (qtd. in Reas and Fry 2007, 3), and as these are reduced to pure abstraction, to a set of behavioral laws that specify what the system should do at every step (Rucker 2005, 12), they become “open to algorithmic mutation, sorting, looping or making tirelessly repetitive, subject to an ‘inhuman’ increase of speed” (Fuller 2005, 66). Abstraction is achieved by breaking processes into small units, articulated in programs, sequences of symbolic representations (Winograd and Flores 1990, 11; Bolter 2001, 30) of instructions suitable for execution by the computer or any other device that can interpret and run the programmed code. The word *program* is sometimes used synonymously with the word *algorithm* (Bolter 1984, 52), a word that in its turn, according to Robert Kowalski is synonymous with ‘logic’ and ‘control’ (qtd. in Goffey 2008a, 15).<sup>80</sup> More than referring to individual steps in a process, ‘algorithm’ identifies the complete set of instructions that are fed to the machine in order to solve a problem or to describe the strategy for its resolution (Bolter 1984, 52; Goffey 2008a, 16). Alan Turing<sup>81</sup> was the first to describe this as an ‘effective procedure’ and the notion is one of the most important not only in modern mathematics as also in computing (Weizenbaum 1976, 46; Goffey 2008a, 16).

We must be reminded that a functioning computer program, Turing’s effective procedure, does not need to “be ‘effective’ in the sense of succeeding in the task for which it is used: doing addition, recognizing a harmony, writing a sonnet. All computer programs are effective procedures, whether they succeed in that (task-related) sense or not.” (Boden 2004, 89) A series of unambiguously defined steps is

<sup>80</sup> This word’s etymology comes from the name of ninth-century Arabic mathematician Abū ‘Abdallāh Muhammad ibn Mūsā al-Khwārizmī, from where we currently also locate the root of the mathematical term ‘algebra’ (Ball 2004, 128). Al-Khwārizmī’s treaty *On Calculation with Arabic Numerals* from 825 CE was translated in the 12th century as *Algoritmi de numero Indorum*, where ‘Algoritmi’ was the translator’s rendition of the author’s name, intending to convey ‘Al-Khwārizmī on the numbers of the Indians’ or ‘Al-Khwārizmī on the Hindu Art of Reckoning’. Misunderstanding ‘Algoritmi’ as a Latin plural, people started to use it as a synonym of calculation method. The ‘th’ is usually explained as being due to a false cognate with the Greek word ἀριθμός (arithmos), meaning ‘number’.

<sup>81</sup> 1912-1954.

guaranteed to produce a result, however a priori undetermined that result may be. As we will see further on, as deterministic as it may be, an effective procedure may produce non-deterministic outputs. Bogost warns us against the tendency to understand effective procedures as established and entrenched ways of doing things, being the term as it is so close to the realm of officialdom and bureaucracy (2008, 122). A computational effective procedure, an algorithm, is not a static course of action, it is a set of constraints that structures all sorts of behavior following a formal language that defines sets of permissive rules, rules that specify what is possible to do, not what *has to be done* (Weizenbaum 1976, 49). In this sense, effective procedures create vast possibility-spaces to explore — spaces that without procedurality would not only not exist but wouldn't even be thought of (Lansdown 1997, 18).

#### 1.2.6 Universal Machines

Florian Cramer states that a “computer program is a blueprint and its execution at the same time. Like a pianola roll, it is a score performing itself”, a score that collapses “the second and third of the three steps of concept, concept notation and execution.” (2002) It is procedurality, the ability to computationally follow a series of rules in a formal system, that defines computers as something fundamentally different from the media and tools that preceded them (Bogost 2008, 122). Procedurality and programmability divide digital and analog machines, but this does not mean that analog machines cannot be programmed, it means that what is meant by *programming* is fundamentally different in the analog or digital realms. As Wendy Hui Kyong Chun explains, in the analog realm programming is descriptive, whereas in digital devices it is prescriptive (2008, 225). Whereas in an analog computer the entire machine performs the computation in a continuous process, by employing numerical methods and by breaking down all the processes into series of arithmetical operations, the hardware of a digital computer is in a sense a layer of the machine that can (at least theoretically) be replaced by any other machine that is capable of reading the executing the same code.

“With appropriate programming, a computer can embody any conceivable process” (Mateas 2005), performing arbitrarily long sequences of simple instructions and transformations (Lloyd 2006, 50) that are ultimately reducible to a limited set of

*universal* logic gates — NOT, COPY, AND and OR — as proved by George Boole<sup>82</sup> in his book *An Investigation of the Laws of Thought* (1854).

Turing and Alonzo Church<sup>83</sup> hypothesized that any possible mathematical manipulation could be performed algorithmically (Lloyd 2006, 51) by the thought experiments, or abstract devices that we now know as *Turing machines* (Wiener 1948, 13). A properly set machine would be able to interpret and process symbols, acting on the information by performing simple operations upon informational units of the simplest kind. The blueprint that Turing developed (1936) showed that the instructions on how to act on the information, as well as the information to be acted upon and the information coding the results of the processes, could all be specified in the same language and communicated to and from the computer in a uniform code (Sack 1996). According to Marvin Minsky, while it is often said that it did not really affect the practical development of the computer,<sup>84</sup> this was indeed the moment when, in essence, the modern computer and some of the programming techniques that accompanied it were invented (1972, 104).

Turing demonstrated that the internal workings of a programmed computer, or for that matter any machine that operates on symbols, could be specified by a table of behavior that would abstract the operations of the machine as a list. Any Turing-complete<sup>85</sup> machine programmed with the table of behaviors of a real-world physical machine (as a typewriter or a calculator) would be able to read the list of behaviors and perform whatever action it indicated as appropriate for each context, being therefore able to simulate the original machine. From any machine, an appropriately

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<sup>82</sup> 1815-1864.

<sup>83</sup> 1903-1995.

<sup>84</sup> The practical development of the computer was later accelerated during World War II (De Landa 1991, 129), and Turing was one of the many that contributed, on both sides of the conflict, to that development. The first electronic digital computer was built in Germany, by Konrad Zuse (1910-1995), in the early 1940s (Lloyd 2006, 52). Herbert Franke (1987) notes that the development of the computer in such a context, tied to what McKenzie Wark calls the 'military entertainment complex' (2007) is an historical accident and that the computer's development, under different historical and political circumstances could have nevertheless happened.

<sup>85</sup> Galanter (2008, 315) reminds us that in order to be Turing-complete, a system should theoretically dispose of unlimited storage space, which is by any means impossible to achieve. This is however a criterium that can usually be disregarded in practical implementations of computational devices. Although Turing describes the machine, he doesn't name it after himself, rather describing it as a set of deterministic mechanical procedures to be hypothetically executed by a human 'computer'.

assembled list of behaviors would create an abstract machine able to recreate its original actions.

In a further development, Turing proved that this abstract machine could itself be described to and be deployed by a lower level universal Turing machine, capable of operating from the description of another machine, interpreting it one step at a time and in effect imitating the other machine's behavior (Minsky 1972, 112; Kittler 1995). Although theoretically simple, the universal Turing machine "can do pretty much anything with information" and "generate mathematical patterns of any level of complexity" (Lloyd 2006, 51). Through repetition and recursion the machines built upon machines built upon machines are rated by Noam Chomsky as the most complex of abstract automata (Chomsky 1957; De Landa 1997). In general, as Stephen Wolfram summarizes, universality means that the setting of appropriate initial conditions in a given system will allow it to emulate any behavior that can occur in any other system (2002, 694). In other words, "a universal system can perform any computation that is theoretically possible to perform; such a system can do anything that any other formal system is capable of doing, including emulating any other system"<sup>86</sup> (Mateas 2008, 269). A universal computation can compute any computation and, as we will see, is in principle equivalent to any other computation. In his definition, Rudy Rucker adds that although common sense may lead one to expect that universality would be fairly hard to come by, it is in fact quite the opposite that is to be found both in natural and artificial systems (2005, 43). Once *any* computational system advances past a certain threshold, that Hofstadter calls "Gödel-Turing threshold" (2007, 241), it becomes universal. And this threshold is fairly low: being able to perform addition and multiplication may be more than enough, while sometimes even more rudimentary capabilities will suffice (Rucker 2005, 43). Wolfram goes as far as to suggest that there seems to be reason to believe that a large number of naturally occurring computational systems may support universal computation, something he terms the 'Principle of Computational Equivalence' (2002, 715) and that will be discussed in more detail ahead.

Universal machines read information, write information, and finally, are able to act on the information and, as a consequence of being themselves described as information, universal machines can literally act on themselves (Fuller 2005, 25). Universal

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<sup>86</sup> Provided, of course, that such system is computable.

machines are transcodable and they are universal media for both structure and process (Mateas 2005).

### 1.2.7 Abstract Machines

In her study of creativity, *The Creative Mind*, Margaret Boden elects representational systems as being some of the most important human creations (2004, 107). Representational systems include formal notations as the Arabic numerals, chemical formulae, musical scores and, more recently, programming languages. Formal notations are codes that make it possible to declare and develop effective procedures of many different kinds.

The term ‘machine’ is problematic to adequately define in more detail than what is provided by the simple definition of ‘a device that uses energy to perform an activity’. A machine needs to be defined based on its actual use, not on its composition or structure (Minsky 1972, 3), therefore, when talking about a machine we must have in mind not only the actual physical object that it may be as well as a relatively clear idea of its purpose.

The design of a machine is always an abstraction. Designs are independent of the media in which they are recorded, or of the particular ways in which they are expressed. They are abstract ideas, just as they are functional specifications. In a sense then, a design is an abstract machine (Weizenbaum 1976, 43). Effective procedures, being designs of processes, are descriptions that will be simulated by universal machines and are therefore in a sense mechanism-independent. They are conceptualized as abstract machines, single “mathematical mechanisms” capable of being incarnated in many different physical mechanisms (De Landa 1991, 18).

The computer was born as an abstract machine and as such it remained for over a decade, until it finally was embodied as a result of the pressures of cryptological research during the course of World War II (129). The machine that more than any other device or mechanism allows us to abstract machines started its existence as an abstraction. Turing described a vague and sketchy physical contraption, making use of components such as an ‘infinite tape’ and a read/write/erase head that would operate on that tape. The logical workings of the system were described in considerable detail, but this description was far from being implemented as a real physi-

cal embodiment. The Turing machine was, perhaps almost too literally, machine-independent, it was a *Body without Organs* (BwO) in the sense defined by Gilles Deleuze<sup>87</sup> and Félix Guattari<sup>88</sup> (1988), rejecting from its inception the boundaries of the material, dispensing with matter and energy because it was primarily information. It was the first step towards crossing the frontier between the world of abstract machines of De Landa's machinic phylum and that of the concrete assemblages of human practices (De Landa 1991, 229).<sup>89</sup>

The classical idea of the machine does not explain the BwO because it does not capture its spirit, it does not understand anything besides the physical workings and the transmission of force or energy (Minsky 1972, 7) and the design, the abstract machine and the BwO are *information*.

The devices that incorporated the machinic paradigms of the clock and the motor were undoubtedly concrete physical assemblages before being abstracted. The 'five simple machines' — the wheel and axle, the lever, the pulley, the wedge and the screw — were abstracted by Hero of Alexandria,<sup>90</sup> in ancient Greece. During the renaissance, Galileo Galilei<sup>91</sup> worked out their complete dynamic theory in *Le Meccaniche*<sup>92</sup> (c. 1600), understanding that they do not create energy but simply transform it. A century earlier, Leonardo da Vinci<sup>93</sup> abstracted several early geared mechanisms, and Sadi Carnot<sup>94</sup> abstracted the steam motor a hundred years after it was originally born as a concrete assemblage (De Landa 1991, 142). True to its nature, the mechanisms of the machinic paradigm of the network started out by being abstractions and were only later assembled in their many different (but equivalent) material embodiments.

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**87** 1925-1995.

**88** 1930-1992.

**89** In a sense, the universal Turing machine is still an abstract machine, and will, perhaps forever, continue to be impossible to fully implement. Besides a read/write head, a finite set of instructions and a finite state register, the universal Turing machine requires a memory device, described by Turing as an *infinite* tape. As big as memory banks have become over the years, it is clearly impossible that they can ever be infinite, so if for practical purposes it is possible to build computational devices that we can classify as Turing complete, this final requisite will never truly be fulfilled, and universal Turing machines will always be only abstract and theoretical machines.

**90** c. 10–70 CE.

**91** 1564-1642.

**92** *On Mechanics*.

**93** 1452-1519.

**94** 1796-1832.

Software — a running program — is a machine that gets its power and substance from another machine, the computer where it is run, or *any* other machine. Running code is a machine that has been embodied by the universal machine (Gelernter 1998, 23), making it become a new machine. This is often referred to as a ‘virtual machine’, something that does not exist as a matter of actual physical reality (24) but only exists while it is being executed by a universal machine. This concept clarifies what it is exactly that programmers do — and by extension what artists and designers that work with digital technologies do — they are machine designers, they program abstract machines that are automatically and only temporarily converted into *the things themselves* when they are handed over to a computer. “A smart artist makes the machines do all the work” (Cornelia Solfrank qtd. in Blais and Ippolito 2006, 17), more to the point, an artist’s work is the creation of the machines that may then do the work.

### 1.2.8 Process Design

When programming, engineers, designers or artists<sup>95</sup> do not create objects or products, as they have for centuries done using traditional media: they create artifacts that are processes, artifacts that are “more comparable to a continual flow than to an object that is divisible into units.” (Perret 2005, 248) As Alan Cooper, Robert Reimann and David Cronin underline in the introduction of their book *About Face 3*, although the practice of programming is also concerned with form, its focus is something that traditional design disciplines do not often explore: the design of behavior (2007, xxvii). As digital environments open to the external world and to interaction, their designers no longer may know anything for certain, they no longer control the well-defined space of possibilities that existed in traditional media and all they can offer are the contents of their own heads, “where internal imagination meets the external world of reality” (Dunne 2005, xvii). And although being largely virtual, and rooted in the transformation of data and not in physical dynamics (Lee 2009, 2), digital artifacts must often nevertheless have some sort of physical embodiment.

In his book *Hertzian Tales* (2005), Anthony Dunne<sup>96</sup> discusses four alternative common approaches to address the conflict between the solidity of objects and the flu-

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<sup>95</sup> For simplicity’s sake we will refer to all of these software producers simply as ‘designers’.

<sup>96</sup> The head of the Design Interactions program at the Royal College of Art in London.

idity of digital media: *packages*, *fusions*, *dematerialization* and *juxtaposition*, four strategies to link the immaterial and the material through design.

Packages are identifiable in the way that commercial design's approach to digital objects has long been to treat them merely as containers for technology, dedicating resources to many clearly secondary aspects of the objects and devoting far less care and time to the development of their fundamental digital cores. This is clearly visible in many digital consumer products — for example cellular telephones — that although being primarily and fundamentally digital devices (that also happen to make phone calls) are often marketed and sold based on almost every feature they present besides their actual software. Physical packages for digital devices are treated as independent objects and not entirely as supporters of their digital functions or as an integral part of those.

With fusion the digital object becomes a confusion of conceptual models, symbolic logic, algorithms, electrons and matter in what Dunne sees as a closing of the gap between the scales of electronics and objects by the direct manipulation of materials as volumes of electrons. Smart materials are an area where this gap is being closed, although primarily for technical reasons so far, as designers have not yet explored the aesthetic dimension of the new materials with the same energy that engineers have made the most of their functional possibilities. Therefore, with fusion and with physical materials that are themselves also computational devices, Dunne concludes, most work in this area does not yet encourage poetic and cultural possibilities to converge with practical and technical ones.

With dematerialization, the digital object is taken to the threshold of materiality. "Although 'dematerialization' has become a common expression in relation to electronic technology, it is difficult to define in relation to the tangle of logic, matter, and electrons that is the electronic object" (11), and its meaning varies, depending on what it is defined in relation to: immaterial/material, invisible/visible, energy/matter, software/hardware or virtual/real. What is certain is that if communication with humans is to be established, the physical can never be completely dismissed, as a physical layer must always be involved in the communication act, and a physical media must transport the message from the informational device to the material body, where it can then reach another informational device: the brain. The most prominent form of dematerialization is found on the role of objects as interfaces.

When the designer is no longer simply packaging the digital technology, she will focus on behavior and procedurality, designing the dialogues between people and digital machines, through physical objects that are interfaces, that are *zones of transaction*. Most of the current work in this area tends to reduce the object to a Graphical User Interface on screen, but there are several examples of explorations of other media, devices and metaphors in the search for an aesthetics of use.

Finally, juxtaposition permits us to discover “analogue complexity in digital phenomena without abandoning the rich culture of the physical, or superimposing the known and comfortable onto the new and alien. Whereas dematerialization sees the electronic integrated into existing objects, bodies, and buildings, the juxtaposition of material and electronic cultures makes no attempt to reconcile the two: it accepts that the relationship is arbitrary, and that each element is developed in relation to its own potential. The physical is as it always has been. The electronic, on the other hand, is regarded only in terms of its new functional and aesthetic possibilities; its supporting hardware plays no significant part.” (17) Although this may remind us of a certain Cartesian dualism (King 1997), what we really face with juxtaposition is a multi-modality of the objects, reminiscent of what happens with somatic messages (Lévy 1997, 45). Different scales and technologies coexist in the same object and they grow obsolete at their own paces. Robert Rauschenberg’s<sup>97</sup> sculptural installation *Oracle* (1962-65), presents an interesting example, because in the course of thirty years and several showings, it has had its technology updated three times, while its materiality and cultural meaning have remained unchanged.

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97 1925-2008.



Fig. 38: *Oracle* (Rauschenberg 1962-65).

Jack Burnham, an American critic and theorist of contemporary arts, mentioned already in 1968 that sculpture was apparently obliterating itself by abandoning traditional sculptural concerns for a ‘dematerialized dynamism’. Burnham identified a transition from object to system that was evident in forms as kinetic sculpture, light art, cybernetic art, and environment art (qtd. in Whitelaw 2004, 18). Also somewhat presciently, around the same time, McLuhan noted how private and corporate lives were becoming information processes, “because we have put our central nervous systems outside us in electric technology” (1964, 57). McLuhan understood how with the newly available technology man was heading to a learning and knowledge economy — what we nowadays call an information economy — where all forms of employment would become “paid learning” and all forms of wealth would result from the movement of information (64).

Returning to Dunne, he reasons that the most difficult challenges for designers nowadays lie in the realms of metaphysics, poetry, and aesthetics, where little research has been carried out comparatively to the realms of technical and semiotic functionality or performance. Dunne defends that in a world where practicality and functionality can be taken for granted, the aesthetics of what he calls the ‘post-optimal objects’ can provide new experiences to everyday life, new poetic dimensions. This observation points us to the practice of a ‘poetics of knowledge’ described by Richard Wright: “an aesthetic or cultural practice that articulates and is informed by scientific knowledge but can function in a wider cultural context” (1997, 24).

Designing algorithmic processes, the computer programmer creates universes of virtually unlimited complexity for which she alone is the lawgiver (Weizenbaum 1976, 115), an idea that is recovered by Lessig (2006) who stresses that though able to create spaces of freedom, computer programs can also create spaces of oppressive control and high regulation because both the freedoms as the constraints and controls are embedded in the architecture of code. But being the lawgiver doesn't necessarily mean that the designer is always an omnipotent puppeteer or that she minutely controls all the details in her creations. As we shall see, the designer's role can be demiurgic but it can also be, as Mitchell Whitelaw (2004) so elegantly puts it, that of a gardener, planting seeds of processes that will evolve and grow somewhat independently and autonomously, processes that are not micromanaged but rather nurtured.

Hiroshi Kawano chooses a metaphor of learning when describing these processes, comparing the relationship between programmer and computer to that between a parent and her child. When teaching a child to, for example, draw a picture, more than instructing very concrete and absolute steps to achieve an outcome, a parent rather tries to lead the child to achieve by herself. Kawano compares this 'how to draw' with the algorithmic procedure of picture-drawing, concluding that in order to pass it on to the child, the parent must know it beforehand, and that the more explicitly she knows and teaches the algorithm, the better results will the child achieve, that is, in a sense the quality of the child's pictures will depend only upon the quality of the algorithm that the parent had already possessed and taught her (1976).

### 1.2.9 Descriptive and Generative Processes

If a designer programs comprehensive tables of behaviors that carefully and precisely describe all the details of an artifact, including actions, narratives, images, sounds, or every possible message necessary, we can say that the processes being programmed are *descriptive*, whereas if on the other hand the processes are less restrained and some of the control is intentionally relinquished by the designer, the processes being programmed will be in a sense *generative*.<sup>98</sup>

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<sup>98</sup> In some sources, *generative* processes are alternatively called *procedural* (Carranza 2001).

In *The Sciences of the Artificial* (1969), Herbert Simon<sup>99</sup> cites Euclid's *Elements* twice, demonstrating what he defines as a 'state description', "a circle is the locus of all points equidistant from a given point", and a 'process description', "to construct a circle, rotate a compass with one arm fixed until the other arm has returned to its starting point". It is implicit that by following the process specified in the second sentence, one will produce an object that satisfies the definition of the first. Simon presents these two modes of description as being something very common in our experience, likening the first to pictures, blueprints, diagrams and chemical structural formulas, and the second to recipes, differential equations, and equations for chemical reactions. "The former characterize the world as sensed; they provide the criteria for identifying objects, often by modeling the objects themselves. The latter characterize the world as acted upon; they provide the means for producing or generating objects having the desired characteristics." (111) Christian Jacob and Gerald Hushlak (2008, 145), while discussing design methodologies in science, art and music, choose the exact same terms, 'blueprints' and 'recipes' to describe this difference in approaches, and Pablo Miranda Carranza reminds that in nature, it is the second one that we commonly find, as macroscopic organisms are epiphenomena (2001), or, as Philip Galanter puts it, emergent phenomena (2008, 313).

We could draw a parallelism with numerical and analytical models, as they're commonly defined in sciences. While an analytical model involves mathematical expressions for the relationships between different bulk properties of the medium being described, a numerical model tries to describe and enumerate each of the component parts of a system, letting the overall behavior of the system emerge from them (Ball 2004, 14). The example chosen by Ball is the motion of liquids or gases, explained by analytical models that work statistically instead of trying to define the properties of the motion and behavior of each of the molecules.<sup>100</sup> On the other hand, Gregory Bateson<sup>101</sup> presents us with an analogy drawn from biology, asking us to consider all the propositions that may be required to describe an organism, millions of them in some cases, orders of magnitudes more in others, interconnected in "loops and circuits" of interdependence and holding for each of them specific metavalues, desired or ideal states (1979, 156). Analytical models are top-down ap-

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<sup>99</sup> 1916-2001.

<sup>100</sup> These methods were in fact developed because it would be impossible to accurately and effectively compute all the individual molecules in a liquid or gas.

<sup>101</sup> 1904-1980.

proaches that dissect the whole into its constituent parts and exactly because of that, they are bound to miss precisely the “emergent (or ‘synergistic’) properties [that] belong to the *interactions between parts*,” (De Landa 1997, 17) as “analyzing a whole into parts and then attempting to model it by *adding up* the components will fail to capture any property that emerged from complex interactions, since the effect of the latter may be multiplicative (e.g., mutual enhancement) and not just additive” (18). If in biology, as noted by D’Arcy Wentworth Thompson,<sup>102</sup> form follows function (1942), we need to understand that, in order to achieve forms akin to nature, we need to let form also follow process, the processes of growth and evolution that occur in the living world (Hemberg et al. 2008, 168).

Analytical models embed a priori assumptions about systems, while numerical models, although arguably never totally free from those assumptions, by changing their scale allow the discovery of synthetic, a posteriori phenomena. Although examples from the real world are the more commonly conveyed, Aarseth reminds that programmed systems are not always necessarily models or representations of something, as they can be evolving and self-organizing entities whose behavior cannot be described as the sign production of a human programmer or as being a mimetic simulation of an external phenomenon (1997, 30-31). As one example of such systems Aarseth presents the cellular automaton<sup>103</sup> known as the *Game of Life*, created by John Horton Conway in the late 1960s after systems proposed by John von Neumann<sup>104</sup> and Stanislaw Ulam.<sup>105</sup>

In the *Game of Life* each cell holds a single bit, existing at every moment in one of two possible alternative states — alive or dead. The universe of the game is an infinite two-dimensional orthogonal grid of square cells, where every cell interacts with eight direct neighbors: the cells directly vertically, horizontally or diagonally adjacent. At each step in the process, all the cells are updated from their current state based on four simple rules: 1) Any live cell with less than two live neighbors dies, as if by underpopulation; 2) any live cell with more than three live neighbors dies, as if by overpopulation; 3) any live cell with two or three live neighbors lives on

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**102** 1860-1948.

**103** A system of a periodic array of cells that hold information by existing in one of several different states.

**104** 1903-1957.

**105** 1909-1984.

to the next generation; and finally 4) any dead cell with exactly three live neighbors becomes alive.

This simplicity does not stop information from being transmitted across the system and it allows the development of patterns of information that are capable of duplicating themselves elsewhere on the matrix (Ball 2004, 241). The *Game of Life* is then an example of an emergent system, a system in which a handful of simple rules combine and interact, making the array of automata largely exceed the complexity of each single automaton, and leading to consequences that were hitherto unpredictable (Bogost 2006, 95). In *Life* one can find structures that stay forever still if undisturbed,<sup>106</sup> structures that oscillate with various regular periods<sup>107</sup> and structures that move along the plane of the world,<sup>108</sup> we can find structures that grow forever, that create new structures<sup>109</sup> and observe very complex interactions between these structures.

We may postulate that in the *Game of Life* and in other systems that we will further study, a generative process is programmed because a numerical model is put in motion by the code. In this generative process we are able to develop many (or all, in the sense that, according to Wolfram (2002, 676) these processes are universal) descriptive processes and analytical models.

The question here doesn't so much regard the absolute loss of control between descriptive and generative processes, although this may exist to a certain extent. Processes gain generative potential when some of their variables are left uncontrolled by the programmer. In low-level systems, as the current example of the *Game of Life*, the designer specifies the system in greater detail than in many other (and less generative) cases, because she sets in motion a world for which she has written the fundamental laws. In doing so she is transferring to the system itself the power over many variables, delegating levels of control and creating more chances for unexpected and novel behavior.

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**106** So-called 'still lives' as the blocks, the beehives, the loafs or the boats.

**107** Such as the blinker, the toad, the beacon or the pulsar.

**108** Usually called 'spaceships', as the glider and the lightweight spaceship.

**109** Such as the glider guns or the puffer trains.

Directing our analysis to communication and art, we find that Cramer (2002) similarly distinguishes between non-algorithmic digital code and program code, the first being exemplified by audio CDs and MP3 files, by hypertext or digital video, while the later would be better represented by algorithmic composition, algorithmically generated text or a graphical demo. Although we can have no digital data without programs, in Cramer's view, the question is *who* programs, and whether designers use software layers that they take for granted or design them themselves. In this context we could equate Cramer's non-algorithmic digital code to *media* code, code that samples<sup>110</sup> and preserves a message instead of creating it, whereas the algorithmic program code performs synthesis, i.e., creates something new. Returning to Lévy's technologies of information, we see that digital technologies are able to convey information produced by other technologies at a far greater degree than both the media and somatic technologies that preceded them. They mediate and remediate information, while at the same time also create new information almost *ex nihilo*, thus becoming closer to the generative power of the original somatic technologies.

With some exceptions, most of the processes that a designer programs will be simultaneously descriptive and generative. In order to manage to communicate in the contemporary media landscape, descriptive processes, conveying non-algorithmic content, should never be disregarded, as they are responsible for much of what makes digital environments be encyclopedic, and they are where much of our current cultural preservation is taking place. Generative programming, on the other hand, is what makes digital technologies be far more dynamic, useful, surprising and altogether helpful than strictly analog media technologies could ever be, independently of their greater or lesser encyclopedic extent. Vannevar Bush's<sup>111</sup> *Mex* (1945) comes to mind as an example of what, shouldn't digital technologies be available, would never become more than a concept. Recovering Edward de Bono's definitions, we could suggest that descriptive processes are 'vertical', selective and analytical, while generative processes are 'lateral', instigative and nonlinear (Cope 2005, 10).

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<sup>110</sup> Both in the more common sense of music and pop culture as in the more strict technical term from signal processing, when a continuous signal is converted to a discrete signal.

<sup>111</sup> 1890-1974.

### 1.2.10 Grammars (Generative and Transformational)

This leads us to a concept, first enunciated by Chomsky (1956; 1957) when, in the study of linguistics he moved away from the surface appearance of sentences towards the abstract principles of language and grammar, to the devices used to generate the sentences. Chomsky proposed the existence of an intrinsic universal grammar that defines what a speaker knows about the language rather than what he actually does with it, a knowledge “which is partly hidden and unconscious, generates an enormous quantity of outgoing information in the form of spoken sentences, while relying on relatively little incoming information, in the form of what others say” (Campbell 1982, 95). This grammar is termed ‘generative’ because it provides to language something equivalent to what DNA provides to a cell: a space of possibilities. Chomsky’s approach was a radical departure from previous work in linguistics because it pointed to the reasons why language is universally creative: “We do not need to copy sentences others have already spoken, although we often do. The point is that we are always capable of inventing new sentences of our own, and we do so spontaneously, in the most casual of conversations.” (95) Grammatical rules can certainly be used to check the validity of sentences, but they are primarily a resource for the formation of new sentences, setting the basic framework of a sentence and later transforming it and filling it with the materials of a real language (De Landa 1997, 217-18). Chomsky understood the existence of these two types of rules, naming them ‘generative’ and ‘transformational’. The generative components of grammar define a structured place of possibilities and the transformational components allow the movement through and the construction in this space.

Ong identifies a fundamental difference between programmed processes and human languages, in that the rules of computational processes must always be stated a priori, while the rules of grammar are “used first and can be abstracted from usage and stated explicitly in words only with difficulty and never completely.” (1982, 7) But according to Chomsky, there is an a priori universal grammar that stands behind both the generative and the transformational components, a universal grammar that is tied to deep and abstract internal principles in the mind and that explains why language is so universal in certain of its aspects, independently of local cultural differences (Campbell 1982, 179; Pinker 1994). Grammar thus becomes an antichance device, that both lays the structure for the formation of language as it keeps it regular and law-abiding (Campbell 1982, 165). On a different perspective,

programming may not always need to happen a priori. Going back to the example of the *Game of Life*, if the space and the ‘physical laws’ of the world are certainly programmed a priori, the structures that are developed in that space are, in a sense, altogether different programs from *Life*. These programs are not specified in the same programming language as the particular implementation of the *Game of Life* is written<sup>112</sup> but are programmed inside *Life* itself, so *Life* becomes their programming language. Furthermore, these programs can be constructed by humans or can emerge from a particular structure or configuration of the matrix of *Life*: if we look at a glider as a program, then a Gosper glider gun structure constructs a glider once every 30 steps; if eight gliders happen to interact in a determined way then they can create a Gosper glider gun that will in its turn produce more gliders.

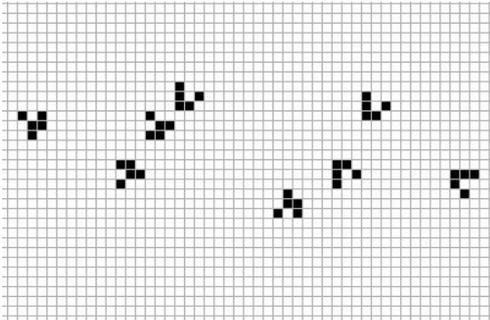


Fig. 39: Eight gliders in collision to produce a Gosper glider gun.

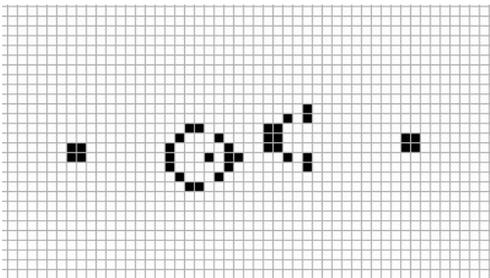


Fig. 40: Gosper glider gun.

<sup>112</sup> C++, Java, etc.

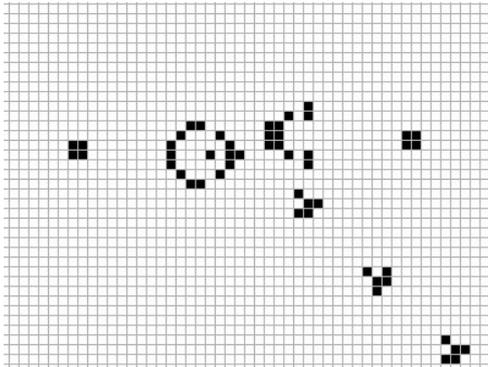


Fig. 41: Gosper glider gun after producing three gliders.

If we can eventually draw a direct parallelism between generative processes and the generative components of grammar, we must be careful to note that generative processes are not achieved only with generative components. Transformational components are also essential to generative processes, as they are necessary in descriptive processes, and often outlined by these. Transformational components overlap the domains of generative and descriptive processes. However, the main interest here is to understand how in language, the universal, generative and transformational components of grammar build a set of rules that constrain the space of possibilities while at the same time make rich expression possible. Without such rules “purely random changes in letter and word sequences in a written language [would] destroy sense and lead to gibberish. But if the changes are random, yet grammatical at the same time, interesting new sentences may result.” (Campbell 1982, 98) Constraints are not causes, or positive controls that make something happen, rather they are limits that define conditions for what is not allowed or not supposed to happen in a system (Wilden 1987, 77). They are an antichance device that allows abundant space for novelty, leaving the system of language essentially open and unbounded (Campbell 1982, 98).

### 1.3 Procedural Practices

#### 1.3.1 Historical Procedural Practices

The exploration and usage of procedural practices in artistic contexts did not start with the development of computers.<sup>113</sup> Of course that the mere existence of computers and the later availability of personal computers provided artists and designers with an easy and progressively more economical access to devices that allowed experimenting with procedural systems. The development of the computer and of computer networks into media, the Internet and the continued digitalization of electrical media nowadays provide grounds for a massive exploration, but even before the computer was invented, procedural creation was already experimented.

As early as the eleventh century, Guido d'Arezzo<sup>114</sup> developed a formal technique to compose a melody to accompany a text. His scheme assigned a pitch to each vowel, so the melody varied according to the vowel content of the text (Roads 1996, 822). Such a system would for all purposes lock the basic melodic creation to a text that most often than not was not written by the composer.

In plastic arts we can find that by the sixteenth century, Pieter Bruegel the Elder<sup>115</sup> numbered the colors of his characters in order to determine their distribution in a painting through a roll of dice (Berge 2003, 177).

Johann Sebastian Bach<sup>116</sup> explicitly used algorithms when composing some of the preludes in his *Das Wohltemperierte Klavier*<sup>117</sup> (BWV 846–893) published in 1722 (Cope 2005, 165).<sup>118</sup> Bach's process qualifies as a 'paper algorithm', a written recipe or sets of instructions for completing a composition that were processed manually. The

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**113** Or in particular with the development of personal computers, or microcomputers, as they were called in the earlier years.

**114** c. 991–after 1033, usually regarded as the inventor of modern musical notation in his 1026 treatise *Micrologus*.

**115** c. 1525–1569.

**116** 1685–1750.

**117** *The Well-Tempered Clavier*.

**118** This is attested by the autograph score of an early version of the first prelude (in C major). "What are chords here appear as repeated groups of arpeggiated sixteenth notes in the final version (...) Clearly Bach intended the example chords to act as a kind of shorthand for the eventual lute-like strumming that emerges in the final version." (Cope 2005, 165)

twenty-four pairs of preludes and fugues in each of the two books of *Das Wohltemperierte Klavier* were composed to a rigid conceptual program, that imposed severe constraints to the composer. The first prelude and fugue pair in each book was composed in C major, the second in C minor, the third in C-sharp major, then C-sharp minor, and so on, in a rising chromatic pattern that continued until B minor. Bach's self-imposed constraints certainly left a big space for his personal intervention in the process of composition, but it is important to note that by using them, he was already delegating the control over some aspects of production and handing creation over to an external system, as well as many decisions that were usually left to the moment-to-moment intuitive choices of the artist or composer.

Looking for examples that historically precede Bach, and forerunners of what he calls “generative art”, Galanter (2008, 317) mentions ancient art forms based on tiling patterns, as Arabic decoration motifs used by architects or artisans in materials as diverse as metal, wood, stucco, mosaic, tapestry or paint (Bourgoin 1973). According to Galanter, the placement of individual elements in these compositions was not decided by the artisan who handcrafted the work or by the architect in charge but was rather dictated by manually executed symmetry-based algorithms (2008, 317). We can find some of these systems in the theoretical works of Albrecht Dürer,<sup>119</sup> as for example the *Underweysung der Messung, mit dem Zirckel und Richtscheyt*<sup>120</sup> (1525) where several systems for the creation of geometrical patterns are described.

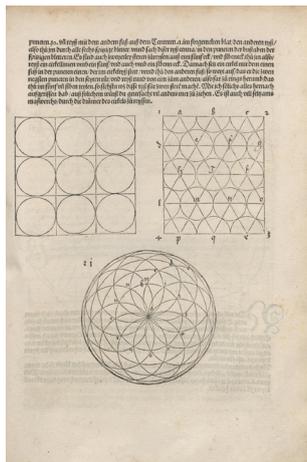


Fig. 42: Dürer's *Underweysung der Messung, mit dem Zirckel und Richtscheyt* (1525, 63).

<sup>119</sup> 1471–1528.

<sup>120</sup> *Four Books on Measurement*, as it is commonly translated, or *Teaching of Measurement, with the Compass and the Ruler*, in a more literal translation.

These highly ordered systems seem to be quite ubiquitous in the history of the arts and crafts. In fact they are so common that Galanter suggests that they can be as old as art itself:

Many are familiar with the discoveries of representational cave paintings some 35,000 years old that depict animals and early man's daily life. But in 1999 and 2000 a team led by archaeologist Christopher Henshilwood of the South African Museum in Cape Town uncovered the oldest known art artifacts. Etched in hand-sized pieces of red ochre more than 70,000 years old is an unmistakable grid design made of triangular tiles that would likely be recognizable as such to Escher or generations of Islamic artists.

While the etchings, like most ancient archaeological finds, are not without controversy, many find them compelling examples of abstract geometric thinking with an artistic response. In a related article in *Science* anthropologist Stanley Ambrose of the University of Illinois, Urbana-Champaign says "This is clearly an intentionally incised abstract geometric design ... It is art." (Galanter 2008, 318-19)

Besides highly ordered grid-like systems of composition, the most common procedural resources to be found in the arts previously to the development of the computer (or even of electric media) were the use of randomness or chance in composition and the recombination of modular parts and often, combinations of chance and recombination. This is what Lluís Mestres calls procedural-aleatory art, a conceptual term that identifies artworks that need to be deployed as computational processes (2004, 108).

Recombination is a method for producing new forms of data through the use of existing pieces of data in new logical orders (Cope 2005, 88). Digital information systems are recombinant, like the alphabet, from which, by multiple arrangements of letters we can get all the books ever written in a given language. The same happens with most of the Western (classical) music, that consists of combinations of the twelve pitches of the equal-tempered scale and their octave equivalents, and the recombinations of the groupings that result from these combinations (89). Recombination of enough parts with a versatile enough grammar allows a stream of endless, and potentially infinite, end results. Recombination of a more limited number of

parts either with an even stricter grammar, or with such a degree of freedom that can for all purposes be seen as equivalent to the absence of any type of rules, can be found in examples dating from the eighteenth century CE or even as far as the fourth century BCE.

One of the oldest, and more famous, examples of chance and recombination systems is the *I Ching*, the Book of Changes, an oracular system from the fourth century BCE still widely used in East Asia. The *I Ching* is built of a combination of sixty-four sets of six lines called hexagrams, each hexagram being the binary combination of six whole (unchanging) or broken (changing) lines ( $2^6 = 64$ ). Each hexagram is linked to a main text and to six smaller ones, one for each line. By manipulating three coins or forty-nine yarrow stalks according to a randomizing principle,<sup>121</sup> texts from two hexagrams are combined, producing one out of 4,096 possible results. These final texts contain the answer to a question written in advance by the user of the *I Ching* (Aarseth 1994, 769).

In Western Europe, one of the simplest early examples is the German landscape game described by Wilden as a case of “combination without complexity” (1987, 173). This game consisted of a set of 24 cards that could be rearranged to form landscapes of varying size and diversity by exploring the possible permutations of the full set of cards.<sup>122</sup> Each card was designed with the same controlled number of ‘planes of depth’, between four and six, and this allowed them to be freely aligned in somewhat harmonious land- and seascape results.

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<sup>121</sup> The method of the yarrow stalks is a biased random number generator, producing results that are not equiprobable. During the Han Dynasty (206 BCE–220 CE) this method was gradually replaced by the method of the three coins. Nevertheless, the accuracy of the randomness is not important as far as the divination properties of the *I Ching* are concerned because the fundamental idea underlining a system of divination is that the appropriate answers will eventually be produced, regardless of the statistical probabilities.

<sup>122</sup> 1,686,553,615,927,922,354,187,720 possible combinations, to be exact (Wilden 1987, 173).

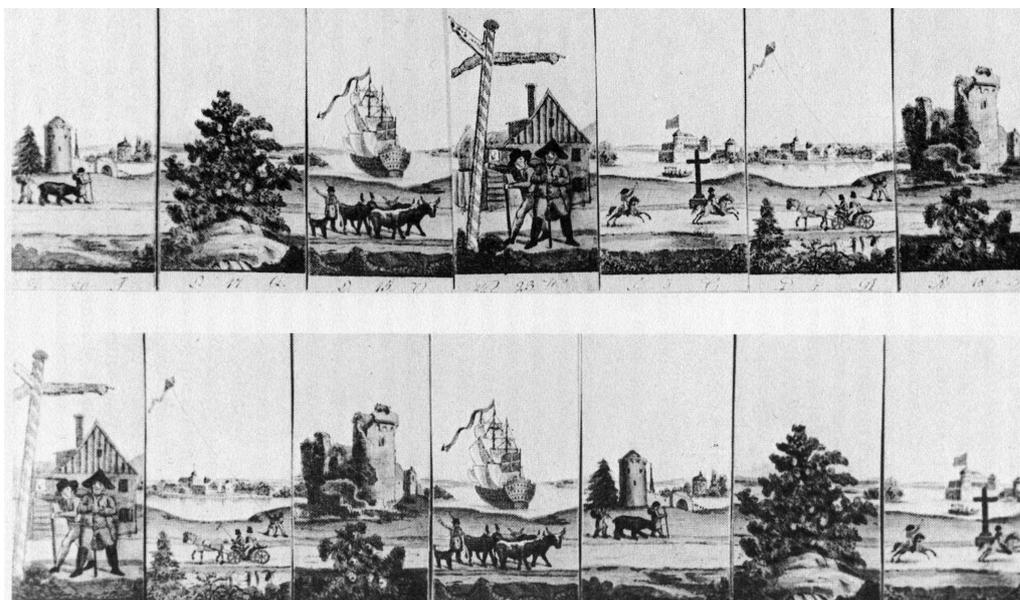


Fig. 43: An eighteenth-century game of landscapes, showing two rearrangements of the same subset of seven cards (Wilden 1987, 174).

Although it can be argued that these card games were not intended as artistic productions and that they were certainly not produced as consciously developing a procedural system, they were nevertheless aesthetic artifacts whose appeal and efficacy derived directly from their recombinational (and therefore procedural) nature.

The most famous documented early example of the use of randomization and recombination in the creative process of an artwork is a composition attributed to Wolfgang Amadeus Mozart,<sup>123</sup> the *Musikalisches Würfelspiel im C* K516<sup>f124</sup> written in 1787 and published in 1793.<sup>125</sup> The *Musikalisches Würfelspiel's* score provides 176 measures of prepared music and a grid that maps the throw of a pair of dice and a sequence number (first throw, second throw, etc.) into the numbers from 1 through 176. The composition to perform would be created by the performer through a sequence of dice throws, and the assembling of the corresponding measures in a sequential score (Galanter 2003, 14). This would show how one might compose, as stated in the title page for the J.J. Hummel edition of 1793 “without the least knowledge of music so much German Walzer or Schleifer as one pleases, by throwing a certain number

<sup>123</sup> 1756-1791.

<sup>124</sup> *Musical Game of Dice in C*.

<sup>125</sup> Pajot is very skeptical about the real authorship of this piece, defending that “there is absolutely no evidence, even a hint beside Mozart’s name being on the title pages of the above issues, that these games had anything to do with Mozart”.

with two dice” (Pajot 2004). Actually, the total number of possible compositions is so large<sup>126</sup> that as Martin Gardner<sup>127</sup> remarked, “any waltz you generate with the dice and actually play is almost certainly a waltz never heard before (...) if you fail to preserve it, it will be a waltz that will probably never be heard again.” (qtd. in Peterson 2001)

In eighteenth century Western Europe these games enjoyed some popularity, not necessarily involving the throw of dice but always trying to infuse a somewhat controlled amount of randomness into the process of musical composition or performance. Other documented examples of musical dice games are Johann Philipp Kirnberger’s<sup>128</sup> *Der allezeit fertige Polonaisen und Menuetten Komponist*<sup>129</sup> from 1757 and Joseph Haydn’s<sup>130</sup> *Gioco Filarmonico*<sup>131</sup> from 1790. In 1783 Kirnberger published a more elaborate system, explaining how to compose sonatas, symphonies and overtures, an how-to-do-it book that was intended for the hours of leisure of music lovers, dispensing them of resorting to professional composition (Wager 2000). Maximilan Stadler<sup>132</sup> is also attributed with the creation of a table to compose minuets and trios that also required the use of a pair of dice, the *Tables from Which One Can Toss Off Countless Menuets and Trios for the Klavier*, from 1781.

The root of these games goes back to much earlier than these works. Samuel Pepys<sup>133</sup> is reported to have had some sort of music composing machine that he used quite often, although there are no details about its format or working mechanisms (Wager 2000). Earlier still we find Marin Mersenne<sup>134</sup> stating in his *Traité de l’harmonie universelle*<sup>135</sup> from 1636-7 that music is only algebra translated into sound and that with the help of the sequential method, any lay person could become a composer within the space of an hour or less (Zielinski 2006, 143). This observation was heavily criticized by many of his contemporaries, but some others, like Kircher, shared this view of music as a discipline subordinate to mathematics. He demonstrates it in book 8

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**126** As many as 11<sup>16</sup> or 45,949,729,863,572,161 (Peterson 2001).

**127** 1914-2010.

**128** 1721-1783.

**129** *The Ever Ready Composer of Polonaises and Minuets*.

**130** 1732-1809.

**131** *Philharmonic game*, sometimes also translated as *Philharmonic Joke*.

**132** 1748-1833.

**133** 1633-1703.

**134** 1588-1648.

**135** *Treatise of Universal Harmony*.

of his treatise *Musurgia Universalis* from 1650, that focuses on the mechanical arts in music and that, among plans for the construction of water-powered automatic organs, notations of birdsongs, diagrams of several music instruments and studies of the human ear, also proposes an apparatus for the composition of music, the *Arca Musarithmica*.<sup>136</sup> The construction of this *Arca Musarithmica* would be similar to that of other combinatorial boxes that Kircher conceived, like the *Cassetta Matematica*,<sup>137</sup> also called *Organum Mathematicum*<sup>138</sup> built in 1661 (142): it would be a relatively small and portable wood box containing specific organizing systems that used thin sliding slats. The slats were positioned vertically one behind the other, and the units of information inscribed on them were arranged so that, by following the rules of operation, they could also be linked horizontally (141).

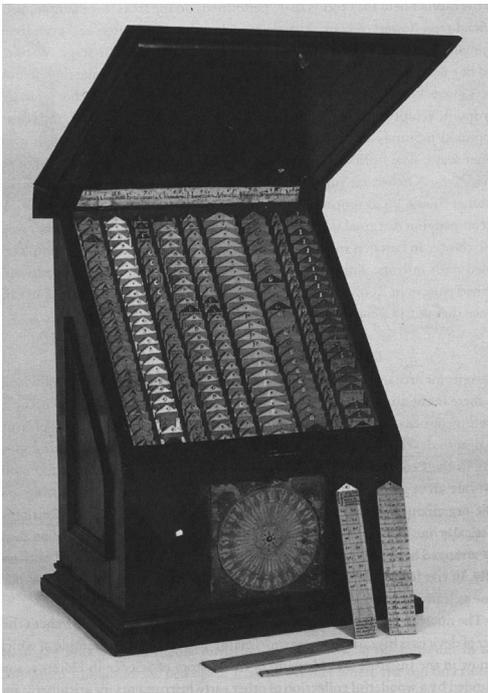


Fig. 44: Kircher's *Cassetta Matematica* or *Organum Mathematicum* (Zielinski 2006, 142).

On the front of the *Arca Musarithmica* we would have clefs and at the back, arranged in tables, would be the keys that could be used in the composition. The slats inside the box would be marked on the front with sequences of four-note chords and on the back with rhythmic variations that could be combined with them. The *Musurgia*

<sup>136</sup> Box for rhythmic sequences of notes.

<sup>137</sup> Mathematical box.

<sup>138</sup> Mathematical organ.

*Universalis*, that this box was supposed to accompany, notes the chord sequences as rows of numbers and explains the method of composing music with the help of the device (143). Due to the extremely vague descriptions formulated by Kircher, and the confusing terminology used in the book, it is not clear to music historians what the precise functioning of the box was supposed to be, or how the music it produced would sound, and different accounts are often so divergent that Zielinski sometimes has the impression that they were describing completely different devices (144).

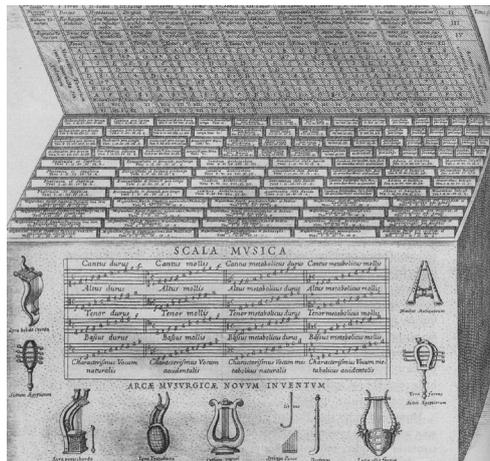


Fig. 45: Kircher's design for the *Arca Musarithmica* (Zielinski 2006, 146).

Independently of the vague, contradictory or sketchy details provided by Kircher, the essence of the *Arca's* design is a collection of precomposed musical, poetic, and rhetorical patterns from where it was possible to create variable, harmonic compositions. Zielinski identifies here the principle of an electronic music sequencer, storing sound sequences and delivering them to different instruments for reproduction or further processing (145). A somewhat simple process, but with far-reaching consequences, as Kircher himself noted at the end of chapter 3, *On Using the Arca Musarithmica*: “It is apparent from that which is put forward here the infinite number of possible combinations, which are given by the different ordering of the five columns. Assuredly there are so many that had an angel begun with the combinations at the dawning of the world, it would not be finished today” (qtd. in 145).

Already in the nineteenth century we can find two more examples of combinatorial systems for the composition of music: the *Kaleidacousticon* system, advertised in the newspapers of Boston, Massachusetts in 1822 (Roads 1996, 823). This system was comprised by a deck of playing cards with instructions indicating how to use

them to compose up to 214 million different waltzes. In 1865 in the United Kingdom, Professor J. Clinton of the Royal Conservatory of Music in London sold the *Quadrille Melodist*, marketed as a practical aid to composition. This was also a set of cards, presumably noted with fragments of music notation, and it “enabled a pianist at a quadrille party (an early square dance) to keep the evening’s pleasure going by means of a modest provision of 428 million quadrilles” (825).

Simple combinatorial systems of this kind do not increase diversity or create complexity (Wilden 1987, 173), no matter how large is the number of possible numerical combinations (175), but they nevertheless allow the systematic exploration of a sometimes vast field of possibilities (Gombrich 1984, 70) by the reader / user / interpreter of a piece, infusing it with a level of uncertainty that wasn’t normally found in artistic pieces of the time. Although still authoring the pieces, the authors or composers of the systems abdicated of a big level of control and, in a sense, created frameworks for the production of final works rather than creating the final works themselves. This would open the doors to the increasing exploration of a large number of systems for metacreation, that were however often presented as games or toys — something that in retrospect may seem inevitable, especially at the time of the highly trained and gifted romantic artists.

Before the advent of computers, automatic or semi-automatic music composition was not only developed with formal systems but also with a variety of machinery. The *Aeolian Harp*, known since antiquity, was described by Kircher in his book *Phonurgia Nova*,<sup>139</sup> from 1673 and became rather popular during the eighteenth century.

Aeolian harps are built with wooden boxes where strings are stretched across two bridges. When placed in front of an open window, the wind blows across the strings, making them resonate and producing a variety of aleatoric sounds that depended on the force of the wind, the number, tension, material and caliber of the strings and also on their relative tunings (Roads 1996, 825).<sup>140</sup>

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<sup>139</sup> The full title of which is *Phonurgia Nova, sive conjugium mechanico-physicum artis & natvrae paranympa phonosophia concinnatum*.

<sup>140</sup> The physical mechanism that is responsible for the functioning of the Aeolian harp is the von Karman vortex effect, first abstracted by Lord Rayleigh (1842-1919) in 1915.

The *Componium* was a room-sized mechanical instrument, constructed in 1821 by Dietrich Nikolaus Winkel,<sup>141</sup> that composed novel music through the simultaneous revolution of two barrels that took turns performing two measures of randomly chosen music, thus exploring several possible combinations of the stored fragments of music. Some years later, a large-scale mechanical machine similar to the *Componium* was devised by a Baron Guilani and exhibited in Vienna (825).



Fig. 46: The *Componium*.

The experimentation with recombination systems was also developed in the literary arts, and also there we can find examples of games and tools for composition and writing.

*Gradus ad Parnassum*<sup>142</sup> was the common designation for a dictionary of Latin and/or classical Greek that provided epithetic and other phrases from classical poets, with the long and short syllables conveniently marked for metrical fit, to help beginners (Ong 1982, 21). The first *Gradus* was compiled in 1687 by the Jesuit Paul Aler<sup>143</sup> and there were several more published in the following years, by Thomas Morell in 1762, F.J.M. Noël in 1810, E. Maltby in 1815, John Brasse in 1828, Liddell-Scott-Jones in 1843, C.D. Yonge in 1850, Charles Lewis and Charlton Short in 1879 and A.C. Ainger

<sup>141</sup> 1773-1826.

<sup>142</sup> Literally 'Steps to Parnassus', sometimes shortened to *Gradus*. This is also the title of an unrelated textbook on counterpoint, musical theory and composition written in 1725 by Johann Joseph Fux (1660-1741).

<sup>143</sup> 1656-1757.

and H.G. Wintle in 1890, to name just a few. The student or aspiring poet could use a *Gradus* to assemble a poem by simply selecting the building blocks and keeping tabs on the metrical fit. “The overall structure could be of his own making but the pieces were all there before he came along.” (22)

In the seventeenth century, the German poet and language researcher Georg Philipp Harsdörffer<sup>144</sup> sought to systematically exhaust the potential of combinatorics in linguistics and poetics. He designed a combinatorial morphologic word creation machine, the *Fünffacher Denckring der Teutschen Sprache*<sup>145</sup> from 1636 that should in principle permit anyone to generate all existing and potential words of the German language by the combination of what Harsdörffer called ‘syllables’, but modern linguists currently call ‘morphemes’ (Cramer 2005, 46). It is with this work that, according to Cramer, language is for the first time turned into a computational and algorithmic system, into a program.



Fig. 47: Georg Philipp Harsdörffer's *Denckring* (Cramer 2005, 47).

Harsdörffer also wrote what Berge would later call ‘factorial poetry’, but was by then more commonly referred to as ‘protean poetry’,<sup>146</sup> following Julius Caesar Scaliger<sup>147</sup> who supposedly invented the genre (Berge 2003, 179) and named it after the Greek god who perpetually changed his face (Cramer 2005, 44). In these poems, certain elements of the text could be permuted in all possible ways as the reader saw fit or

<sup>144</sup> 1607-1658.

<sup>145</sup> *Five-fold thought ring of the German language.*

<sup>146</sup> *Poetices Proteos.*

<sup>147</sup> 1484-1558.

chance defined, changing the meaning but preserving syntactic correctness. Cramer defends that the origin of this permutational poetry is even older, going back to Publilius Optatianus Porfirius<sup>148</sup> in the fourth century CE, specifically to the *Poem xxv* from his *Carmina*,<sup>149</sup> in which the words can be rearranged to create new verses with coherent meaning. The poem is composed of just four lines and twenty words:

*Ardua componunt felices carmina Musae  
dissona conectunt diversis vincula metris  
scrupea pangentes torquentes pectora vatis  
undique confusis constabunt singula verbis.* (qtd. in Edwards 2005)

The text itself invites the reader to rearrange the words and to form new verses, manipulating words within their designated lines or exchanging them with words of similar metrical qualities in other lines to create new verses. Assuming certain metrical rules are observed, a total of 1,792 verses can be created from these four lines (Edwards 2005). From an operational point of view, Harsdörffer's protean poems were much simpler, requiring less skills for the manipulation of their contents. One of Harsdörffer's protean couplets was:

*Ehr, Kunst, Geld, Guth, Lob, Weib und Kind  
Man hat, sucht, fehlt, hofft und verschwind.*<sup>150</sup> (qtd. in Berge 2003, 179)

The ten words composed in *italics* could be permuted by the reader without altering the rhythm, as they are all monosyllabic. This system therefore allows the creation of 3,628,800 different poems, all of them grammatically correct.<sup>151</sup> Berge's designation, 'factorial', is derived from the way one can calculate the number of possible permutations. With  $n$  words to permute, the number of possibilities would be  $n$  factorial, that is, the number  $n! = 1 \times 2 \times \dots \times n$  (Berge 2003, 179).

<sup>148</sup> 233-c. 305 CE.

<sup>149</sup> The poems of the *Carmina* or *Carmina Figurata* were published collectively in one volume for the first known time in 1590 (Edwards 2005).

<sup>150</sup> Honor, Art, Money, Property, Praise, Woman, and Child / One has, seeks, misses, hopes for, and disappears. (Berge 2003, 179)

<sup>151</sup> Provided one changes *sucht* to *Sucht*, *fehlt* to *Fehl*, *man* to *Mann*, according to Berge (2003, 179).

Based on Harsdörffer's work, on Kircher's *Ars magna sciendi, sive combinatoria*<sup>152</sup> from 1669 and in the work of Ramon Llull,<sup>153</sup> the German poet Quirinus Kuhlmann<sup>154</sup> composed the sonnet XIV. *Libes-kuss: Vom Wechsel menschlicher Sachen*<sup>155</sup> in 1671, consisting of 13 × 12 nouns that could be arbitrarily shuffled to a total of  $13!^{12} \approx 3,399 \times 10^{17}$  permutations (Cramer 2002).

In 1666, Gottfried Leibniz<sup>156</sup> publishes his *Dissertatio de arte combinatoria*,<sup>157</sup> where he cites several other examples in monosyllabic Latin, from Bernhardus Bauhusius, Thomas Lansius, Johan Philippus Ebelius and Johan Baptistus Ricciolus (Berge 2003, 180).

### 1.3.2 Twentieth Century Pre-Computational Procedural Practices

In 1965, French novelist Marc Saporta would write and publish a factorial novel, *Composition N° 1*, consisting of 150 loose pages, unnumbered and printed on one side only, one of which is the title page, while all the others are the novel. The cover of the box that holds all the pages provides the following instructions: "The pages of this book may be read in any order. The reader is requested to shuffle them like a deck of cards." (qtd. in Badman 2004)

Saporta's novel is an example of what today we refer to as proto-hypertexts (Kolb 1994, 329) or incunabular hypertexts (Moulthrop 1994, 300), nonlinear and combinatorial literary works of variable extension that were designed to be read quite unlike linear books, thus demanding a more elaborate and active role from the readers and (at least potentially) providing each of them with slightly different or all the way contrasting reading experiences. One other good example would be a book that is itself a commentary on hypertext and culture, Deleuze and Guattari's *Mille Plateaux* (1988), a book that although shaped as a print artifact, was designed as a matrix of independent but cross-referential discourses which the reader is invited to enter more or less at random (xx). *Mille Plateaux* has no defined sequence, beyond a stipulation that the conclusion should be saved for last, and the book's sections,

152 *The Great Art of Knowing, or Combinations.*

153 1232-1315.

154 1651-1689.

155 *14th Kiss of Love: On the Permutation of Human Matters.*

156 1646-1716.

157 *Dissertation on the art of combinations.*

or *plateaux*, may be read in any order, therefore bestowing upon the reader the task of building a network of virtual connections throughout (and beyond) the book (Moulthrop 1994, 300).

We can find the same principle in *Un Conte à votre façon*<sup>158</sup> from 1973 by Raymond Queneau,<sup>159</sup> a short story in 21 parts that starts with a question and two commands for action as answers to this: “1. Would you like to read the tale of the three sprightly peas? If so, go to [part] 4; if not, go to [part] 2.” (Queneau 2003b) From here the reader is led through a series of alternative paths that inevitably lead to one of two possible endings and as a consequence force to leave several possible parts of the path along the way.

Texts such as these, by opening to reader choice and selection in the determination of the structure to be read, point to the idea of a “multiple authorship responsibility in which the specific functions of the composer, the performer, and indeed the consumer overlap” (Gould 1984b), an idea that Glenn Gould<sup>160</sup> expands in *The Prospects of Recording* (1984a): “Because so many different levels of participation will, in fact, be merged in the final result, the individualized information concepts which define the nature of identity and authorship will become very much less imposing”.

One of the masterworks of combinatorial literature was produced by Queneau in 1961, the *Cent mille milliards de poèmes*,<sup>161</sup> a small book of ten pages, each containing a single sonnet. Each of the ten pages is cut in fourteen horizontal sections, allowing the replacement of any of the lines in a sonnet by one of the nine alternatives, thus enabling the composition of  $10^{14} = 100,000,000,000,000$  different poems, respecting in each case the constraints of sonnet composition. Berge classifies this particular type of combinatorial literature as ‘exponential’, for the number of poems of  $x$  verses that one can obtain is given by the exponential function  $e^x$  (2003, 180). The number in this case is so high, that it led the French mathematician and Dada poet François Le Lionnais<sup>162</sup> to write in the postface of the French edition of *Cent mille milliards de poèmes* that “The work you are holding in your hands represents, itself alone, a quantity of text far greater than everything man has written since the invention of

<sup>158</sup> *Yours for the Telling*, in John Crombie’s translation (Queneau 2003b).

<sup>159</sup> 1903-1976.

<sup>160</sup> 1932-1982.

<sup>161</sup> *A Hundred Thousand Billion Poems*, in Stanley Chapman’s translation (Queneau 2003a).

<sup>162</sup> 1901-1984.

writing, including popular novels, business letters, diplomatic correspondence, private mail, rough drafts thrown into the wastebasket, and graffiti.”

Le Lionnais and Queneau were the founders of the influential *Oulipo*, the *Ouvroir de littérature potentielle*,<sup>163</sup> a group that also included as members Georges Perec,<sup>164</sup> Italo Calvino,<sup>165</sup> Claude Berge,<sup>166</sup> Jean Lescure<sup>167</sup> and Marcel Duchamp,<sup>168</sup> among several others. The motivation of the Oulipo was the exploration of literature, much in the same sense that one could explore mathematics (Lescure 2003, 173), searching for historical constraints and procedures in literature and setting out to discover new ones, new processes, new structures. Having a strong interest in experimental literature, the Oulipo’s initial name was S.L.E., short for *séminaire de littérature expérimentale*,<sup>169</sup> later changed to *Olipo*, and finally, for the sake of symmetry, adding the second letter of the word *ouvroir* to the O, which definitely rendered *Olipo* as *Oulipo* (173).

The word *potential*, according to Queneau, “concerns the very nature of literature; that is, fundamentally it’s less a question of literature strictly speaking than of supplying forms for the good use one can make of literature. We call potential literature the search for new forms and structures that may be used by writers in any way they see fit.” (qtd. in Lescure 2003, 176) Le Lionnais, adds that “[i]t is impossible to compose texts that have poetic, surrealist, fantastic, or other qualities without having qualities of potential. Now it is these last qualities that are essential for us. They are the only ones that must guide our choice.” (qtd. in Lescure 2003, 176) For the Oulipo, the goal of potential literature was to furnish writers with techniques for a new liberty and, although the first literary work of the Oulipo is the combinatorial *Cent mille milliards de poèmes*, the Oulipo is about far more than just combinatory literature (Berge 2003, 178).

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**163** *Workshop of potential literature.*

**164** 1936-1982.

**165** 1923-1985.

**166** 1926-2002.

**167** 1912-2005.

**168** 1887-1968. Lescure reported that “Marcel Duchamp, from one of the Americas, became interested in the Oulipo. The Ouvroir flattered itself to count him among its corresponding members. He died an Oulipian.” (2003, 176).

**169** *Seminar of experimental literature.*

Le Lionnais defined two *lipos*, an analytic and a synthetic, analytic lipo developing a historical, critical and almost archaeological work by seeking possibilities existing in the work of certain authors unbeknownst to them, and the synthetic lipo constituting its principal mission: the opening up of new possibilities previously unknown to authors (Lescure 2003, 176). For Berge, an analysis of the Oulipian tendencies will reveal not two but rather three currents or vocations of the Oulipo: the search for new structures, the research into methods of automatic transformation and the transposition of concepts from different branches of mathematics into the realm of words (178). Potential literature was therefore not a homogenous and closed field of work but rather a melting pot of complementary experiments (Mestres 2004, 95).

The first vocation sought to replace traditional restraints like the sonnet or the haiku with other linguistic constraints, namely palindromes or ‘lipograms’.<sup>170</sup> Perec wrote *Le Grand Palindrome* in 1969, with roughly 1,500 words<sup>171</sup> and the 300-page long novel *La Disparition*<sup>172</sup> also in 1969, a lipogram in *e*, where the letter *e* (the most common in the French language) is not used during the entire text,<sup>173</sup> and *Les Revenentes* (1972), a lipogram in *a*, *i*, *o* and *u*. An earlier example of a lipogram in *e* is *Gadsby: Champion of Youth*, a novel written by American writer Ernest Vincent Wright<sup>174</sup> in 1939.

Perec’s *La Vie mode d’emploi* (1978) was developed from a massive list of constraints that specified contents for each chapter, like e.g. the number of people involved, the length of the chapter in pages, countries, quotations from other novelists, etc. Other lipograms would keep the authors from using arbitrary sets of letters, like the prisoner’s constraint that forbid letters with ascenders or descenders<sup>175</sup> (Bogost 2008, 121) or imposed more complex rules, like serially allowing or disallowing letters in the text. In 2004 French author Michel Thaler,<sup>176</sup> not associated with the Oulipo,

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<sup>170</sup> While palindromes are structures that can be read the same way in any direction, lipograms, (from the Greek *lipagrammatos*, missing letter) are systems of constrained writing in which a particular letter or group of letters is not allowed.

<sup>171</sup> A more recent example is Nick Monfort and William Gillespies’s *2002* (2002) a palindromic novel of 2,002 words (Bogost 2008, 121).

<sup>172</sup> *The Disappearance*, a novel that follows a group of people that cannot find a hunting companion.

<sup>173</sup> *La Disparition* was translated to English by Gilbert Adair also as a lipogram in *e*, *A Void*, and to Spanish as a lipogram in *a* — the most common vowel in Spanish — titled *El secuestro*.

<sup>174</sup> 1873?–1939.

<sup>175</sup> b, d, f, g, h, j, k, l, p, q, t, and y.

<sup>176</sup> A pseudonym for Michel Dancel.

published the 233-page long novel *Le Train de Nulle Part*<sup>177</sup> that was written without using a single verb. ‘Homosyntax’ proposed the replacement of all the words in a given text by new words, while preserving grammar and syntax, or to build prose from a given syntactic sequence such as VVSSSSASSVVSSSVSASASVSASSSSVVSSASSV (V=Verb, S=Substantive, A=Adjective), while the ‘snow ball’ proposed the writing of texts with a number of elements that would be progressively increased to a set point and then decreased back to the original value. Outside the Oulipo, we can find similar working methods being used by Austrian-American composer Arnold Schoenberg,<sup>178</sup> that tested and transformed the structure of musical space in much the same way as the Oulipo explored the literary space. Schoenberg created constraints for his compositions, sometimes ruling a priori that a piece should use the full range of the chromatic scale, whereas at other times, much like in lipograms, he avoided — or insisted upon — the repetition of certain notes or series of notes (Boden 2004, 72).

The second Oulipian vocation, the research of methods of automatic transformation, is exemplified with Lescure’s ‘S+7’ (sometimes called ‘N+7’) method of text production, one of the most cherished discoveries of the Oulipo (Mestres 2004, 96), explored by Lescure himself but also by Queneau in *Traslation*. The simple, yet labour intensive text production process implied starting from any given preexisting base text and, with the help of a dictionary, to replace every name (substantive, S) by the seventh following name (+7) found in the dictionary, counting upwards. The results will naturally vary depending on the dictionary that is used, on alternatively performing the transformation on other lexical classes, such as verbs, or on performing multiple transformations in each text.

The ‘definitional method’ replaced the components of a text — verbs, nouns, adjectives, adverbs, and so on — by their dictionary definitions, generating a multitude of different texts from somewhat short source-texts. This process was also called ‘littérature sémo-définitionnelle’, shortened to L.S.D. and was developed in the P.A.L.F.<sup>179</sup> project by Perec and Marcel Bénabou (97). ‘Vocabulary clept pomes’ are achieved by writing a poem and then delivering to another poet a simple list of the words used in the poem, intended to be used as *materia prima* for a new work, this method is very

177 *The Train from Nowhere*.

178 1874-1951.

179 *Production Automatique de Littérature Française* or *Automatic Production of French Literature*.

similar to ‘pied poetry’, that involves rearranging all the words of a poem to achieve a new one (the rules allow varying punctuation and capitalization) (Sneyd 2005).

Finally, the third vocation is exemplified by recursive or iterative processes, repeated ‘infinitely’ so that a given source text can spawn a variety of new texts. We can also find examples in combinatorial works such as the aforementioned *Cent mille milliards de poèmes* or Jacques Roubaud’s collection of poems  $\in$  (1967), that proposed the reading of a set of 361 texts in four alternative but well-determined orders, refusing any sort of randomness or reader determined choice (Berge 2003, 180). Finally we can mention the tangential poems of Le Lionnais, Jacques Duchateau’s intersection of two novels and Queneau’s multiplicative texts, composed from algebraic matrices (179).

Oulipo’s sometime very strict formal procedures were naturally influenced by cybernetics and communication theory, but their motivation was not found in electronics or computation but rather in literature, and their starting points, as well as their objectives were related with the essence of writing. As a key to Oulipo’s inspiration we find a deep reflection about the literary craft, and constraints, combinatorics, textual distribution strategies and their rules are converted into the core of the writer’s work (Mestres 2004, 94). Oulipian formal procedures are often criticized as being mannerist, as if somehow they may drive the heart of the artwork from more essential matters, however, these critics fail to see that the main difference between mannerism and the Oulipo are their disparate goals: while the mannerist intended to create a sense of wonder, having a formal goal that arose from the formal, the Oulipian saw text as the one and only goal, and it was in text that one could effectively understand form and content (99). Oulipo was perhaps the most organized group studying formal writing procedures, but it was far from being the first to be interested in them.

In 1920, Tristan Tzara<sup>180</sup> published the *Dada Manifesto on Feeble Love and Bitter Love* (1987), in the eight part of which he presents the recipe to create a Dada poem, formulated in a way that can literally be read as software (Cramer 2002):

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<sup>180</sup> 1896-1963.

To make a Dadaist poem:

Take a newspaper.

Take a pair of scissors.

Choose an article as long as you are planning to make your poem. Cut out the article.

Then cut out each of the words that make up this article and put them in a bag. Shake it gently.

Then take out the scraps one after the other in the order in which they left the bag.

Copy conscientiously.

The poem will be like you.

And here you are a writer, infinitely original and endowed with a sensibility that is charming though beyond the understanding of the vulgar. (Cramer 2002)

By this time, Alexander Rodchenko,<sup>181</sup> Kazimir Malevich,<sup>182</sup> Vladimir Tatlin,<sup>183</sup> Naum Gabo<sup>184</sup> and several others in the Soviet Union were establishing Constructivism, developing a truly systematic approach to art making (Glimcher and Rose 2005, 7). It was Malevich's Suprematist work that drove many of them from Cubism to nonrepresentational or totally abstract art, and to divide the development of artworks in two separate stages, starting with the theoretical study of the elements from which the artwork would be constructed and following it by what they referred to as a 'laboratory' analysis of how these should function together. Early Constructivists believed that this would lead to works that had been 'constructed', and not 'composed' in the traditional manner of art. Rodchenko describes a group of spatial constructions from 1921, and the rule-based method that he followed:

These are the latest spatial constructions. I developed them experimentally. The exclusive purpose was to bind the constructor to the law of expediency of the forms used, to make him uphold their lawful coherence as well as to demonstrate universality, so that one can build out of these identical shapes all kinds of constructions for various systems, types and applications. In these works, which are real constructions, I promulgate a mandatory condition for the fu-

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181 1891-1956.

182 1879-1935.

183 1885-1953.

184 1890-1977.

ture industrial builder: Nothing random or uncontrolled. Everything has to be reduced to universal initiative; it has to be simplified, generalized. (Glimcher and Rose 2005, 8)

It is interesting to note how Rodchenko refers to a law that guides the design: the expediency of forms, a self-imposed rule that the least number and types of forms should be used to achieve a given construction. He also implies that the construction of the artwork is not dependent on the artist's singular hand, he rather suggests that the artist's job is that of designing the constructions of the work (8).

William S. Burroughs,<sup>185</sup> describes Tzara's presentation of this process at a surrealist rally, causing a riot among the audience and leading André Breton<sup>186</sup> to expel him from the movement on the spot (2003, 90). In the 1950s, the British-Canadian painter, writer, artist at large and regular collaborator of Burroughs, Brion Gysin,<sup>187</sup> developed a cut-up method that intended to bring to writers the method of collage, that at the time had been used by painters for already fifty years.<sup>188</sup> According to the description that is given by Burroughs, Gysin's method was not too different from Tzara's:

The method is simple. Here is one way to do it. Take a page. Like this page. Now cut down the middle and cross the middle. You have four sections:  
1 2 3 4 . . . one two three four. Now rearrange the sections placing section four with section one and section two with section three. And you have a new page. Sometimes it says much the same thing. Sometimes something quite different — cutting up political speeches is an interesting exercise — in any case you will find that it says something and something quite definite. Take any poet or writer you fancy. Here, say, or poems you have read over many times. The words have lost meaning and life through years of repetition. Now take the poem and type out selected passages. Fill a page with excerpts. Now cut the page. You have a new poem. As many poems as you like. As many Shakespeare Rimbaud poems as you like. (Burroughs 2003, 90)

<sup>185</sup> 1914-1997.

<sup>186</sup> 1896-1966.

<sup>187</sup> 1916-1986.

<sup>188</sup> And used also by photography and cinema: "all street shots from movie or still cameras are by the unpredictable factors of passers by and juxtaposition cut-ups. And photographers will tell you that often their best shots are accidents" (Burroughs 2003, 90).

Tzara's method relied on one act of selection, one single choice from the operator or writer, the choice of "an article as long as you are planning to make your poem", while Gysin's cut-up technique allows for far more arbitrary decisions and is not at all exempt from selection, revision and rewriting (Montfort 2003). Tzara said "poetry is for everyone", Burroughs added that "cut-ups are for everyone" (2003, 90), that everyone could make them, and that they were experimental in the simple sense of being something to do "right here write now. Not something to talk and argue about." (90) According to Burroughs, all writing is in fact a process of cut-up, a collage of words, just made more explicit and subject to extension and variation by the use of scissors and glue. Cut-ups could be applied to fields other than writing, in science, games and military strategy, bringing chance, accidents and serendipity to the world. Cutting and rearranging the world, there would be no reason for anyone to accept a second-rate product when they could have the best — "and the best would be there for all" — because the processes and tools would be freely available for anyone wishing to write.

Burroughs described the cut-up technique as a live montage that did not have to obey common restrictions imposed on literary practice, furthermore he already pointed to an interpretation of the technique that would place it at the core of digital practices in the new media: "Somebody is reading a newspaper, and his eye follows the column in the proper Aristotelian manner, one idea and sentence at a time. But subliminally he is reading the columns on either side and aware of the person sitting next to him. That's a cut-up." (qtd. in Fuller 2005, 38)

If with Tzara, Gysin, Burroughs and the Oulipo, the texts are seemingly always the goal, we can nevertheless also find a very strong presence of a certain poetics of programming, of code, algorithms, calculus, chance and effective procedures at the heart of the creative practice (Mestres 2004, 101). We can find the will to distribute the tools and the processes of creation and to make this poetics readily available for everyone, but also to make audiences and critics aware of the nature of the processes being deployed. If Bach used algorithms, he certainly did not feel the need to publish those along with the compositions that were created with them, and most likely regarded them as a useful composition tool that was not, in any case, neither a fundamental part of the creative process nor art in itself, but perhaps more of a shortcut for certain parts of the artwork that could be solved mathematically. Twentieth-century composers and artists, on the other hand, not only valued the processes

and the methods for automatic or semi-automatic composition,<sup>189</sup> as they often also found them to be as artistically determinant as any other aspect of the process and as fundamental as the end results themselves.

John Cage,<sup>190</sup> one of the most important twentieth century American composers, was famous for using composition processes that involved indeterminacy and also for seeding the pieces with chance operations, either by forcing choices on the performers or by using mechanisms that were far from being totally controllable by the performers, thus opening the door to the unexpected and to disparate outcomes in each performance.

Cage composed several pieces for (or including) the ‘prepared piano’, a transformation of the classical concert piano through the placement of several ‘preparations’ or objects between or on the strings, on the hammers or dampers of the instrument. The preparations for each piece were usually specified by Cage, but no matter how rigorous this specifications would be,<sup>191</sup> the preparation was usually intended to alter the timbre of the piano in varying ways, so that the repeated stroke of the same key could (and often would) produce somewhat controlled but impossible to control variations of timbre.

His piece *4'33"* (1952), in three movements, was composed for any instrument or combination of instruments, which are instructed not to play during the entire duration of the piece.<sup>192</sup> Deeply inspired by Zen Buddhism, that Cage studied since the 1940s, *4'33"* epitomized Cage’s idea that any sounds constitute, or may constitute music, because the piece was not designed to be heard as four minutes and thirty-three seconds of silence, but rather to consist of all the sounds heard, but not played, during that length of time. More importantly, if considering the injection of chance in composition and performance, *4'33"* is a piece created by sounds that are not com-

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**189** Surrealists explored a different sort of ‘automatic’ writing and drawing, intended to explore the subconscious and the psyche of the artists, so their use of the term was more related to the lack of conscious control over the process of artistic production than to the transfer of that control to a mechanized or formal process. It was, nevertheless, about relinquishing control over the pieces and over the final output of the processes.

**190** 1912-1992.

**191** Including not only the positioning and assembling of the preparations as well as their descriptions: nuts, bolts, rubber bands, or other objects of various sizes.

**192** The first being of 30 seconds, the second of two minutes and twenty-three seconds and the third of one minute and forty seconds.

posed or performed but are brought to the piece by all possible systems except the traditional channels of music performance (whichever these may be at any given time, space or context).

Other pieces composed by Cage included elements of surprise or chance by using sound sources that were only partially controllable by the performer. *Imaginary Landscape N° 1* (1939) was scored for two conventional instruments, a muted piano and a cymbal, and two variable-speed amplified phonographs playing sinusoidal single-tone test records. Besides being one of the first examples of electroacoustic music, this was also one of the first pieces where Cage deliberately seeded random instructions, or instructions to indeterminacy, to the performers (Mestres 2004, 60). *Imaginary Landscape N° 4* (1942) for 12 radio receivers detailed precise instructions for each performer's modulations of volume, but naturally left to chance, context and serendipity the precise sounds that each performer's radio receiver would play-back to the audience. *Music of Changes* (1951) used chance operations throughout the composition process: using the *I Ching* (that also inspired the title of the piece) and an elaborate formal system based on charts with  $64 \times 64$  cells, chance processes would determine which sound event to select from the chart, and then the duration and dynamics of that sound event, selected from two other charts. Silences were also dictated by the system and almost nothing in the final score was left to the composer's discretion (Cage 1973, 57). Cage saw randomness and chance as a way to simulate the chaotic behaviors of nature, but he was also drawn by the formality of the method, that allowed him to escape his ego and will during the process of artistic creation (Mestres 2004, 66).

By the late 1950s and early 1960s we can find several artists engaged in experimentation with serial and grid systems and creating artifacts that they see as *real* objects, as hypermediated, and as being completely anti-illusionistic, in the sense that they defied the canvas's traditional role as a framed window and displayed their own intrinsic nature frontally on the picture plane (Glimcher and Rose 2005, 9). Ed Ruscha and Andy Warhol<sup>193</sup> both developed conceptual projects from early on their careers, with an architecture that could be diagrammed as follows:

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193 1928-1987.

Step 1: Action by artist.

Step 2: Create record and preserve evidence of that action.

Step 3: Repeat n times.

Step 4: Assemble multiple records to create work. (Glimcher and Rose 2005, 11)

Early pop art pioneers emphasized what they perceived as culturally critical issues by focusing their attention on the development and elaboration of step 1, but this framework lends itself equally well to the simplification of the first step and the elaboration of steps 2 and 3, a methodology that was characteristic of the work of early Minimalists and Conceptualist artists (11).

In 1966 Hans Haacke, expressed his program as an artist in a statement that, according to Galanter, can almost be read as a manifesto for procedural artists that explore complex systems (2003, 18):

...make something which experiences, reacts to its environment, changes, is non-stable...

...make something indeterminate, which always looks different, the shape of which cannot be predicted precisely...

...make something which cannot 'perform' without the assistance of its environment...

...make something which reacts to light and temperature changes, is subject to air currents and depends, in its functioning, on the forces of gravity...

...make something which the 'spectator' handles, with which he plays and thus animates...

...make something which lives in time and makes the 'spectator' experience time...

...articulate: something natural... (Haacke 1966)

Sometimes, the process alone turned out to be the artwork itself. "Ideas alone can be works of art" said Sol LeWitt,<sup>194</sup> "they are in a chain of development that may eventually find some form", and they do not even need to be made physical (1969b). It was a musician, American minimalist composer La Monte Young, that proposed the seminal example of conceptual procedural artwork, with his *Composition 1960 #10* (1960), a single piece of paper containing the written instruction "Draw a straight

<sup>194</sup> 1928-2007.

line and follow it.” This is the quintessential conceptual piece, consisting of an instruction that is unambiguous enough to be performed by a man or a machine, but at the same time, physically impossible to thoroughly execute by either of them (Cramer 2002).

Three of Young’s *Compositions 1960*, #7, #9 and #10, composed mainly of words, became primary influences on the *Fluxus* movement, created after George Maciunas<sup>195</sup> met Young in New York in 1960-61. *Composition 1960 #7* was a more traditional musical score, comprised of the sustained interval of a perfect fifth, B and F#, with the single instruction “to be held for a long time”. It was a distillation of Young’s previous works to a radical minimal conclusion “even less than a haiku: no season, no place, and, in musical terms, no theme, no development, no variations, no contrast, just a concern for time (long) and pitch relationships (...), just B and F# to be sustained for a long time.” (Young 2001)

*Composition 1960 #9* was a straight line drawn on a file card, intended as a score to be interpreted by a performer, and was conceived as an answer to the graphic notations of Cage. These steps towards progressively more minimal compositions culminated with *Composition 1960 #10*, the first to not even be specified as an instruction for a piece of music or for a performance but simply as *an instruction*. These pieces led Henry Flynt to define concept art as “an art of which the material is ‘concepts,’ as the material of for ex. music is sound” and since concepts “are closely bound up with language, concept art is a kind of art of which the material is language.” (1961) As such, whenever concept art defines formal instructions or logical scores, it can be seen as being software, even if it is not expressed as formal instructions to a computer. According to Cramer, Tzara’s recipe for a Dada poem qualifies as software in much the same way as a Perl or Java expression of the same process would. In this sense, a piano score is software, whenever its instruction code can be executed by a human pianist as well as by a player piano or a computer connected to a MIDI piano (Cramer 2002).

In Young we find a curious duplicity of concept notation and executable code that can also be found in several pieces produced by the Fluxus network of artists during the 1960s and 1970s or in LeWitt’s 1971 *Plan For a Concept Art Book*, a series of pages bearing exact instructions on how to draw lines on them, how to strike out

<sup>195</sup> 1931-1978.

specific letters from the printed contents or how to manipulate them in various ways. If Young's piece was a concept notation creating an artwork that itself would exist only as a concept, LeWitt's is only a concept notation for a material, graphic artwork (Cramer 2002) but it nevertheless is expressed as both a concept and a set of formal instructions to deploy it.

In a sense, pure concept art as *Composition 1960 #10* does not need to be materialized. More than engaging the viewer's eyes, emotions or senses, this piece engages the mind, as LeWitt puts it in his *Paragraphs on Conceptual Art* (1969b). The piece starts as an idea, and "the idea becomes a machine that makes the art". The piece is not made physical in any sense, as an image, sound, motion or volume, its software is not loaded into computers, but it runs in human brains.

### 1.3.3 Procedural Literacy

The fact is that by using a mechanical contrivance, a violinist or an organist can express something poignantly human that cannot be expressed without the mechanical contrivance. To achieve such expression of course the violinist or organist has to have interiorized the technology, made the tool or machine a second nature, a psychological part of himself or herself. (Ong 1982, 83)

In 1974 Theodor H. Nelson wrote *Computer Lib / Dream Machines*, a double book that was doubly subtitled as *You Can and Must Understand Computers Now / New Freedoms Through Computer Screens — A Minority Report* and that was devoted to the premise that "everybody should understand computers" (2003, 303). In it Nelson discussed the unfortunate historical circumstances that made computers become a mystery to most of the world, and defended that knowledge and understanding of computers should be readily available to anyone, introducing the idea of 'software literacy' (Reas and Fry 2007, 3). Nelson described computers as being simply a necessary and enjoyable part of life, much like food or books, not being everything, but an *aspect* of everything. Not knowing this would be "computer illiteracy, a silly and dangerous ignorance" (2003, 303). The importance of software literacy resided in contemporary life's immersion in media — "we live in media, as fish live in water" (306) — and in the urgency of being able to control this environment, of making the best use of it, of managing to live with media in the best possible way. Nelson believed that the more one knew about computers, the better one's imagination would

be capable of flowing between the technicalities, of sliding the parts together, and of discerning the shapes of what one would have these things do. Not seeing the computer as a limitless partner, Nelson nevertheless found it to be deeply versatile, but called our attention to the necessity of understanding what it could do, what were the options and the costs of working with it.

It is interesting to note how already in 1974, when many of the media that would be digitalized in the following decades were still analog, when the ARPANET was still in its early years,<sup>196</sup> Nelson was already putting such a strong emphasis in the usage of computers as media and as communication tools, focusing on literacy issues in *Computer Lib* and covering the potential of the computer as a medium in *Dream Machines*. Concluding that the media, or the structured transmission mechanisms (and the messages they carry) cannot escape being personalized by those who run them, Nelson appealed to the necessity of understanding how they work, so as to balance the “understanding of the things that media misrepresent” (318).

It is of course common sense that understanding how things work is necessary to know how to make them (Laurel 1993, 41), but that at which Nelson pointed was at how difficult it may be to acquire this knowledge. On a superficial level, and according to Friedrich Kittler, contemporary GUIs dispense with writing and hide a whole machine from their users (1995).<sup>197</sup> From the user’s point of view, a machine can very often be regarded as a closed box with which one interacts through input and output channels. The user occasionally acts on the machine through the input channels and from time to time the machine will act on the user through output channels. It follows that normally the user will not need to know the details of what exactly is happening inside the box, thus dealing with the machine as a ‘black box’, a term used by Minsky as a way to indicate the user’s lack of concern and knowledge about the machine’s interior (1972, 13). A large majority of machines is designed like this, hiding their inner workings and presenting just a simple interface to the user.<sup>198</sup>

<sup>196</sup> Nelson was undoubtedly familiar with both the ARPANET and email, already one of its biggest uses at the time.

<sup>197</sup> Kittler places the last historical act of writing in the early 1970s, at the moment when Intel engineers laid out several meters of blueprint paper to design the hardware architecture of their first integrated microprocessor. This manual arrangement of circa two thousand transistors and their interconnections was then miniaturized to the size of the actual chip — gigantic, by today’s standards — and was written into silicon layers by electro-optical machines (1995).

<sup>198</sup> We can think of examples as a washing machine, a microwave oven, a telephone, even of machines that demanded more practice or even specific training for their use, as photographic cameras or automobiles.

Being the computer such a complex and multilayered machine, it is naturally in the user's best interest to have some of its internal workings — and more likely than not, *most* of its internal workings — abstracted through various interfaces and high-level software. When developing an exploratory use of the computer, having to deal with all the inner workings of the software being used, with the operating system, the BIOS, the registry, the peripherals, would make most of the tasks become nearly impossible to accomplish. On the other hand, once one is particularly interested in understanding the inner workings of the machine or in modifying them, when one wants to develop a constructive use of the computer, one will need to know more than just the machine's input-output properties (Minsky 1972, 13). The structure of the machine needs to be considered in more detail, to the point of understanding the interactions between parts and the functioning of the machine as a whole (32).

Software involves the mechanization of the means to put into service the resources of the computer's hardware and the logical resources of other software. It is, very literally, 'control machinery' or, to put it simply, control (De Landa 1991, 155). Whenever one chooses to use software, one is using resources that were programmed by third-parties, and therefore is, for all purposes, delegating some control of the logical machine to these resources, and abdicating from their direct control. Paul Virilio went as far as to identify an enslavement of the human being to these machines, a programmed symbiosis of man and computer in which the so-called dialogue between man and machine hardly conceals the disqualification of the human in favor of the definitive instrumental conditioning of the individual (1995, 135). This is not an enslavement to machines or to the people who build and own them, but, strictly speaking, to the conceptual models, the values and systems of thought that those machines (and the software they run) embody (Dunne 2005, 21). Although most interfaces are translators or facilitators meant to help, in many cases they also make users less powerful, because users are only allowed to operate previously set functions within a given interface: "[y]ou can only compute what the software lets you compute, and only manipulate what you see" (van Schaik 2008, 180), in other words, one is confined to producing that which happens to be easy to produce, or producible at all, within existing tools (Mateas 2005). Because it hides processes from end users, and because it diverts control from them, prepackaged software carries paradigms of untouchability, of ways of doing things and of choices presumed by the programmers that are presented as defaults beyond which the users are presumed (or even discouraged) to go to. This is a problem that is often presented as being part

of the political and philosophical foundations of the Free/Libre/Open Source Software (FLOSS) movements (Mansoux and de Valk 2008b).

Shrink-wrapping of code in a GUI certainly allows artists and designers to focus on working the sensorial fields, relying in the software to generate whatever appropriate code objects will simulate their media. The designer thus feels ‘above’ the medium, able to calibrate it to her needs and unaffected by its mechanisms and technicalities (van Schaik 2008, 182). However, as we have seen, while being a metamedium that is able to remediate other media, the computer is never a neutral carrier and in the process of remediation it more often than not creates radically new media. Staying locked in metaphors from earlier media can lead designers to restrict the creative usage of the new media forms (183). Simple examples with profound repercussions can be found in the excessive imitation of print media when designing online media, with websites that ‘flip’ pages or emulate the layouts of broadsheet newspapers<sup>199</sup> (183) or in the font selection mechanisms of current desktop publishing and word processing applications (Lafuente 2008, 198).<sup>200</sup>

Jef Raskin<sup>201</sup> wrote that GUIs are not human-compatible, that they had “become so pervasive (or is it perversive?) that many computer users can’t even think about anything else as a human-computer interface” (1993), because they are “habit-forming, even addictive. Start to use them and you are hooked forever.” When we build mechanisms for repetition and for deferred control into the technologies and get used to them, we tend to assume them as indisputable and unquestionable truths. If artists do not understand the black box, they may end regarding it as a dictator of aesthetic

**199** Recent applications for reading digital books try to simulate printed books to such levels that come close to *kitsch*, ‘turning’ the pages and presenting simulated pages behind the one currently being read (in a fixed number that does not change regardless of where in the book a reader happens to be). They use serif typefaces regardless of the resolution of the display and justify text in blocks even if the systems do not allow hyphenation, thus creating true typesetting aberrations.

**200** In general these applications offer a whole collection of typefaces in a drop down menu, listing all fonts or font families alphabetically, or in some cases creating subgroups for the different alphabets: Roman, Greek, Cyrillic, Chinese, and so on. This simple GUI encourages users to pick a font and get to work in the document right away, ultimately even dispensing users from this choice, should they prefer to stay with the predefined default selection. As useful as this may be for many users and some specific contexts of utilization, it also helps to build the perception of a font as a finished product, when in most cases the font files can be opened and manipulated like every other file by anyone with access to an appropriate editor and fonts (as many digital artifacts) could also likely be understood as resources that one could edit, mutate and evolve to suit one’s particular needs. Fonts are digital, Read/Write, tokens (Lessig 2008, 37), as are many (if not all, ultimately) of the objects one can access, manipulate or create in digital technologies.

**201** 1943-2005.

paths linked to standard interfaces, and to be blinded by the dependency on whichever new products or formats are made available to them by the industry or other third-parties (Balvedi 2008, 263). If media users and scholars do not understand the black box and how code operates as an expressive medium, they will lose the crucial relationship between authorship, code and audience reception (Mateas 2005).

Therefore van Schaik raises a question that reflects the concerns of Nelson: “It takes us years of education to learn to read, write and talk as ways of interacting with our environment. Isn’t it strange, then, that one receives barely any kind of education in interacting with computers (as a modern communication environment)?” (2008, 180) If we look at the traditional practice in the fields of fine arts, design and music, to mention just a few examples, we find that they used to involve the development of fine skills of craftsmanship to produce works of virtuosity. After modernism those skills included the comprehension of the underlying systems of the media in which artists worked, and their modes of production, distribution and consumption. Nowadays, crafts are abstracted (McCullough 1998) and virtuosity takes another meaning, involving not so much motor skills but an understanding of computer science, digital signal processing and mathematics applied to media (Magnusson 2008, 236).

Programming is a very abstract activity, but it has many of the properties of a concrete craft. Programming is a “combination of writing and mechanical tinkering” with which designers build “elaborate Rube Goldberg machines” (Mateas 2005) that are pregnant with expressive power. Addressing “computer painting”, Duane Palyka defended that artists using the computer wouldn’t need to know about their medium below the plastic level any more than the painter has to know about the chemistry of paints, but he was careful to note that in a computer, this plastic level includes programming (1976).

Seymour Papert defended that programming is a skill that should be available to everyone not as a ‘technology’ — a mechanism for the manufacture that is abstracted from human labour — but as a means of conceptual exploration (qtd. in Yuill 2008, 74). As Kay explains, the ability to *read* a medium means that one can access materials and tools that were created by others, making full use and benefiting of them. The ability to *write* in a medium means that one can generate materials and tools for oneself and others. In order to be literate, one must have both abilities. “In print writing, the tools you generate are rhetorical; they demonstrate and convince. In

computer writing, the tools you generate are processes, they simulate and decide” (qtd. in Reas and Fry 2007, 3). “To use a tool on a computer, you need little more than point and click; to create a tool, you must understand the arcane art of computer programming” (Maeda 2004, 113).

With digital technologies, an artist or designer doesn’t just create solutions with the tools she is provided but is empowered to expand her role and to become a toolmaker, creating tools that will in turn generate the solutions to the problems at hand. And the power of computation comes precisely from the ability to, as far as one can describe any process in detail, being able to actually turn the computer into that process, mechanism or contraption, effectively bringing it to existence. Conversely, that is where the greatest difficulties also reside, because in order to program, “you have to understand something so well that you can explain it to something as stonily stupid as a computer” (Fuller 2008, 10). A designer is never absolutely free in any case, because programming languages are also themselves tools that were programmed by someone else but by developing a strong computational literacy designers are allowed to open up a region of freedom, “to climb up and down the dizzying tower of abstraction” (Mateas 2005) to better encode their messages and ultimately to create artifacts that are truly native to the medium.

Artists and designers need to recognize the computer as the tip of a techno-cultural iceberg and understand that the most interesting work to be done in digital technologies is likely to derive from a deeper comprehension of the underlying scientific and technological principles that have guided their development over the years (Wilson 2002, 6).

*Scientia potestas est*: “Knowledge is power”. So said Sir Francis Bacon (1561-1626), pioneer of modern science in his *Meditationes Sacrae* (1597). But not all knowledge is equally powerful. Knowledge of principles, knowledge of codes, knowledge of structure, knowledge of strategy — this is not mere knowledge but literacy. Literacy is power. Literacy gives one power over the details, the messages, the parts, the tactics of whatever topic, activity, field, or discipline is concerned. (Wilden 1987, 58)

#### 1.3.4 What Makes Digital Media Unique?

“What is unique about computation as an artistic medium?”, asks Alan Dorin (2008, 290), offering a clue to a possible answer in the high rate at which symbols are manipulated by computers and digital technologies. This rate is so high as to make individual symbols disappear in what we humans perceive as fluid flows of information, and to turn our experience of them akin to that of interacting with physical, dynamical systems. We notice how our perception systems have thresholds that are surpassed, blending individual symbols into a seemingly continuous flow, as atoms and molecules are seen as macroscopic solids. Noting that our interactions with computers are often at the level of the symbols they manipulate rather than with the machines per se, Dorin argues that there doesn’t need to be a hard experiential distinction between the two levels and that our interactions with the computer “have the potential to be as rich and rewarding as our interactions with the physical environment” (290). This has profound implications on art and communication.

Digital media are software. Computational artifacts are both objects and processes, and they cannot be read as texts, listened to as music, or seen as cinema or video. As Alexander Galloway states, an active medium rooted in cybernetics and information technology is one whose materiality moves and restructures itself, it is an action-based medium (2006, 3). Galloway distinguishes two basic types of actions in computational artifacts: ‘machine actions’ and ‘operator actions’. The distinction is made between those actions that are performed by the software or hardware and those that are performed by the user, or the human part in the human-computer system. Using computer games as an example, he writes: “winning *Metroid Prime* is the operator’s act, but losing it is the machine’s. Locating a power-up in *Super Mario Bros.* is an operator act, but the power-up actually boosting the player’s character’s health is a machine act.” (5) According to him, although theoretically useful, this distinction is completely artificial because both the machine and the operator work together in a cybernetic relationship and the two types of action are ontologically the same, existing as “a *unified, single phenomenon*, even if they are distinguishable for the purposes of analysis.” It is also important to remember that even when digital media remediate previous media forms, the transcoding that creates the sensorial level of the communication is, much like the action on a theatre or live performance, happening at that moment in time (Murray 1997, 81). Manovich expands these ideas by noting that if conventional media like books or film tend to position a user inside

a diegesis whose structure is fixed by the author, digital media and modern human-computer interfaces generally allow the users to perform complex and detailed actions on the data that is presented to them, to get information about objects and processes, to copy them, move them to other locations and even to configure how they are presented. By offering direct modes of interaction with information, the numeric representations of data become more communicative and the user is given the means to view the process of change that is a consequence of her intervention, better understanding “the complex relationships that produce the results for which his intervention is responsible” (Csuri 1976). Conventional and digital media thus allow two fundamentally different approaches — and ultimately incompatible (Manovich 2001, 95) — that need to be mediated in digital environments.

Action-based media need to be experienced and are always dependent on either some level on interaction or time-based reading. Even in cases where by any reason the action is not directly perceived, many of the digital technologies reveal some degree of *prochronism*. This term, used by Bateson, refers to how biological organisms maintain a physical record of how, in their own past, they successively solved formal problems in growth and pattern manipulation (1979, 12). This record is carried in the forms of organisms (229), in the shell of a snail, in the morphology of plants, insects, and mammals, and presents the temporal transitions that they underwent during their individual processes of growth (Chen 2008, 66). According to Bateson, the time that the living organism underwent from being an embryo to its present state can be swiftly read, supplementing temporal observations on how the organism may interact with the surrounding environment. Although it may not detail every aspect of the interactions, it nevertheless carries enough information about each organism, it keeps a record of the system’s growth over time and consequently, of its past actions.

But unlike living biological organisms, the space of morphological or behavioral possibilities of digital systems is not bound by DNA or evolution. It is bound by programming, by the interactions with other natural or artificial systems and with operators. Therefore, beyond *prochronism*, action based media always offer the potential for new actions. They are always multilinear and indeterminate, even when only potentially.

Norbert Wiener's<sup>202</sup> theory of cybernetics (1948) presented a model in which organisms and machines were treated as equal. It depended on three insights: 1) the role of the sense organs in the creation of a new stage in the history of automata; 2) the fundamental role of feedback in the regulation of the behavior of both living systems and machines; and 3) a new conception of the relationship that linked messages and organisms. Wiener suggested that one of the basic differences between older forms of machines or automata and the new cybernetic automation was to be found in how the later were coupled to an external world. This coupling was realized through exchanges of energy between the devices and their surroundings and also, and more importantly, by "a flow of impressions, of incoming messages, and of the actions of outgoing messages. The organs by which impressions are received are the equivalents of the human and animal sense organs." (42) Therefore, in contrast to earlier forms of automata, limited in their ability to communicate and interact with their environment, cybernetic automata are able to exchange information with their environments and to assess that information in such a way as to modify future actions on the basis of past performance (that is itself, assessed as information) (Tomas 2004, 52).

Man is immersed in a world which he perceives through his sense organs. Information that he receives is coordinated through his brain and nervous system until, after the proper process of storage, collation, and selection, it emerges through effector organs, generally his muscles. These in turn act on the external world, and also react on the central nervous system through receptor organs such as the end organs of kinaesthesia; and the information received by the kinaesthetic organs is combined with his already accumulated store of information to influence future action. (Wiener 1954, 17)

Wiener calls this process of adjustment and information exchange of 'feedback', and sees it as providing a fundamental way to establish a common ground between the living organisms and the communicating machines, since it is through the continual self-adjustment that entropy in either kind of system is controlled and internal order is maintained, while at the same time keeping away from equilibrium (Seife 2006, 89). Wiener's third insight focuses on the relationship between messages and organisms. He proposes that an organism can be treated as a message and, consequently, that it can be described analytically, without trying to "specify every

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202 1894-1964.

molecule in it,” or to “catalogue it bit by bit.” (Wiener 1948, 95) All one has to do is only “to answer certain questions about it which reveal its pattern: a pattern which is more significant and less probable as the organism becomes, so to speak, more fully an organism” (95). And ‘pattern’ is synonymous with ‘message’, and both are coextensive with ‘information’ (Tomas 2004, 52). So, “messages, patterns, organization and information link and regulate the behavior of living organisms, machine systems, and even social systems on the basis of a common cybernetic ecology” (53). Cybernetics thus proposed a dissolution of the traditional conceptual boundaries between living organisms and machines, suggesting that *all* systems could be analyzed similarly. And in a sense, inorganic artifacts become more alive as they gain the potential to develop what Christopher Alexander calls ‘living structure’ (2002b) but that we could perhaps call naturally occurring structure or behavior, as Alexander does not connect his definition of living structures with biological or organic life. Wiener further proposes that his new science of cybernetics, the study of “automata, whether in the metal or in the flesh” is a branch of “communication engineering, and its cardinal notions are those of a message, amount of disturbance or ‘noise’ (...), quantity of information, coding technique, and so on” (1948, 42).

Communication engineering or the mathematical theory of communication largely regarded the model of the transmission of a signal from point A to point B, studying what happens with digital media, how information is coded and how protocols are established, packets are transported, checksums calculated, etc. Fuller reminds us that we need to carefully analyze the aspect of computation itself, of effective procedures and algorithms, because it is it that opens up the possibilities of virtuality, simulation, abstraction, feedback and autonomy of processes in digital technologies (2008, 4).

Unlike digitized information,<sup>203</sup> algorithmic code allows a generative process. Instead of creating new information by juxtaposition or by letting the reader fill the interstices like media technologies did,<sup>204</sup> computation opens a whole new world of possibilities within reach of digital media creators when they themselves design the software layers.

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<sup>203</sup> Conventional data such as images, sound or text documents.

<sup>204</sup> Or computers do when they are used as storage and transmission media.

### 1.3.5 Epigenesis

Roman Verostko, an American artist that has been working with computers since the late 1960s, identifies himself as an ‘algorist’, a term he coined (1995) to describe artists like himself, Hans Dehlinger, Cohen or Ken Musgrave, that created using algorithmic procedures applied to a very broad spectrum of art practices.

Since the late 1960s Verostko has been developing paintings and drawings elaborated by his self-written software *Hodos*<sup>205</sup> (that has gone through multiple versions) and painted by a pen-plotter that controls brushes, pens, pencils or other tools he chooses to attach. Conceding that the physical materialization of his artworks is created by the pen-plotter, Verostko works by writing code, instructions to how his plotters should paint, and likens his code to a score written by a composer to be performed and interpreted by other musicians. “When hearing a performance today we assume that Chopin’s musical idea, as he conceived hearing it, has reached us via the musical score — an instruction, an algorithm. Inasmuch as Chopin’s musical idea is adequately represented in the score, and, inasmuch as the performer interprets the score as Chopin intended, then we enjoy an experience of Chopin’s ‘mind-ear’” (2003). Certainly, he continues, the performer’s contribution “colors each performance in a unique way and is not taken lightly” but “the musical score transcends an individual performance and continues to have a meaningful existence over generations.” (2003) He clarifies that the score is written in a code that consists of symbols that specify time and qualities of sound such as pitch and relative loudness and that when the term ‘code’ is used we generally refer to such instructions or algorithms in notational form, to a language that was developed for representing instructions. We are basically talking about *process descriptions*.

In his text *Epigenetic Painting*, Verostko states that “the software code is a formal system equivalent to the art concept, an isomorphism in a computer language” (1988), and he develops an analogy with the biological process of *epigenesis*. This is the process by which genetics and life sciences describe how a mature life form develops from its embryo or seed, growing a phenotype, the physical organism, from a genotype, the DNA. The term was coined by Conrad Hal Waddington<sup>206</sup> for his

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<sup>205</sup> The Greek word οδός means *path* or *way*. Verostko notes that μέθοδος (meta-hodos) is the etymological root of the word ‘method’ (Verostko 2003).

<sup>206</sup> 1905-1975.

central field of interest, whose old name was embryology, and it “stresses the fact that every embryological step is an act of becoming (Greek *γένεσις*, *genesis*) which must be built upon (Greek *ἐπί*, *epi*) the immediate status quo ante” (Bateson 1979, 47). Verostko suggests that the transition from the code to the physical materialization of the artworks can be seen as being epigenetic, because it generates a phenotype (a painting, drawing or other physical artifact) from a genotype (the algorithms or program code) (Blais and Ippolito 2006, 208). His software has information about how to ‘grow’ the painting through a series of “recursive graphic routines; each unfolded offspring is a variant of its predecessor” (Verostko 1988). Verostko is careful enough to stop the analogy here, as in his work the offspring cannot in their turn create a new generation of artworks, although they certainly influence the artist in the design of new generations of software.<sup>207</sup> Verostko’s rules do not evolve in a literal sense, as they do in artworks developed by artists as Karl Sims, for example. Therefore Verostko was not describing a *real* evolutionary computation, in the sense that computer sciences nowadays understand them, but he was calling attention to a fundamental concept in the design of computer generated artworks, by explicitly separating these two layers of the processes.

In evolutionary computation, the distinction between genotype and phenotype (whether or not they are named as such) is necessarily explicit and a fundamental part of the conceptual design of the code and of the system as a whole. Sims develops works that explore artificial evolution and that are implemented using evolutionary computation. He describes the genotypes as the coded representations of a possible individual or problem solution (Sims 1994b, 1), whereas phenotypes are the morphologies (whether real or virtual) that are generated from the genotypes. His algorithms typically use populations of genotypes that are mapped to phenotypes that are then evaluated according to some fitness criteria and selectively reproduced, by copying, mutation and/or combination, restarting the cycle. The fitness criteria themselves are not necessarily a part of the code, because they can be defined by human choices, either of the artist himself or of the viewers/users of the artworks. This is the case in the *Galápagos* installation (1997b), that he described as an “interactive Darwinian evolution of virtual ‘organisms’” (1997a). In *Galápagos* twelve computers simulate the growth and behavior of a population of abstract animated forms that are displayed on twelve different screens arranged in an arc. The viewers participate in this exhibit by selecting which organisms they find most interesting and stand-

<sup>207</sup> And therefore, in a sense, closing the circle of information and influence.

ing on step sensors in front of those displays (1997a). The selected virtual organisms will continue to live, and they will copulate, mutate and reproduce (Manovich 2001, 79), spawning new generations of virtual organisms. The remaining organisms are removed from the system, and their computers are occupied by new offspring from the survivors. These are copies and combinations of their parents, with their genes altered by random mutations. As the evolutionary cycle of reproduction and selection continues, more and more interesting organisms can emerge (Sims 1997a).

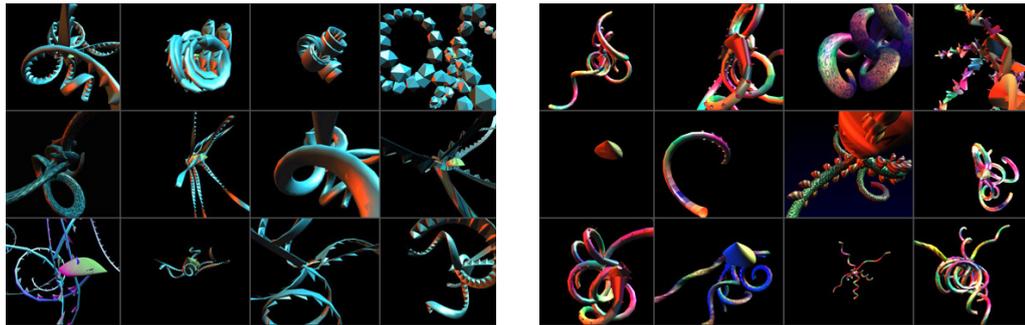


Fig. 48: Two grids of ‘relatives’ from the same evolutionary progression in Sims’s *Galápagos* (1997).

This division between genotype and phenotype was very clear for Verostko, as it was actually hardcoded in his process, dependent as it was from different technological resources, different spaces and times. Working for more than forty years, Verostko has embraced this split as part of his artistic discourse, and has been perfecting the plastic expressivity of his plotter-driven brushes. By the mid-seventies, the available output devices for computers were generally limited to technologies that would either produce fixed, immutable outputs (line printers, microfilm plotters, pen plotters, etc.) or that through the creation of analog signals could produce some (however simple) temporal outputs (oscilloscope screens, laser beams). Graphic interactive usage of computers, as we know it today, was still in a distant horizon.<sup>208</sup>

<sup>208</sup> The Boeing company coined the term ‘computer graphics’ in 1960, when it developed simulations of landings on runways designed to determine the movements of a pilot sitting in the cockpit. A figure representing the pilot was animated in real-time through an entire range of movements from a sitting position (Reichardt 1971, 15; Brown 1997). Ivan Sutherland’s *Sketchpad* project had been developed in 1962 (2003), allowing users to construct complex line drawings on screen by using a lightpen as an input device. With *Sketchpad* users could interact with drawings, creating, deleting, moving or transforming lines in ways that until then had been impossible to experience in computers, as outputs were typically limited to plotters and paper (Levy 2001, 148). Engelbart’s ‘Mother of all demos’, *A Research Center for Augmenting Human Intellect*, (Engelbart 2003; Atkinson 2007) happened late in 1968, the same year when Sutherland developed the first head-mounted visual display (Negroponte 1995, 118), but however revolutionizing these and other seminal projects were, it would still take a few good years until the concepts were developed into usable technologies.

It was then almost natural that artists using computers would identify multiple roles as canvas and environment, as tool and creator (Tyler 1976), that were performed by separate parts of the systems. Very naturally, the outputs were regarded as Lévy's media technologies, as surfaces where phenotypical materializations were registered. In 1976, William Kolomyjec described his artistic tools as comprised of "the digital computer and peripheral graphic equipment", going as far as to already classify different outputs as different media, depending on the nature of the peripherals that created them: "with a plotter or hard copy unit, the medium should be considered as 'printmaking.' When a computer and a digagraphic display console with refresh capabilities are joined, computer graphics can be considered as cinematography. One final example would be three dimensional output. A computer and a numerically controlled machine, such as a milling machine, could produce a form of output which, for all practical purposes, would be sculpture." (1976)

In most of the contemporary computational art and design however, the same does not often happen. Nowadays the computer's screen is seen as an integral part of the machine, not as a peripheral. Save for specific cases, artworks are developed *on* screen and *for* screen: projectors are seen as screens, not as different media, and printouts are often regarded as printed screens, fabricated objects are seen as three-dimensional realizations of what modeling applications present on screen: this is the legacy of WYSIWYG.<sup>209</sup> But we could argue that theoretically it is always possible to identify a division between genotype and phenotype, even if the coincidence of spaces between where the code is programmed and where the artwork is executed, somehow blurs the perception of the two phases. As an extreme example, Joline Blais and Jon Ippolito (2006, 2008) present what they identify as a system without phenotype, Tom S. Ray's *Tierra* (1991), an artificial-life system that does not offer much more than simple documental graphs as visible outputs of the myriad of complex systems that it continually develops.

We are reminded of an important distinction made by Chomsky (1957) between competence and performance. He saw competence as being regular and orderly while performance would be more entropic (Campbell 1982, 181). In digital aesthetic systems we may eventually describe both as having the opposite characteristics: competence, having some somatic characteristics, although orderly, logic and in that

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<sup>209</sup> Acronym for 'What You See Is What You Get', used to describe a computer system that presents the editable content as a very realistic simulation of the final output.

sense regular, can be made to be very entropic. Performance, akin to media technology, is usually factual and precise. As Carranza notes, usually the description of the form is declarative and closed to interpretation, because there is a one to one mapping between the genotype and the phenotype (2001) but in nature, he further adds, this is not often the case. In nature, the mapping from genotype to phenotype is procedural and not descriptive. Nature's evolution didn't make it become a space of mere uniform replication, but rather a space of change fed on randomness that leads to creativity, learning and evolution (Bateson 1979, 47). Bateson notes:

(...) the realms of epigenesis and of evolution are, at a deeper level, typified in the twin paradigms of the second law of thermodynamics: 1) that the random workings of probability will always eat up order, pattern, and negative entropy but 2) that for the creation of new order, the workings of the random, the plethora of uncommitted alternatives (entropy) is necessary. It is out of the random that organisms collect new mutations, and it is there that stochastic learning gathers its solutions. Evolution leads to climax: ecological saturation of all the possibilities of differentiation. Learning leads to the overpacked mind. By return to the unlearned and mass-produced egg, the ongoing species again and again clears its memory banks to be ready for the new. (48)

The analogy of the genotype, of this conceptual model, used in an evolutionary computation or integrated in some other set of processes usefully points us to the dilemma between 'software formalism' and 'software culturalism' enunciated by Cramer (2002). In his view digital aesthetic artifacts and software art can be evaluated according to their focus on formal poetics and aesthetics of code and the individual subjectivity expressed in algorithms, a point of view curiously termed as "code (form)" by Blais and Ippolito (2006, 24) or conversely, what they define as "result (function)", and Cramer "a cultural, politically coded construct" (2002).

## 1.4 The Ubiquity of Computation

### 1.4.1 Definitions of Computation

Computation is a general term defining any type of information processing, ranging from simple mathematical calculations to human thinking, from the interactions between elemental particles in nature to artificially programmed digital environments. Following Turing's abstract model, we see that computing — to process information by a computer or any other device — is nothing more than to “replace discrete symbols one at a time according to a finite set of rules” (Bolter 1984, 47). A simple definition proposed by Rucker is that a “*computation* is a process that obeys finitely describable rules” (2005, 11) and if in general when we discuss computers and human-made technology these rules should be defined using a model that is understood and can be expressed in an algorithm, we nevertheless can also use the term to define processes that are less formal. Regardless of the kinds of elements involved, as long as the process follows definite rules it is a computation of some sort (Wolfram 2002, 716). The term also refers to the abstraction and not to the actual physical processes that are involved in each particular case. If this was not so, the description of a process in the form of a programming language would not define a computation, but only the description of the physical process itself would. Regardless of how it is executed, a computation is the same (Lee 2009, 5). Generalizing, we can regard a computation as a process that transforms inputs into outputs, being the inputs and the outputs the states of the underlying system that supports the computational process (Rucker 2005, 13).

Kevin Kelly proposes a thought experiment that considers all technology as a type of computation (2009b). While we normally think of computation as being just the domain of computers, in his view it is really a formal arrangement of matter and energy that can occur in every substance and that is naturally occurring in nature, without any predefined goal or latent meaning (Rucker 2005, 60). Kelly uses examples of systems that actually perform computations in nature, such as DNA, but his suggestion extends further and follows the many ideas developed over the years by scientists as Konrad Zuse,<sup>210</sup> Edward Fredkin (1992a), Martin Davis (2004), Charles Seife (2006), Seth Lloyd (2006) and Wolfram (2002), among several others, that proposed that the universe was fundamentally a universal digital computer. Looking at

<sup>210</sup> 1910-1995.

the universe as a physical system, this radical view, described alternatively as digital physics, digital philosophy, universal automatism or pancomputationalism, suggests that the evolution of the universe is a computation and that all the processes of nature can be described computationally; it describes the universe as being a computational system — or a network of computational processes — that by following fundamental physical laws computes, that is, dynamically develops, its next state (output) from the current one (input). Described as a computer, the universe and all of nature can be studied as one.

Rucker gives us an example of how to regard the world as a massively huge parallel computation that has been running for thirteen and a half billion years and keeps constantly running: “To get a good image of physical parallelism, imagine sitting at the edge of a swimming pool, stirring the water with your feet. How quickly the pool’s surface is updated! If you toss a twig into the pool, the ripples spread out in a perfectly uniform circle. How do the ripples know where to go? The patterns emerge from reality’s parallel computation.” (2005, 89) Elaborating, he proposes an architecture for classical physics, consisting of: *many processors*, distributed, ubiquitous and without any central control; *one shared memory* because reality is one; *locality* as each processor only accesses its local neighborhood; *homogeneity*, as each processor obeys the same rule; and *synchronization*, because there’s a uniform speed at which all processors run.

This seems like a very normal — perhaps even unavoidable — conclusion to arrive to once one starts to study computers and computation, and develops new scientific frameworks that allow the formation of new ontologies. In the light of our contemporary culture and our current civilizational metaphors, we can even speculate that should the computer already be available when in 1623 Galileo described nature as being “written in mathematical language” (qtd. in Spengler 1962, 43), he wouldn’t alternatively have described it as being ‘computational’ or as being written in a computational language.

Wolfram summarizes (2002, 465), describing how the history of physics has seen the development of a sequence of progressively more accurate models for the universe, from classical mechanics through quantum mechanics, to quantum field theory and ever beyond, leaving one to wonder whether this process will go on forever or if it will eventually come to an end where we will reach a final ultimate model for the

universe. Actual results in physics suggest that whenever one tries to achieve a new level of accuracy, one always finds more complex phenomena and, according with traditional scientific intuition, one will need models of progressively greater complexity. In Wolfram's view, universal automatism seems to suggest that underneath all the complex phenomena that we observe in physics there may lie a set of simple programs which, if run for a long enough time would be able to reproduce the universe in every detail. He never claims to have already found these programs, not even if the discovery of these programs is possible, but he amasses a number of clues that seem to lend some credibility to the hypothesis. The discovery of the existence of such programs, or program<sup>211</sup> would be the ultimate validation of the idea that human thought can comprehend the construction of the universe, but it wouldn't necessarily mean that one could immediately deduce every aspect or behavior of the universe (or any system in the universe, from elemental particles to sentient human beings). As we will see, there is a big distance between a system's underlying rules and its overall behavior, which is precisely why, according to Wolfram, it is conceivable that a simple program could reproduce all the complexity that we see in physics (466).

The history of the universe could then be seen as the record of all the steps in an ongoing enormous computation, and the universe as a computer that would be computing itself (Lloyd 2006, 3), as every other computation occurring in the universe (K. Kelly 2009b). Of course that an explicit simulation of the universe would by definition be impossible to realize, because even if it is in principle always possible to work out the outcome of any program by simply running it and watching its output (Wolfram 2002, 465), if the universe is computational, it could only be simulated efficiently by a computer that was as big and powerful as itself (Lloyd 2006, 54).

To see this universal information-processing technology in action, one need only open one's eyes and look around. The machine performing the 'universal' computation is the universe itself. (16)

#### 1.4.2 The Principle of Computational Equivalence

Wolfram states that whenever one finds behavior that is not evidently simple, in essentially any system, if one thinks of it under a computational point of view, one will find it to be equivalent to many different kinds of processes (2002, 716). He calls this

<sup>211</sup> We can always consider any larger set of interacting programs as a single program.

the ‘Principle of Computational Equivalence’ (PCE) and although it can be stated in various ways, the simplest and most general is just to say that “almost all processes that are not obviously simple can be viewed as computations of equivalent sophistication” (716).

We have seen how a computational process can emulate (or simulate) other processes. We have also seen that a computation is universal when it is able to emulate any other computation, and that the threshold for universality is indeed low: Wolfram (2002) and Matthew Cook proved that a simple cellular automata with Wolfram’s Rule 110 is Turing complete and computationally universal (Rucker 2005, 69), and both Wolfram and Rucker suggest that when we examine the naturally occurring computational systems that surround us, like air currents, growing plants, even drying paint or the human brain, there seems to be reason to believe that the vast majority of these systems are able to support universal computation (Rucker 2005, 43).

Wolfram therefore states the PCE as being extremely broad, and applicable to essentially any process of any kind, either natural or artificial, with implications in natural sciences, mathematics, philosophy and elsewhere in human culture (2002, 715). He presents as the key unifying idea in the formulation of the principle the hypothesis that “all processes, whether they are produced by human effort or occur spontaneously in nature, can be viewed as computations” (715). Following this, Rucker proposes that we take “of equivalent sophistication” to mean “able to emulate each other” and understand the PCE as stating that most naturally occurring complex computations are universal (2005, 49).

Knowing that a particular computational system is universal just tells us that it is possible to set initial conditions that will lead the system to emulate any other system and eventually to cause a sophisticated computation to occur, it does not tell us what will happen if the system is initiated from typical (or random) initial conditions (Wolfram 2002, 719) nor it will help us in setting initial conditions that can actually simulate other systems. Any process that is universal can be programmed — through the setting of initial conditions that will bound the development of the process — to become another process. Any process that is not universal<sup>212</sup> will not be able to be programmed to such an extent.

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<sup>212</sup> As several naturally occurring processes that are below the Gödel-Turing threshold.

### 1.4.3 Computational Classes

In either case, all computational systems can be classified as belonging to one of four classes identified by Wolfram in the 1980s<sup>213</sup> and discussed at length in his book *A New Kind of Science* (2002). Based on the observation of the patterns produced by the outputs of several computational systems, but more systematically in the mapping of the outputs of all the 256 possible rules for the programming of two-color two-dimensional cellular automata, Wolfram noticed that while the output of every process differed in detail, the number of different types of patterns found in all the outputs was limited and could be fitted into just four classes of behavior that he numbered in order of their increasing complexity (231).

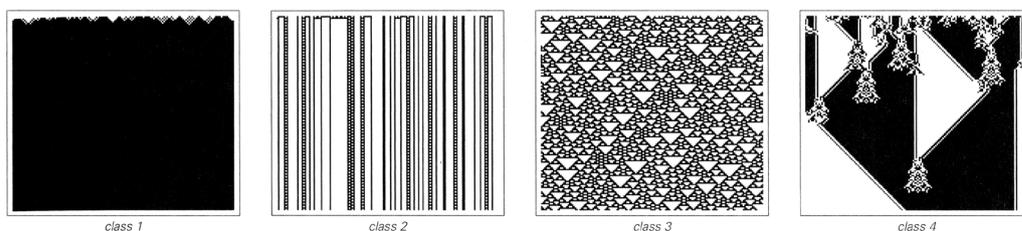


Fig. 49: Examples of the four classes of behavior as seen in the evolution of two-dimensional cellular automata from random initial conditions (Wolfram 2002, 231).

Each of the classes evidences distinctive features. In class 1 the behavior is simple and almost all the initial conditions for a given process will lead to the exact same uniform final state (235), the system dies out or becomes uniform (Rucker 2005, 68) in one of the two possible states.<sup>214</sup> In class 2 computations there are many more different possible final states, but each of these will consist of just a certain set of simple structures that either remain the same forever or simply repeat every few steps (Wolfram 2002, 235) and class 2 becomes periodic, generating repetitive or nested patterns (Rucker 2005, 68). These first two classes are described by Rucker as being simple computations, the remaining two are complex computations (25). Class 3 computations show an intricate behavior that seems confusing and in many aspects random, although some structured patterns can sometimes emerge.<sup>215</sup> Finally

<sup>213</sup> Wolfram claims to have arrived at this classification scheme for cellular automata in 1983, publishing it in 1984. He cites work developed by Christopher Langton, Wentian Li, Norman Packard, Hyman Hartman, Hughes Chaté and Paul Manneville for ordinary, probabilistic and continuous cellular automata (2002, 948).

<sup>214</sup> Black or white, 0 or 1.

<sup>215</sup> Such as the small triangles visible in the example.

class 4 computations present a mixture of order and randomness where one can find localized structures that move around and interact with each other in complicated ways (Wolfram 2002, 235). Where in class 3 the outputs are disordered and confusing, in class 4 they are ‘gnarly’ (in the sense proposed by Rucker),<sup>216</sup> that is, they are non-repeating and rich with persistent local structures.

If we think about physical matter, a vacuum, as described by newtonian physics, can be the example of the simplest, most orderly state of matter, where nothing at all ever happens. A crystalline solid is orderly in a periodic and predictable way whereas fluids as liquids or gases are extremely disorderly, close to that Wolfram would classify as a class 3 computation (Rucker 2005, 115). Class 4 computations can be discovered in phase transitions of matter (although some of the simpler cases can be nested class two structures) and in living beings.

It is not always clear where the borders between the computation classes are, especially between classes 3 and 4, or between classes 2 and 4, because systems can appear to be non-repeating for a long time and then turn out to be periodic but to have a very long cycle (25). These four classes were not formally defined by Wolfram,<sup>217</sup> so although there are certain requisites that a system needs to fulfill to belong to any of the classes, it can be difficult to prove beyond any doubt what is the class of a particular computation.

We should also be reminded that in all cases where computations are not closed systems, the exchanges of information developed with outside systems will affect behaviors of the system. Ultimately, exchanges of information can be responsible for the emergence of behaviors. Returning to Rucker’s example of a swimming pool as a computation (2005, 89), we can imagine its calm and undisturbed surface as being a class 1 computation<sup>218</sup> but when we throw in a twig, the interaction will result in

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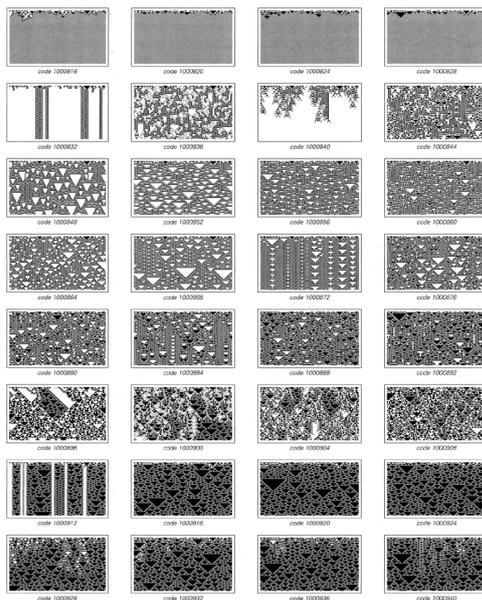
**216** Rucker explains that the original meaning of ‘gnarl’ was simply “a knot in the wood of a tree”. In California surfer slang, ‘gnarly’ started to be used to describe more complicated and rapidly changing surf conditions and, by extension, it started to be used to describe anything that presented a more than average degree of intricate detail. Rucker presents as examples clouds, fire and water as being gnarly in the sense of being beautifully intricate, of possessing patterns that seem purposeful but that are not quite comprehensible. All things living are also gnarly, because they inevitably do things that are much more complex than one might expect (2005, 112-14). In Rucker’s view, class 4 computations are *always* gnarly.

**217** Rucker suggests that it can be impossible to do so (2005, 25).

**218** Macroscopically speaking, at least, as at the microscopic level the pool is most certainly a class 3 computation.

the temporary development of a class 2 computation that will fade to the original class 1 stillness.

Systems can exhibit more than one type of behavior, depending on their inputs, and the ordering by complexity that Wolfram establishes is also a hierarchical ordering, because only class 4 computations are capable of exhibiting all the four classes (Rucker 2005, 68). More precisely, after we determine that a system is capable of exhibiting a class 4 behavior, we will know that given the proper inputs, the system will be able to exhibit any of the other three classes of behavior. This does not necessarily mean that a class 4 system is universal, but as Rucker notes, all universal computers are able to exhibit all four classes of computation because they will be able to simulate them. Another critical feature of any class 4 systems is that there must always exist certain structures that can persist forever in them (Wolfram 2002, 281), being resilient to the normal procedures of the computation and even eventually to external influence.



**Fig. 50:** Grid of examples from a totalistic cellular automata involving nearest neighbors and four possible states per cell (Wolfram 2002, 241).

When laying out a grid of examples taken from totalistic cellular automata involving nearest neighbors and four possible states for each cell, Wolfram concludes that although the numbering of the classes reflects their overall complexity, it is often the case that class 4 computations somehow fall between classes 2 and 3, intermediate

to both in terms of what one might think of as overall activity (2002, 242). Systems of class 1 and 2 rapidly settle down to states in which essentially there is no further activity, while class 3 systems are continuously changing and in a sense maintain a permanent high level of activity. Class 4 systems are in the middle of 3 and 2, never dying out completely nor remaining at the high levels of class 3.

In some respects it is not surprising that among all possible cellular automata one can identify some that are effectively on the boundary between class 2 and class 3. But what is remarkable about actual class 4 systems that one finds in practice is that they have definite characteristics of their own — most notably the presence of localized structures — that seem to have no direct relation to being somehow on the boundary between class 2 and class 3. (Wolfram 2002, 242)

The real significance of these four classes, of the different responses to changes in initial conditions or to external inputs fed to the systems is, according to Wolfram, that they reveal the basic differences in the ways in which each of the classes handles information (252). Wolfram sees class 1 systems as always forgetting information because whatever the initial conditions are or whatever information is fed to the system at a given point, they quickly evolve to a single final state that shows no trace of the original information. If we think about the twig and the pool, although there is a disturbance caused to the system, it rapidly normalizes the information received with that disturbance and resumes the ‘forgetful’ class 1 state. Class 2 retains some information in the final configuration of structures, but this information is always completely localized and the system never manages to communicate the initial conditions or external inputs from any of its parts to another. The information that is communicated to the system has a local effect, and maybe even permanent repercussions but is kept from traveling through the system.

Class 3 systems, on the other hand, have the very characteristic feature of being able to develop long-range communication of information. Any change made anywhere in the system will almost always be communicated, sooner or later, to even the most distant parts of the system. This doesn’t mean that the information is preserved by the system, but that its effects in the system can eventually be global. Class 4 systems are then intermediate between class 2 and class 3: although possible, long-range communication of information does not always occur, because any particular

change in the system is only communicated to the other parts if it affects the localized structures that move across the system (252).

The existence of these moving structures is a fundamental feature of class 4 systems, it is what makes these systems capable of preserving and communicating information between their different parts and what ultimately allows the emergence of their characteristic complex behaviors (281). With appropriate initial conditions, class 4 systems will generally be able to emulate the behavior of all the other three classes (291) and Wolfram strongly suspects that any system that shows overall class 4 behavior can turn out to be computationally universal (691).<sup>219</sup>

Rucker further identifies four subregions in class 4 computations, from the borders with class 2 to just before the total randomness of class 3, at the interface between order and disorder. The most orderly of class 4 computations are quasi-periodic, seeming just like class 2 computations with a slight and apparently unpredictable drift. Increasing the level of apparent disorderliness we can find systems that generate easily visible structures, like the gliders in the *Game of Life*. Rucker calls these structures ‘strange attractors’, after the attractors of chaotic dynamical systems. “Then we enter a critical transition zone, which is the heart of the gnarl” (2005, 116) and we see systems that display bifurcations, that is, systems that show multiple strange attractors and that alternate attractors. ‘Bifurcation’, in this sense, means the change of something in a system in such a way as to make its behavior move to a different attractor. As disorder increases in a class 4 system, it begins experiencing bifurcations in which a strange attractor repeatedly gives way to another, displaying varying configurations as the computation evolves. Finally, at the tip of disorder, just before reaching class 3, we find what Rucker calls ‘pseudorandom chaotic systems’, producing outputs that are empirically indistinguishable from true randomness, systems that, unless we have some prior knowledge about their nature as class 4 computations, we would probably classify as already being class 3.

Rucker links the behaviors of these four different classes to the different drives that a system needs to satisfy and to the system’s homeostasis (174). This term, originated in biology, reminds us that biological organisms can also be seen as computational processes, even if not as simple systems but rather as very complex ‘systems of sys-

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<sup>219</sup> Or maybe we can think that computationally universal systems are those that we can clearly define as being class 4 computations?

tems'. Whenever a system has a single drive to satisfy, it will in principle find a fixed point in its phase space, or a single internal state and stay there. This is what will typically happen with class 1 computations, whereas a system with two drives may develop a class 2 computation, hunting across the equilibrium, often in a regular and periodic way. Whenever there are more than two drives to satisfy, a class 3 or 4 computation will inevitably ensue. Computation always exists, and class 1 systems remind us that even when there is no apparent activity, whenever the system seems to be idle, to stand still or to be 'dead', computations are nevertheless always happening.<sup>220</sup>

In a biological perspective, everything dies, so in a sense, all biological processes ultimately become "simple class one computations. For most inputs  $In$  and most times  $t$ , an organism's output state  $P(In, t)$  is 'Sorry, I'm dead now.'" (433)

#### 1.4.4 Determinism

To address determinism in computation we need to discuss the concepts of feasibility, predictability and the two types of unpredictability proposed by Rucker.

The definition of a computation as a process that obeys finitely describable rules implies on the one hand that the rules act as a guide or a kind of recipe for generating every possible future state of the computation, and on the other that a computation should be utterly deterministic (Rucker 2005, 11). Although there may be some margin to consider subatomic quantum processes as being fundamentally nondeterministic (Lorenz 1995, 159),<sup>221</sup> beyond the scale of the subatomic, and for the purposes of this work, we can regard all computations as being deterministic, as being systems where temporal evolution is governed by precise laws (7) and where the present state and inputs completely determine the future (8).

Rucker defines a computation as being 'feasible' if it produces its result in a humanly reasonable amount of time (2005, 19). This is a very important concept when discussing the deterministic nature of computational processes because feasibility is

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<sup>220</sup> Class 1 computations do not die in a literal sense, they rather keep producing the same outputs at every step of the process.

<sup>221</sup> And even at this level, there are discussions as to whether so-called random quantum behaviors can in fact be considered to be nondeterministic or if they are just simply unpredictable as we will further see.

a relative notion, one that depends on the system one intends to use in running a particular computation, and something may be ruled unfeasible on a given system if it takes longer than one is reasonably willing or able to wait (23). Unfeasibility is therefore not synonymous with uncomputability.<sup>222</sup> All naturally occurring computational processes are, naturally, computable in their systems, although it may not be feasible to emulate them in other systems.

A computation must always be decidable, it must be, tautologically, computable. Independently of its feasibility, we can then define it as being ‘predictable’ if we can devise another computation that achieves the same results in a shorter time than the original computation. Rucker gives us an informal definition: “*P* is *predictable* if there is a shortcut computation *Q* that computes the same results as *P*, but very much faster. Otherwise *P* is said to be *unpredictable*.” (20) If a computation is unpredictable, the only way one has to find its final state (or any arbitrary state in its future) will be to wait until the computation reaches said state.

Rucker proposes three possible classifications for how predictable any computation may be. He defines systems as ‘predictable’ if there is a way to exponentially accelerate the computation, therefore arriving to its results much sooner than the original system would. An ‘unpredictable’ system cannot be speeded up exponentially, and although some shortcuts may lead to small increases of velocity, for practical purposes the gains will not be too noticeable or radical. Finally, a ‘strongly unpredictable’ system will be impossible to speed up, not even by a linear factor.

Simple computations<sup>223</sup> are in principle always predictable, because by entering either a uniform state or a cyclic series of states, they will always be possible to emulate in another system with exponential gains of speed. Complex computations<sup>224</sup> will on the other hand very often be unpredictable or strongly unpredictable, depending on where they are run.

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**222** Uncomputability or undecidability is an altogether different concept. Gödel’s incompleteness theorems showed that the capacity for self-reference leads to paradoxes in logic, this led Turing (1936), in his study of Hilbert’s *Entscheidungsproblem* and the ‘halting problem’ in Turing machines to prove that self-reference leads to uncomputability and that there are no analytical shortcuts that can tell the future state of some general computation any faster than by doing the computation step by step (1992).

**223** Class 1 and 2.

**224** Class 3 and 4.

From here, from the aforementioned Principle of Computational Equivalence and from Turing's theorem,<sup>225</sup> Wolfram proposes his 'Principle of Computational Irreducibility' (that Rucker prefers to alternatively name as 'Principle of Computational Unpredictability'), stating that most naturally occurring complex computations are unpredictable (49).

According to this principle, the reason that leads a human observer to think of any given natural computation as being nondeterministic is the fact that these computations are usually many orders of magnitude more complex and faster than anything we can simulate with the systems one has access to: digital computers or human brains. This means that it is unfeasible to simulate processes like ripples in the surface of the pool, ocean waves, global weather, or many others, but this does not mean that they are not the result of deterministic computations carried out in the physical world, computations that we have every reason to suspect to be class 4 and strongly unpredictable (115). This means that at least in principle all physical processes can be digitally emulated, but there are other difficulties besides unfeasibility when one tries to do so: the initial conditions and the supplemental inputs of the system (104).

In emulating complex systems it will usually be extremely difficult to possess all the information that is necessary to correctly define the initial conditions of the computation. Dynamical systems such as (the real or the mathematical models of) a swinging pendulum, a rolling rock or a breaking wave vary deterministically as time progresses. In principle the state of these systems at any given moment can be specified by the numerical values of one or more variables (Lorenz 1995, 8). Scientists usually interpret natural dynamic systems as either varying in perceivable discrete steps, when systems are technically known as 'mappings' and describable by difference equations that express the values of all the variables at the next step in terms of the values at the current step, or alternatively, as varying continuously, when systems are technically known as 'flows' and describable by differential equations that express the rates at which all of the variables are currently changing (12-13). As one would expect from a computational view of the systems, it is always possible to create a mapping from any flow by observing the flow at selected intervals of time (13), by sampling it at an appropriate frequency. The problem with natural computations is that the number of variables that need to be considered is tremendously high. Ide-

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<sup>225</sup> Stating that every universal computation has an unsolvable halting problem (Rucker 2005, 400).

ally, every particle in the system should be considered in the computation and no statistical models should be used as shortcuts.

If all the required variables cannot be known, the insufficient initial conditions will lead to an accumulation of errors in the computation, and will make it impossible to accurately simulate the system in the short or long-run (1995, 12). This is a phenomenon that scientists that study chaotic systems define as the ‘sensitive dependence on initial conditions’ (Gleick 1998, 8) and it extends to more than the enumeration of all the variables required to initialize a system but also to the accuracy with which these are detailed. Complex systems with many different interacting parts can evolve to significantly diverse states by amplifying omissions and errors but also very small inaccuracies in the initial values (Morowitz 2002, 13). It is often difficult to measure physical quantities with an exact degree of accuracy (and below a certain threshold it becomes actually impossible, according to quantum mechanics) so in a sense, it may very well be that it is always unfeasible to perfectly simulate a naturally occurring computation.

Therefore, a naturally occurring or physical computation is not repeatable, although it can be approximately repeated. The fuzziness of the natural world keeps its computations from being precisely repeatable because we do not, and cannot, have a perfect control over the input of the computations. We can have a very close value to the input, but we will not have an exact value, and every time we try to approximate it, it will vary in some different way, producing in the long run various fluctuations in the output (Rucker 2005, 99). A physical computation, unlike artificial computations,<sup>226</sup> can never be reset to the exact same initial input, so that we can observe the exact same series of outputs. This happens because the dynamics of the system amplify the tiniest details of the initial and interactive inputs so that they have large and noticeable effects (100). So outputs seem random or chaotic or both, but only because the details of the initial and interactive inputs are not fully known (101).

A key distinction between bouncing balls and PCs is that our PC computations are repeatable. This is because PCs are digital, with a feasibly small range of initial values and because they are well isolated from unwanted inputs. But because bouncing balls are analog, their computations are not repeatable. The difference between analog systems and digital systems is not that the analog

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<sup>226</sup> That we can develop with computers.

computations are in any way less accurate. The difference is that analog systems have so many states that it's physically impossible to control the inputs of an analog computation precisely enough as to make them repeatable. As it happens, the physical computations we enjoy watching are the least likely to be repeatable. (102)

Under the light of pancomputationalism we can regard the entire universe as a massive computation (Lloyd 2006, 3) so in a sense, every computation in the universe will be a part of this colossal system and will have some information exchanges with other computations, outputting information and, more importantly in this context, inputting information from other systems, constantly interacting with them. These interactions will affect the processes, sometimes in catastrophic ways, sometimes slightly, but regardless of this scale, they will influence the development of the computation. This influence is deterministic, like every other computational process, but, much like the initial conditions, in a majority of the cases it will be very hard to make an inventory of all the interactions and to determine their values with exactness.

On a more human perspective, Boden (2004) proposes a psychological classification of the predictability of events (or the perception of the outcomes of processes) in three categories. 'Absolutely unpredictable' (A-unpredictable) events are unforeseeable in principle because they are subject to no laws or whatever determining conditions (243). Although it may be a useful abstract and absolute category to consider, stated in these terms, this A-unpredictability directly contradicts the premises of Wolfram, Rucker and other proponents of universal automatism, and approaches some interpretations from quantum mechanics, embracing the idea of the possibility of total indeterminacy that the universal automatism thesis necessarily denies. Regarded as a psychological category, however, A-unpredictability becomes very real and is a useful description of how human observers interpret phenomena that are apparently void of any understandable causality, internal logic or order. A-unpredictability is the unpredictability of class 3 computations, of the toss of a (true) coin, of systems that are so intricate, complex and 'noisy' that one quickly stops trying to find some sense and predictability in their outputs. Even if one believes that all processes are deterministic, one will be unable to understand the computations behind A-unpredictable processes, let alone simulate them.

‘Relative unpredictability’ (R-unpredictability) is defined as the impossibility to predict an event in practice, in the sense that it may be unforeseeable by human beings and/or by other finite systems, including computers. This category is so called because this sense of the term is defined relatively to the predictor and, naturally, all A-unpredictable events must also be R-unpredictable, with respect to all predictors. This is also an important psychological classification of unpredictability, because R-unpredictability can be overcome by knowledge, by information or by tools of information. Failure to predict R-unpredictable events is attributed by Boden to ignorance (of details and/or general principles) and/or to the complexity of the event. By discovering new scientific laws, by inventing more accurate measuring instruments or more powerful tools, the ability to predict may be much improved and therefore R-unpredictable events may become predictable (245).

Finally, ‘butterfly-unpredictability’ (B-unpredictability) is related to a system’s sensitive dependence on initial conditions, it is the unpredictability of computations that cannot be accelerated and can be computed “only by actually working through the consequences of the equations” (250). It is also the unpredictability of chaotic phenomena like the weather system or turbulence in fluids.

In conclusion, we have that all computational processes are fully deterministic, although they may not be feasible or predictable. ‘Determinism’ should then be interpreted only in its technical meaning of obeying finitely describable rules and, as we have seen, what we usually interpret as lack of determinism, free will or randomness in the decision processes may be consequences of unpredictability. This conclusion does not imply (or even suggests) ideas such as religious determinism, fate, destiny or any lack of free will.

This means that against common sense, deterministic computational processes are able to yield genuine surprise and must not necessarily flow along in a routine fashion (Rucker 2005, 20). The intuition that the mathematics needed to describe the natural world involved only smooth functions that would always provide a reasonable approximation to reality in the same degree as the accuracy of the data gathered, turned out to be mistaken (Boden 2004, 249). Unpredictability cannot always be overcome, no matter how rigorous and precise are our measurements of the world, deterministic systems can be sources of real surprise and an increased

level of detail, that extra decimal place in the measurement of initial conditions can be the grounds for astonishment (248).

In response to the objection that computers cannot think because they merely follow human instructions, Turing noted that machines took him by surprise with great frequency (Chun 2008, 227). This was not because they could think (not at the time, and not nowadays still) but because we are not able to fully understand in advance all the consequences of one's program. If this is true with artificial computations, those programmed by humans, it becomes even truer when those computations interact with other artificial computations or with natural computations, with the environment or with humans. When universal automatism proposes that all natural processes are computational, it implies that mental processes and human creativity are also deterministic, something that is apparently contradicted by our sense of having a free will. Wolfram's Computational Irreducibility answers by showing that the mind is a computation that is simultaneously deterministic and unpredictable (Wolfram 2002, 1135; Rucker 2005, 294; Hofstadter 2007).<sup>227</sup>

Let me make one more point. If you fear that determinism means you're a machine without a soul, consider that, given what we know about class four computations, there's no reason to think that we can't be both deterministic and unpredictable, no reason to think that your soul couldn't in some sense be a gnarly computation. Consider: The world could be perfectly deterministic and still look and feel exactly the same as it looks right now. Indeed, I think that's the true state of things. Quantum mechanics simply doesn't go deep enough. And we have nothing to lose by moving beyond it to a fully deterministic universal automatism. (Rucker 2005, 121)

The inevitable questions that derive from these beliefs are whether machines will ever be able to display imaginative or creative activity, whether we will be able to program machines to develop these behaviors and whether we will recognize these behaviors should they ever be shown by machines.

When machines are R-unpredictable and their computations are unfeasible to us, they force us to adopt the "intentional stance" towards them. De Landa (1991, 157)

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<sup>227</sup> Wolfram associates the amount of free will related to any particular decision with the amount of computation required to arrive at it (Wolfram 2002, 1135).

exemplifies by describing how one plays a game of chess against a machine. If the machine is slow and takes several minutes or hours to make a move, we do not actually confront it face-to-face but rather tend to view it as a clever contraption that can be outsmarted directly via the logical considerations of its internal design. We have time and opportunity to consider the features of the machine's internal logic and to develop our strategies based on this analysis. If the machine is able to play in real time, that is, as fast or faster than a human, we will have no other choice than to confront it as an opponent by attributing it beliefs and desires of its own. We will have to relate to the machine's strategies by formulating questions related to the *will* of the machine, its view of the game and ultimately its view of the opponent in order to be able to win the game (157). We will start thinking about the machine in much the same terms as we think about a human opponent, we will think about the machine as we think about ourselves.

#### 1.4.5 The Principle of Computational Irreducibility

In the notes to *A New Kind of Science* Wolfram develops a short history of computational irreducibility (2002, 1132) and of the discussions that since antiquity have been developed around the notion that there could be fundamental limits to knowledge or predictability. Most of these discussions assumed that there was a fundamental inadequacy of the various models that were developed but that once the models were available there would in principle be no difficulty in working out their consequences and consequently of understanding the phenomena that they described.

Already in the 1500s, when symbolic algebra was introduced, and formulas for solving cubic and quartic equations were discovered, the expectation began to develop that with good enough formulas it would in principle be possible to solve any purely mathematical problem. A century later, after several models for natural systems were developed, it was generally assumed that their basic consequences would always be possible to find in terms of formulas or geometrical theorems. However, in 1684 Isaac Newton<sup>228</sup> was already commenting that calculating the gravitational interactions between many planets would exceed the capacity of any human mind. Although during the eighteenth and nineteenth centuries there were successful formulas found for many of the great problems in mathematical physics, the three-body problem continued to pose serious difficulties.

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228 1643-1727.

In the nineteenth century it was then shown that the three-body problem could not be solved in general in terms of ordinary algebraic functions and integrals,<sup>229</sup> but perhaps in part because of a generalized shift towards probabilistic theories<sup>230</sup> there was still the conviction that for the relevant aspects of behavior, with sufficient cleverness or insight, it would be possible to arrive to formulas for their accurate description.

By the 1950s computers began to be used to work out numerical solutions to equations and a few experiments were done in systems with simple underlying rules, typically assuming that their results were just approximations to what could in principle be represented by exact formulas. This view was strengthened in the 1960s, when the question whether computer simulations would be able to outrun the actual systems being simulated — particularly with weather systems — was often discussed. It was normally assumed that the issue was about getting better approximations to the underlying equations (that would always exist), of achieving better initial measurements or about other factors that would eventually be resolved, but not something more fundamental as is the Principle of Computational Irreducibility as stated by Wolfram.

During the 1940s and the early 1950s, particularly in the context of von Neumann's game theory and Wiener's cybernetics, the idea that it should be possible to make mathematical predictions even about complex human situations started to develop, but by the 1970s, these attempts were usually regarded as unsuccessful, not because of any fundamental reason but rather because there were just too many disparate elements to handle in practice, so it was generally believed that an increase in computational power or in data collection would eventually solve the problem.

Although some of the notions behind computational universality and undecidability emerged in the 1930s, starting with Kurt Gödel's<sup>231</sup> incompleteness theorem, they were in general regarded as not being relevant to the questions that arose in natural sciences. In the 1940s these notions were presumably in the basis of some arguments about free will and fundamental unpredictability of human behavior in the area

**229** In the 1820s it was proved that quintic equations (polynomial equations of degree five, in the form  $ax^5 + bx^4 + cx^3 + dx^2 + ex + f = 0$ , where  $a \neq 0$ ) could not, in general, be solved in terms of radicals and by the 1890s it was demonstrated that degree 7 equations could not be solved even if elliptic functions are allowed.

**230** Such as quantum and statistical mechanics.

**231** 1906-1978.

of economics, and in the late 1950s some philosophers tried to establish a connection between Gödel's theorems and determinism, although, according to Wolfram, "mostly there was just confusion centered around the difficulty of finding countable proofs for statements about the continuous processes assumed to occur in physics." (2002, 1132) In the 1960s, the development of algorithmic information theory led to the discussion of objects whose information content cannot be compressed or derived from anything shorter. This, however, is not quite the same idea that Wolfram presents as computational irreducibility. During the 1970s computational complexity theory began to investigate questions regarding overall resources needed to perform computations, concentrating however on computations that performed fairly specific practical tasks. In the following decade it was noted that certain problems about models were NP-complete,<sup>232</sup> but this was not immediately connected to any underlying general phenomenon.

The interest in issues of predictability in models of physical systems started to increase in the late 1970s, and it became clear that when the equations in these models are nonlinear it often becomes difficult to find their solutions. It was at least at some levels assumed that this was associated with sensitive dependency on initial conditions and with the phenomena of chaos. In the 1980s, the use of computers for the study of models of natural systems increased, along with various approaches that usually tended towards higher process intensity and larger quantities of processing time, implicitly assuming that "this was necessary in order to overcome the approximations being used, and not for some more fundamental reason." (2002, 1132) Examples of what Wolfram now identifies as PCI were found in physics and other fields, but no special significance was attached to them. Wolfram devised the concept during the early 1980s, while studying cellular automata and failing to devise formulas that predicted their behaviors.

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<sup>232</sup> The complexity class NP-complete, with NP standing for nondeterministic polynomial time, is a class of problems with two properties: 1) any given solution to the problem can be verified quickly (in polynomial time); 2) if the problem can be solved quickly (in polynomial time) then so can every problem in NP. Although solutions can be quickly verified, there is however no known efficient way to compute a solution in the first place. The most important characteristic of NP-complete problems is that we do not know any fast solution to them, that is, the time required to solve the problem using any currently known algorithm increases very quickly (faster than polynomial time) as the size of the problem grows. As a consequence, NP-complete problems are usually addressed using approximation algorithms.

Wolfram believes that one of the reasons why computational irreducibility was not identified before is because for more than two centuries students and scientists have been led to think that basic theoretical science could somehow always be done with convenient formulas — and almost all textbooks tend to discuss only the cases that happen to come out this way. Although during the 1990s and 2000s a broader range of examples of PCI have been identified, there still remains a widespread belief that if a theoretical result about the behavior of a system is truly fundamental, then it must be possible to state it in terms of a simple mathematical formula. Much of what Wolfram presents and discusses throughout his book is the view that this must not always be the case, and that very often it is a computational description of the system that is able to foresee its future behavior. This description is however in many cases irreducible, meaning that whatever results it produces are unpredictable.

#### 1.4.6 Randomness

Edward N. Lorenz<sup>233</sup> defined randomness as the lack of determinism (1995, 7). If a deterministic sequence is one in which one and only one thing can happen at the next step, in a purely random sequence *anything* that can ever happen may happen next (6). A tossed coin would be the best mundane example of complete randomness, as in the long run the statistical results of a large number of tosses will split evenly between heads and tails. A broader definition of randomness would however present a random sequence as one in which any one of several things can happen next, even though not necessarily anything that can ever happen may happen next.

If we believe that all computations are deterministic and that the thesis of universal automatism is valid, then every process in the universe is inevitably determinist and this definition can only be understood as a construct in the sense proposed by Henri Margenau<sup>234</sup> — as an entity that the mind creates in order to understand the sensory world in a hierarchy of emergences (Morowitz 2002, 173)<sup>235</sup> — and not as a realist definition of randomness. Lorenz's definition allows us to state that something looks random (and this is enough in his context) but certainly does not allow us to know what it is to *be* random.

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<sup>233</sup> 1917-2008.

<sup>234</sup> 1901-1997.

<sup>235</sup> According to Harold Morowitz, building constructs is something uniquely human (or perhaps uniquely *sentient*), part of the search for ontology, for the reality behind cognitive events (2002, 173).

An appropriate definition of randomness can only be formulated if one considers issues of perception and analysis and still, a standard definition has not been so far produced by mathematics or statistics (Wolfram 2002, 552). In spite of some claims for particular definitions, and a singular intuition that everyone has about the nature of randomness, the concept has remained quite obscure.

On discussing randomness, determinism and their meanings on the study of creativity, Boden (2004) finds three different categories for randomness. The first two categories are very closely related and are defined as 'absolute randomness' (A-randomness) and 'explanatory randomness' (E-randomness). A-randomness is the abstract classification of the total absence of any order or structure in the domain concerned, whether this is a class of events or a set of numbers (239). Recognizing that it is extremely difficult to define A-randomness technically, Boden proposes only this intuitive definition of it.

From a phenomenological point of view, E-randomness is not very different from A-randomness, and is defined as the total lack, in principle, of any explanation or cause for the absence of order or structure (239). As with R-unpredictability, E-randomness can be explained by ignorance and overcome by knowledge or information.

Finally, 'relative randomness' (R-randomness) is the lack of any order or structure that is relevant to some specific consideration. As an example, Boden presents poker-dice, that fall and tumble R-randomly with respect to both the knowledge and the wishes of the players (239). This is usually what is meant at the level of everyday language, when someone observes that something seems random — that there are no significant discernible regularities in the phenomenon, at least with whatever methods of perception and analysis one uses at the time (Wolfram 2002, 552).

If an event is A- or E-random, then it must also be R-random with respect to all considerations. An R-random event however, is not necessarily A- or E-random, since it may be strictly constrained in some terms other than the aspect by reference to which it is R-random. Actually, outside of those terms, an R-random event may very well be not random at all (Boden 2004, 239).

The natural occurrence of all the three types of randomness proposed is a controversial question. While there is no disagreement about whether R-randomness hap-

pens — being relativistic and contextual, defined by the particulars of the information that the observer holds — some A- or E-random events are believed to exist by quantum physicists, while strict determinists and pancomputationalists believe that they are “like the unicorn: an intriguing concept that does not apply to anything in the real universe” (239).

Given the everyday notion of randomness and the three categories proposed by Boden, we will need to build on them to develop more precise definitions, so that we can eventually be able to understand the role and importance of randomness in the creative process, and in aesthetic systems. The first step for this, according to Wolfram (2002, 552) is to be able to understand exactly what it means to not be able to recognize regularities in something.

Regularities in any system are synonymous with the existence of some degree of redundancy in it (552). Redundancy, as stated by Shannon’s second theorem of information theory (1949) makes information be reliable in an otherwise unreliable and noisy world, allowing to (at least theoretically) protect a message from any amount of noise by shielding it with an appropriate amount of redundancy. Therefore redundancy, repetition of content or structure, is potential information. It is coded diversity available for use as and if required and it *is* structure (Wilden 1987, 187). Redundancy means that more signals are present and sent than those that are strictly necessary to transmit the essential information in a message (188). Shannon asserted that the English language is about fifty percent redundant when he considered samples of eight letters at a time, while with sequences of up to one hundred letters the amount of redundancy rose to approximately seventy-five percent and with longer samples the figure would become even higher, as in whole pages or chapters, where the reader is able to get an idea of the long-range statistics of a text, including its theme and literary style (Campbell 1982, 71). According to Shannon, this means that much of what we write is dictated by the structure of the language and is therefore more or less forced upon us by default.

If a structure would be absolutely not redundant, if no aspect of its structure could be inferred from any other, then the structure itself would be its most compact possible description (Simon 1969, 110). Simple structures display a high degree of redundancy, from complete uniformity and consequently total redundancy in class 1 systems, to periodic repetition in class 2. Complex structures display significantly smaller de-

degrees of redundancy, that lowers as the overall activity of the system increases. Class 4 computations are therefore more redundant than class 3 computations and these last can eventually display a zero degree of redundancy.<sup>236</sup> If no redundancies can be identified, then there is no shorter description of a system than the system itself.<sup>237</sup> Wolfram presents as an example the following three images, each of them containing 6,561 cells from a two-dimensional cellular automaton:

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**236** Simon (1969) described the three types of redundancy that could be found in complex systems: ‘recombination of parts’, ‘decomposability’ and ‘recoding’. The first of these happens in systems that are composed of only a limited kind of subsystems, as e.g. proteins, whose variety arises from the rearrangement of only twenty different amino acids. Likewise, the 117 elements in the periodic table provide all the building blocks for an almost infinite variety of molecules, or, looking at the human body, we find that with as little as two hundred and ten different types of cell, a structure is built with as many as one hundred trillion ( $10^{14}$ ) total cells. A system that is composed by a recombination of parts is necessarily redundant to some degree and can be described with a restricted alphabet of elementary terms that correspond to the basic set of elementary subsystems from which the complex system is generated (1969, 110). At a related level, systems may be decomposable, and in this case only aggregative properties of their parts will enter into the description of the interaction of those parts. From a generalization of this notion, Simon presents the ‘empty world hypothesis’: most things being only weakly connected with most other things, a tolerable description of reality needs to take into account only a tiny fraction of all possible interactions, thus, adopting a descriptive language that allows the absence of something to go unnoticed, it is possible to describe things quite concisely (110). Finally, through appropriate recoding, one may discover redundancies that may not be obvious in the structure. The most common of recodings is the description of a dynamic system’s time path by a differential law that generates that path. The simplicity of this resides in a constant relation between the state of the system at any given time and the state of a system a short time later. As an example, the structure of the sequence 1, 3, 5, 7, 9, 11, etc. can be most simply expressed by observing that each member of the sequence can be obtained by adding two to the previous member (111). This description gives us an insight of the structural redundancy of the sequence, and, should this be extended to infinity, one could easily understand its state at any given point  $n$  by simply applying the description to its value and getting as a result  $n+2$  — incidentally, this is the sequence that Galileo found to describe the velocity at the end of successive time intervals of a ball rolling down an inclined plane (111).

**237** And the information of the system cannot be compressed. An extremely ordered structure, like those produced by class 2 computations can be reduced to a small description. “A trillion digits of this sequence, 0101010101010..., can be perfectly compressed, without any loss of information, into one short sentence with three commands: *print zero; then one, repeat a trillion times*. On the other hand a highly disordered sequence like a random number cannot be reduced. The smallest description of a random number is the random number itself; there is no compression without loss, no way to unpack a particular randomness from a smaller package than itself.” (Kelly 2009a).

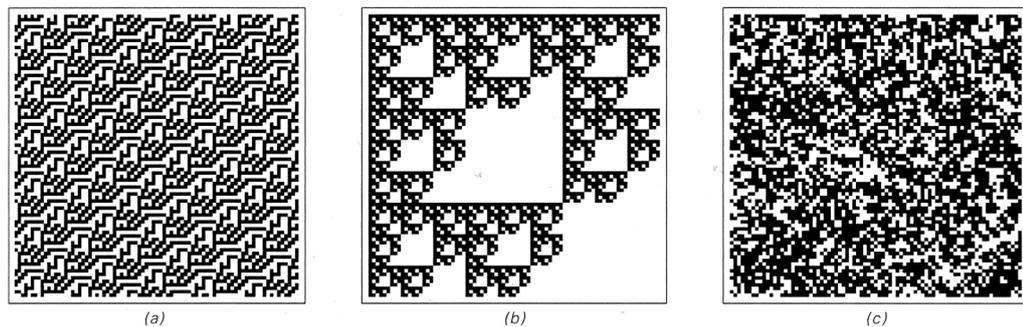


Fig. 51: Different degrees of apparent randomness in cellular automata (Wolfram 2002, 552).

Each of the images presents a different degree of apparent randomness: *a* and *b* display obvious regularities, *a* being modular and *b* nested, so, as difficult to describe as they may be, they wouldn't probably be classified as random by many observers. Image *c*, however, has almost no obvious regularities, thus seeming quite random. In any of the three cases, a full and detailed description of the image could be achieved by describing the colors of each of the many cells that they contain. This would produce a fairly lengthy list of 6,561 values for each of the images, so this description would have exactly the same length for any of the images regardless of the redundancies present in their structures. If we use the regularities and redundancies that we can see in the first two images, we will readily construct much shorter, but still precise and complete, descriptions, while on with the third we will still have to detail every single color value in the grid (552).

But as it turns out, image *c*, like images *a* and *b*, was generated through a quite simple computational process, so it can be fully described by a program that has the exact same length of those behind *a* and *b*. The point in this example is that the simplicity of the process does not affect the fact that with our standard methods of perception and analysis, the third image is for all practical purposes, totally random while the other two are clearly not (552). Our visual perception and our intellectual deductive powers do not reveal any significant regularities that would allow us to produce a shorter description of the image<sup>238</sup> so, if one cannot have access to the algorithmic description behind image *c*, one will most likely have little choice besides specifying the colors of each individual cell (553).

The question this raises to Wolfram is if our knowledge of the existence of a short description, of a program that originates image *c*, should make us see it as not being

<sup>238</sup> And, incidentally, neither do the standard methods of mathematical or statistical analysis.

random? From a practical point of view the fact that there is a short description may not be too relevant if that description is not available or easily discoverable by any of the methods of perception and analysis that are available to us (554). Without the description, image  $c$  is E-random; if and when the description is known, the image will no longer be E-random, although it may still be R-random. From a conceptual point of view, Wolfram deems unsatisfactory to have a definition of randomness that depends on our methods of perception and analysis and that is not, somehow, absolute (554). David Cope agrees, deeming perception as variable from observer to observer and often far from reality. Randomness is a process, not a thing, and as such, it cannot be discerned from its outputs alone (Cope 2005, 52).

A possibility would be to define randomness so that something is considered random only if no short description whatsoever exists of it (Wolfram 2002, 554). But we wonder, is such an epistemological definition useful? Maybe not. Wolfram strongly suspects that no useful description of randomness can be based solely on this algorithmic approach, but that a definition must make some reference to how such short descriptions are supposed to be found (555). We need a precise definition of randomness under the light of universal automatism: “something should be considered to be random whenever there is essentially no simple program that can succeed in detecting regularities in it” (556). This is similar to a definition offered by Murray Gell-Mann: “applied for instance to a single string of a thousand digits, random means that the string is incompressible. In other words, it is so irregular that no way can be found to express it in shorter form. A second meaning, however, is that it has been generated by a random process, that is, by a chance process such as a coin toss, where each head gives 1 and each tail 0.” (qtd. in Cope 2005, 52) Complexity, or incomprehensibility are then common definitions (or explanations) for randomness, but there are further attempts to arrive at a more precise, and testable, definition, one of which is to test processes under identical conditions (52).

The key to thinking about randomness is to imagine such a system to be in some particular state, and to let it do whatever that particular system does. Then imagine putting it back into exactly that initial state and running the whole experiment again. If you always get exactly the same result, then the system is deterministic. If not, then it's random. Notice that in order to show that a system is deterministic, we don't actually have to predict what it will

do; we just have to be assured that on both occasions it will do the same thing.  
(Stewart 1997, 280)

But, as we have seen, predictability and randomness are both sensitive to initial conditions. If with software it is in principle possible to repeat the exact same initial conditions for a process, once one steps out of the virtual machine, it will in principle always be impossible to have such a fine degree of control. Although in abstract this may seem like a good test for randomness, not only it will always be affected by that worldly inaccuracy as, it will very often be impossible to actually test, especially with more complex systems.<sup>239</sup> It is no surprise then, that Lorenz states that tangible physical systems generally possess at least a small amount of true randomness (1995, 5).

#### 1.4.7 Three Mechanisms for Randomness

In tangible physical systems, especially in nature and in naturally occurring computations, one of the single most common things one encounters are systems that exhibit randomness. It could well be that in each and every of these systems there could be a different cause for randomness but Wolfram argues that this is not the case and he identified no more than three basic mechanisms for randomness (2002, 299).

The first, and most commonly considered in traditional sciences, essentially corresponds to the assumption that there are sources of randomness in the external environment that continuously affect the system under observation. As an everyday example we can consider a boat that bobs up and down on a rough ocean. Although there is nothing intrinsically random about the boat itself, there is randomness in the continually changing ocean surface where the boat floats. As the motion of the boat follows the ocean's surface, it will also seem random to an external observer (301). Naturally occurring computations, being almost impossible to isolate from interactions with other computations, are frequently affected by such external inputs.

In the second mechanism there is no interaction with the environment but there is a source of randomness at the initial conditions. The system then computes deterministically and predictably, involving no other random inputs beside those fed at its origin. A tossed coin, a wheel of fortune, a roulette wheel, and other similar gen-

<sup>239</sup> Such as biological, geological, cosmological processes, etc.

erators of randomness work in essentially this way. They do not develop a process that generates randomness but their mechanism is sensitive to that randomness that is present in the initial conditions provided for their operation.<sup>240</sup> The phenomena studied by chaos theory are examples of such a great sensitivity to initial conditions that no machine with fixed tolerances can ever be expected to produce repeatable results (306).

In both these cases we will have two variations of the same general property, two manifestations of the sensitive dependence on initial conditions. In the first the influence of external conditions will be permanent, in the second it will only be present at the start of the computation, and this is where the difference really resides, in permanent influence or in a single event that communicates some randomness to the system, thus affecting its future development.<sup>241</sup> Both these mechanisms assume that the randomness one can see in any system will ultimately come from outside the system so in a sense, neither will take any responsibility for explaining the origins of randomness, they both in the end just say that randomness comes from the outside of whatever system one may happen to be observing (300).

The third mechanism tries to explain the origins of randomness. As Wolfram shows (27), computational processes can produce apparently random behavior even when they are given no random inputs whatsoever, when they are initialized from controlled initial conditions and have no interaction with other systems.

And they do this without relying on the so-called pseudorandom processes. Most programming languages provide these as a way to produce unpredictable results, an easy method to pseudorandomly take any of a range of possible actions. Pseudorandomness is however totally deterministic because it is generated from deterministic algorithms. There are several methods to generate seemingly random sequences of values, usually starting by some hard to predict, like the internal date of the computer's clock, the time it has been running so far, or other schemes. The fact is that

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**240** It is indeed possible to build precision mechanisms that can toss coins or spin wheels in ways that always produce a certain outcome, void of whatever randomness is usually present in the systems.

**241** In deterministic systems the initial conditions are, in a sense, just the conditions that the system happened to be in when an observation is started. A system's state at any point in time can be taken as the initial conditions for a new computation, that which the system will develop from that time onwards. The setting of random initial conditions can then be compared to the perturbation of the system at any point during its computation by interaction or through the communication of random information.

whenever a programmer calls a pseudorandom function from a programming language, she will actually be relying on the irrelevance of the data that is chosen to provide the sense of randomness (Cope 2005, 53). With enough time and if provided with the generating algorithm, a programmer could, if necessary, accurately predict the sequence that the random number generator would produce.<sup>242</sup> This means that pseudorandom generators are theoretically predictable and not random in a strict sense of the word.

As a consequence of Wolfram's discovery that simple programs can generate random behaviors, we can reasonably expect that similar mechanisms can also occur in many systems in nature (2002, 301), to the point of, as he believes, being in fact ultimately responsible for a large fraction, if not essentially for all, of the randomness that is discovered in the natural world (301).

The first two mechanisms that Wolfram presents are not responsible for creating randomness *ex nihilo* but rather for the communication of randomness between systems. That means that although they are not able to explain how randomness is produced at the lowest level, they will be useful in describing randomness that is observed in particular systems (301). Wolfram presents the third mechanism as the one that is most common in nature (299), which leads us to conclude that randomness is not always a reflection of our ignorance but that it emerges from computational processes.

## 1.5 Computation and Creativity

### 1.5.1 Artificial Creativity

Pancomputationalism proposes that everything in the natural world is the outcome of computation and computational processes. However skeptical one may be about this view of things, compelling cases defending it were presented by several scientists and philosophers, so we can, at least for the purposes of this discussion, accept the argument as valid or at the very least plausible. Under this view of the universe, all the behaviors that can be observed in nature, organic or otherwise — the behavior of plants, animals and humans, the behaviors of planets and stars, as well as

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<sup>242</sup> In fact, most programming languages allow the programmer to control the random number generator and to use it to generate sequences that look random but that are totally deterministic and repeatable.

that of atoms and subatomic particles — can be regarded as being computational in essence. Although all computations are deterministic, through Wolfram's principle of computational irreducibility we know that many of these computations, if not the majority, are unpredictable.

Although apparently contradicting what common sense identifies as free will, human behaviors and traits can be regarded as being computational and as such, if we follow the principle of computational equivalence, at least some of its aspects can in principle be explained or emulated, partially or in full, by other computational systems.

Using this analogy, and through the use of computers, we can better understand human creativity or we can try to create something that we perhaps call machine creativity, trying to develop computational systems that are, or appear to be, creative to some degree (Boden 2004, 1). We can develop media and artworks that not only reflect the human author's creativity (as in traditional media), not only make use of the human user or wreader's<sup>243</sup> creativity (as in interactive media) but that can actually act creatively.

Much along the same lines as artificial intelligence is studied — itself also a field that simultaneously tries to study human intelligence and to develop computational systems that are intelligent, that try to simulate intelligence or to apply aspects of intelligent behavior in other systems — we can think about *artificial creativity*. We may understand that all creativity requires intelligence and that therefore artificial creativity must be a part of artificial intelligence (Cope 2005, vii), much in the same way that we can consider that all intelligence requires life and that therefore all forms of artificial intelligence must necessarily be forms of artificial life. But we can likewise consider that creativity is a subset of intelligence and that the later is a subset of life and that aspects of creativity can be developed independently of the development

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<sup>243</sup> The portmanteau word 'wreader' identifies the fusion of the acts of reading and writing that is developed in interactive systems as hypertexts, computer games and other digital environments. In these systems the user is very often not a passive receiver of the information but she also actively contributes to the organization of the materials, to the definition of the structure of the narrative or, ultimately, to the creation of the contents of the piece. In constructive systems (borrowing Michael Joyce's term), the user is required to "create, change, and recover particular encounters within a developing body of knowledge or writing process" (Joyce 1995, 101) which necessarily equates his work, at least partially to that of the original creator, or writer, of the piece or system.

of intelligence, as well as aspects of intelligence may exist without life (however one may define it) can be identified or existent.

Although the term ‘artificial creativity’ can be, as Cope points, too broad to cover the study of the various ways by which humans invent new art (vii), it is nevertheless true that all artistic practices are developed through the usage of different combinations of human creative abilities and that if we want our media, our aesthetic systems, to act creatively, we will need to understand what are these abilities, how do they work and what makes us identify their outputs as being creative. As with artificial intelligence, we need to understand whether or not computer programs can effectively model creativity and if they can in fact create. As artificial intelligence gave rise to a new approach in studying the mind, computational psychology (Boden 2004, 15), artificial creativity may come to give rise to new approaches in aesthetics and design.

### 1.5.2 Creativity

In *The Creative Mind* (2004), Boden develops a study of creativity and gives us an overview of work being developed in the field of artificial intelligence, looking at computer scientists, computer artists and to what she calls ‘unromantic artists’ (147), the computer programs concerned with the arts, and art making.

In order to understand the phenomenon of artificial creativity (a term that Boden herself never uses) she starts by trying to define and understand creativity. According to Boden, creativity is the ability to come up with ideas or artifacts that are “new, surprising and valuable”. ‘Ideas’ in this context can include abstract notions as concepts, as well as more concrete but still immaterial things as poems, musical compositions, scientific theories, cooking recipes, choreographies, jokes and so on. ‘Artifacts’ include paintings, sculptures, steam engines, vacuum cleaners, pottery, origami, and many other things one could name in the realm of physical objects or systems (1).

Cope defines creativity as “[t]he initialization of connections between two or more multifaceted things, ideas, or phenomena hitherto not otherwise considered actively connected.” (2005, 11) Dorin sees creativity as a defining trait of human artistic practice and recognizes that it is not something that science finds easy to explain, despite

its recognized significance and the many attempts that have been made to elucidate its virtues from the arts (2008, 294).

Creativity is indissociable from originality, and if we understand something as being original if it has never been seen or produced before in the exact form that is presented to us, we find that computers are quite able to easily generate seemingly original output, pseudorandomness functions simplifying this process. Almost endless recombinations of modules can easily be programmed, generating infinite melodic or rhythmic sequences, or infinite books, like in Jorge Luis Borges's<sup>244</sup> library. Whether these are understood by the human audience as being original or are seen as being creative is an altogether different concern, and a much more complex phenomenon. To be creative it is not enough to be original in this sense, because this originality only satisfies the first of Boden's requisites, novelty. As randomness is continuously used in the production of ever-novel outputs, it ceases to be surprising and, ultimately, it may cease to be valuable, if it ever was in the particular context where it was initially used. Therefore, although indissociable from creativity, originality should not be the focus of its definition (Cope 2005, 12).

Cope presents the two modes of thought proposed by de Bono since the mid 1960s, who distinguished between a selective and analytical mode of thinking that he called 'vertical' and a more creative, generative and instigative mode that he termed 'lateral' thinking. While vertical thinking proceeds by logical steps and usually conforms to learnt patterns or modes of operation, lateral thinking is open to the intrusion of information that may be possibly relevant, it is inclusive and nonlinear in essence, striving to disrupt habitual lines of reasoning (10). Lateral thinking must be nurtured and new stimuli must be introduced to the thought process, either willingly or by chance, in order to shift the thinking in new directions.

Cope, like de Bono, sees creativity as a process, not as the result of a process (44). This process, Boden explains, happens in three main ways, corresponding to three sorts of surprise that are generated: combinatorial, exploratory and transformational creativity (2004, 3). The first of these, combinatorial creativity, involves making unfamiliar or novel combinations out of familiar ideas and/or artifacts. Examples include analogy, collage, poetic imagery and the manipulation of recombination systems. New combinations can be generated deliberately or, very often in the case

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244 1899-1986.

of human creativity, unconsciously, through the association of aspects in two ideas: when a physicist compares an atom to a solar system, when a journalist or cartoonist compares a politician with an animal, or in many other examples from literature or visual arts.

Combinatorial creativity is from the three that which is behind a big part, or perhaps even most of human creativity. It is also perhaps the easiest of the three to model in a computer, because it is relatively simple to choose any two different ideas or data structures and to put them alongside each other (7). Transcoding helps the programmer to use data structures that originally were in different domains and to find a common ground between both, or to produce a convergence of both in the final output. This way, images and sounds, for example, can be combined creatively, even if automatically and almost without constraints. Through the swift generation of multiple combinations, arising from composition or concatenation, eventually selected by the computer according to some preprogrammed rules of selection, one can enhance human creativity by engaging in what Aarseth calls a ‘postprocessing’ collaboration with the machine (1997, 135). Given a multitude of outputs, of novel combinations that are performed automatically by a computer, a human designer can select from those the few (or many) in which she identifies some value, which surprise her, and that will potentially surprise her audience.

Like Bach and his algorithms, we nowadays find artists and designers working with digital technologies, and creating systems for their private creative use, systems that are not destined to users or audiences and that are not creative per se but that are programmed to reinforce or enhance the designer’s creativity — systems for creativity, not systems that *are* creative.

The other two modes of creativity are quite different from the first, because they involve the definition of a conceptual space,<sup>245</sup> its subsequent exploration and eventually even its transformation. Once a conceptual space is established, creation through its understanding and methodical research will constitute an act of exploratory creativity, while the deliberate transformation or transcendence of this space

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<sup>245</sup> A formal definition of conceptual space and of the concepts of exploratory and transformational creativity is given by Geraint A. Wiggins in *Towards a More Precise Characterisation of Creativity in AI* (2001) and in *Categorising Creative Systems* (2003).

will be a far more radical, challenging and rarer form of creativity, labeled by Boden as transformational creativity (2004, 4).

Exploratory and transformational creativity depend on the existence of a conceptual space, on the existence of ‘rules’ and ‘constraints’ — both in the context of human creativity,<sup>246</sup> as in the context of artificial creativity. The conceptual space is a search space of partial and complete possibilities, but it is not the space of *all* possibilities, rather a subset of this universe of possibilities, a superset of the conceptual space at any given point in the creative process (Wiggins 2001, 1).<sup>247</sup> Rules and constraints define the grammar of the creative processes and also their phase-space, their space of possibilities and freedom. Therefore, “far from being the antithesis of creativity, constraints in thinking are what make it possible” (Boden 2004, 95), even in the mode of combinatorial creativity, where in principle constraints are less of a concern, as the conceptual space does not need to be so well-defined, or to be defined at all. As Boden notes, creative ideas are surprising because they go against our expectations, but something that is totally unconnected with the familiar does not arouse surprise but more often than not bewilderment and confusion. When a conceptual space is not minimally defined, there may be a real lack of connection with what happened previously in the process and people will not be able to see the creative output as relevant to what they may have regarded as being the problem-domain in question (97). Because of conceptual spaces, or creative phase-spaces, creativity is always contextual (Cope 2005, 13), even in the combinatorial mode, when the context is defined by the reader, and not by the author, by the user of the system and not by its creator. Boden adds an important point:

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<sup>246</sup> Although here these may be existent but less clearly defined.

<sup>247</sup> Wiggins (2001) defines this universe,  $U$ , as a multidimensional space whose dimensions are capable of representing anything, and where all possible distinct concepts can find a correspondence with distinct points of  $U$ .  $U$  is not restricted to concepts that are capable of representing the domain in which we wish or need to be creative, as this would rule out the cross-domain transfer of ideas, through processes as analogy and metaphor. Wiggins proposes that we should assume that  $U$  contains all complete and partial concepts and that, although it may be possible to distinguish between complete and incomplete concepts, in most cases it is nevertheless enough to think of both partial and complete concepts simply as “concepts” (2001, 2). He presents four axioms for the definition of  $U$ : 1) All possible concepts are represented in  $U$ ; 2) All the concepts represented in  $U$  are mutually distinct; 3) All members of the type of conceptual spaces are strict subsets of  $U$ ; and 4) All conceptual spaces include the most partial concept of all, the empty concept, notated as  $\perp$ , therefore  $\perp \in U$  (2001, 2).

If, by some miracle, a composer had written atonal music in the sixteenth century, it would not have been recognized as creative. To be appreciated as creative, a work of art or scientific theory has to be understood in a specific relation to what preceded it... Only someone who understood tonality could realize just what Schoenberg was doing in rejecting it, and why. (Boden 2004, 74)

Although substantially more complex and difficult to achieve than combinatorial creativity, exploratory creativity can also be developed with computers, in either of the three regimens of human-machine collaboration enunciated by Aarseth: pre-processing, coprocessing and postprocessing (1997, 135). Abiding to constraints, after all, comes naturally in computers, programmed using formal languages that are themselves creators of possibility spaces. Some artificial intelligence systems can transform their conceptual space, by altering their own internal rules, but the main problem is not to make the transformations themselves, but rather to manage to, while programming, state our aesthetic values clearly enough to enable a system to successfully evaluate each transformation (Boden 2004, 9).

If we manage ways to transform and evolve the grammar of a system over time, these transformations will inevitably be reflected in the products of the system. Jeremy Campbell gives us an example: "Mutation of a single letter in a DNA sequence is one thing. Mutation of a rule is quite another, and the consequences are likely to be more interesting. A change of rule could lead to an innovation, a burst of originality, so easy to explain in terms of language, but so hard, until now, to make plausible in terms of Darwinian evolution." (1982, 98)

According to Boden, when considering exploratory creativity, in order for a computer program to be really creative or just to appear to be creative, it must inhabit and explore a conceptual space that is rich enough to yield indefinitely many surprises. Ideally, when developing transformational creativity, it should be able to extend this space, eventually even breaking out of it and constructing new ones. The results of the process must be individually unpredictable, because they are original, but they should all bear some sort of recognizable conceptual style, and they should be generated by the program alone, using only its computational resources rather than inputs from human operators (2004, 163). Furthermore, the process must involve some sort of judgment, that is, it must involve decision processes and aesthetic criteria. In this sense, purposeful behaviors should be more common than random

processes and any randomness that is integrated in the process must be constrained by the creative domain and the contexts concerned. There must be also some processes that allow either memory and/or retrospection, so that the program is able to sometimes reconsider its past choices when deciding the following steps. Finally, novel data structures that the program produces must be recognized by humans or other systems as being valuable in some way, as being aesthetically pleasing, as being effective from a communicative point of view or as containing new and relevant information — the program itself should ideally be able to at least partially evaluate this degree of value when selecting between possible alternative structures for itself, avoiding nonsense or cliché. “If the relation between the program’s generative strategies and its results casts light on human creativity, not forgetting the creativity of those who interpret the novel ideas, so much the better.” (164)

Boden further distinguishes two instances of creativity, regardless of their modes, and talks about psychological creativity, and historical creativity, or if we prefer, relative (or personal) and absolute creativity. Psychological creativity (P-creativity) involves surprising and valuable ideas that are new to the person or system that conceives them, hence their relativity, while historical creativity (H-creativity) is achieved with absolutely original ideas or artifacts, that no human or system have created ever before and that arise for the first time in history (2). Although in the context of arts H-creativity is extremely valued, in the context of communication design and of its products it is less clear whether its value should be the same. For the purposes of this work it will maybe suffice to speak of creativity, assuming, as Boden also proposes, that all instances of H-creativity are naturally also P-creative and that very often the distinction between both is fortuitous and dependent on factors that are external to the creative process itself.

### 1.5.3 Strong and Weak Artificial Intelligence

Computer scientists and artificial intelligence researchers often distinguish two scenarios for the study, development and usage of artificial intelligence systems: the so-called ‘strong artificial intelligence’<sup>248</sup> and ‘weak artificial intelligence’.<sup>249</sup>

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<sup>248</sup> Or artificial general intelligence.

<sup>249</sup> Alternatively known as ‘narrow’ or ‘applied’ artificial intelligence.

Put simply, strong artificial intelligence seeks to develop general purpose systems that match or equal the intelligence of human beings. Usually developing bottom-up processes, its primary goal is to create machines or systems that can successfully perform any intellectual task that a human being can, with similar or preferably higher efficiency and ideally with the same versatility. Scientific research (and science fiction) often associate this ability to perform general intelligent actions with human traits as consciousness, sentience and self-awareness, because along with other traits like perception and cognition, these seem to be an integral part of the processes of intelligence. It is nevertheless unclear whether these traits are indeed necessary for an artificial system to reason as well (or as badly) as human beings can — if for example one is able to simulate the neural correlates of consciousness, one would not automatically gain the ability to represent knowledge or to use natural languages. Consciousness or self-awareness are still somewhat vaguely comprehended phenomena, intuitively understood but difficult to explain in precise scientific terms, as is emphasized by Rucker (2005) and Hofstadter (2007), and precisely because they are central to the research in artificial intelligence (as well as in other fields), they are still at the core of much of the work being developed in the field.

It is of course also possible that some of these traits that we commonly identify as ‘human’ — particularly consciousness and self-awareness — are emergent properties from a fully intelligent system and that it may become natural to also ascribe them to machines once they begin to act in ways that are clearly intelligent, regardless of the approach used to develop that intelligence in the first place. Hofstadter seems to defend this perspective in *I Am a Strange Loop*, proposing the existence of variable degrees of sentience in each animate being or system as ‘strange loops’<sup>250</sup> that come into existence within the system (2007, 360), due to that system’s ability to think, to possess a sufficiently large repertoire of interpretable and triggerable symbols (203).

Donald Norman argues that much of human intelligence results from the ability to devise and construct artifacts that increment the very cognitive capabilities and physical traits that are associated with intelligence itself. As capable as human brains are, they are nevertheless finite in capacity and limited in power, but through

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<sup>250</sup> Strange loops may involve self-reference and paradox and arise when one finds oneself back at the starting level while moving up or down through a tangled hierarchical system, or an heterarchical system, as Hofstadter calls them. The concept was originally proposed and discussed in *Gödel, Escher, Bach* (1999) and subsequently elaborated in *I Am a Strange Loop* (2007).

the invention of tools, artifacts or theories, humans have discovered ways to overcome those limitations. Our technologies don't only expand our bodies but, as Norman says, they quite literally "make us smart" (1993, 7). Norman's argument also points a fundamental problem with 'intelligent' technologies: the fact that in most of the cases the intelligence does not reside within the technologies themselves but rather in their designers (2007, 13). This means that technologies do not 'think', that they are not intelligent, but that they materialize and operationalize ways of making things that contribute to an optimization of the processes in which they are used. Most technologies develop relations with humans that are symbiotic in the sense that Licklider proposed of a merger of two components, one human, one machine, where the mix is smooth and fruitful, and the resulting collaboration exceeds what either is capable of alone (22). Technologies can therefore provide means to expand intelligence without actually being endowed with any intelligence — examples abound, from pocket calculators to most of the software in personal computers. When describing what computers could do for intellectual work, Licklider envisioned that in due course they would be integral parts of the formulation of problems and of real-time thinking, problem solving, researching and the conduction of experiments, they would get into literature and would mediate and facilitate communication among humans (Flichy 2007, 37). But they would do this without intelligence, albeit with other resources that at the time seemed more urgent and attainable than intelligence, such as vast memory and extraordinary speed. Nowadays these resources are for the most part so common and taken for granted that we start valuing the intelligence that a system may manifest, however small, besides the simple access or speed that it may provide us with.

As an alternative or a complement to strong artificial intelligence, weak artificial intelligence seeks to use software and computational processes to study or accomplish specific problem-solving or reasoning tasks that do not necessarily encompass the full range of human cognitive abilities (and sometimes are even completely outside of these). The models used in the task resolution are not necessarily derived from or trying to emulate the human approaches to the same problems, but rather trying to search for the most adequate or efficient solutions to a given problem, regardless of any similarity with human reasoning or operation.

Both approaches to artificial intelligence, strong and weak, derive from the already mentioned *Chinese Room Thought Experiment* (Searle 1981). In the text, these terms

were used as names for two alternative arguments that distinguished different hypotheses about artificial intelligence. The ‘strong artificial intelligence hypothesis’ proposed that computers could eventually be developed to the point of thinking and of effectively having a mind,<sup>251</sup> making a much stronger statement than the weak artificial intelligence hypothesis, that almost imposed the impossibility of higher thought and merely stated that an artificial system could only act like it thought and had a mind. The strong hypothesis assumed that something special happens to the machine or system, something that goes beyond the capabilities one can test and that this something *is* intelligence. Many researchers in artificial intelligence do not put much emphasis on a literal interpretation of the strong hypothesis, using this term to describe any system that acts like a mind, regardless of whether a philosopher would be able to determine whether it actually has a mind or not. What researchers are interested in can then be expressed in a related statement that describes the strong artificial intelligence hypothesis more loosely, as being interested in systems that can think, *or* can act as they think, as well as or better than humans do.

This apparently small concession is not without consequences. As Weizenbaum noted, the work on artificial intelligence tends to be conceptualized in one of two modes, often called performance mode and simulation mode (1976, 164). If the goal of artificial intelligence is to build machines that behave intelligently, whether or not they are in fact endowed with intelligence at the human level or whether or not they are able to shed any light on human intelligence, contributing to its understanding, then they are working in performance mode. If on the other hand the comprehension of human intelligence is fundamental to the development of the artificial intelligence, if the system accurately tries to simulate the workings of the human mind, we may then say that it is working in simulation mode. The dividing line between both modes is naturally far from being absolute (165).

Since the Turing machine and the Turing test<sup>252</sup> were proposed that machine intelligence has historically been conceptualized as imitation, by imagining the machine not only as having the ability to mimic or emulate other machines but also as being

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<sup>251</sup> A mind, an I or a soul, following Hofstadter’s terminology (2007).

<sup>252</sup> What we now call Turing test was proposed by Alan Turing (1950) as a method to answer the question of whether a computer could think. His original model was called *The Imitation Game* and proposed that a human interrogator would communicate with two agents, one of them human, the other a machine, by means of a text-based interface. This interface, similar to a teletype terminal or to an Internet Messag-

able to imitate humans. As Andrew Goffy notes, although imitation has the merit of encouraging a speculative exploration of the cultural aspects of computing, it also has the problem of narrowing the possible approaches to the question of machine intelligence, of limiting the space of possibilities for artificial intelligence (2008b, 133). The human mind is the only example of general intelligence to which we have access, so it is naturally the first example to study when trying to understand intelligence as it manifests in humans but, unless we are too anthropologically centered,<sup>253</sup> it can be difficult to imagine it as being the only possible general intelligence.

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ing system is proposed as a way of removing the aural qualities of speech and the visual appearance of the subjects, dispensing with the need to embody the computer.

If by using written communication alone the interrogator is not able to distinguish the human from the machine, then in Turing's view, the machine wins the game and can be considered as having achieved thinking and intelligence. In his text he does not define either thinking or intelligence, as also does not claim that passing the test proves either, he merely uses it in the attempt to prove an epistemic point.

This imitation game became somewhat of a standard for the evaluation of strong artificial intelligence, independently of the strategies used in the programming of the computer agents that play it. Turing left out from his description many of the practical details of the implementation of such a test: which sort of questions should be asked, how many different interrogators and agents should be used, what should their qualifications be and how long should the tests last. Although these may lack for the specification of a particular test, if we think of the tests as evaluating an artificial general intelligence then all these details will not be significant, because ultimately the machine will have to be versatile enough to always (or in a significant percentage of the tests) pass as human, independently of the context. The one suggestion that Turing did specify was that multiple tests should be performed so that the final result would be averaged and not the outcome of a single conversation.

Turing himself predicted that by the year 2000, an average interrogator would, after five minutes of conversation, be able to make a correct identification (that is, to defeat the computer) in 70 percent of the cases (Stewart Copeland qtd. in Ariza 2009, 50). Ray Kurzweil predicted that machines would be able to pass the test by the end of the 2020s, while Mitchel Kapor was less optimistic and was convinced that no machine would do it until then (Ariza 2001, 51). Others still, defend that with current technology it may be impossible to pass the test and that we will need to wait for further advances in computational hardware before any machine is able to successfully and repeatedly demonstrate the skills required. Such is the case of Seth Lloyd, a researcher on quantum computing, a technology that he expects will be able to provide the means for the successful development of strong artificial intelligence (2006).

Several alternative tests have been proposed over the years, some of them related in setup and methods, like the John Henry test (a competition between a human and a machine in which there is a clearly defined winner within a narrowly specialized, and not necessarily intelligent, domain), the total Turing test (that replaces the text-based interface with a full physical and sense-based interaction with a robot) or the Lovelace test (that tries to evaluate creativity in particular and not general intelligence) (Ariza 2009, 54). Some other proposals were made in which tests would be developed in alternative media, using music, for example, but in the end, any kind of language, such as music, should be roughly equivalent in the context of these tests, as Turing's proposal makes clear that written human language has more than the required abilities to represent human-level thinking (2009, 56).

**253** And we certainly are anthropologically centered in many cases, especially on those matters that pertain to something as human as intelligence.

#### 1.5.4 Strong and Weak Artificial Creativity

Much along the same lines we can think about a distinction between strong artificial creativity and weak artificial creativity, where a strong approach would try to understand and follow human creativity, operating in simulation mode, while a weak approach would try to make artificial systems act creatively regardless of a human model, focusing in the performance mode.

In a talk about generative art,<sup>254</sup> Marius Watz (2006) proposes a similar distinction applied to generative art systems, identifying with the idea of strong generative art those pieces where one can find a dominant conceptual focus, where the process or system is itself conveyed as the aesthetic object, where the perceived purity of chance or logic operations is embraced by both artist, system and audience and where, ultimately, there is a tendency for the removal of the author from the artistic process or object.<sup>255</sup> Weak generative art is exemplified by pieces or systems that develop computational models of form, by semi-automated creation processes that integrate chance or randomness, by combinatorial systems that explore permutations of parametric systems and finally by pieces that explore the plastic qualities of the software. Regardless of the approach, Watz identifies a series of implications from generative art practices, the most important of them being the possibility to provide us with knowledge and with a testing ground for a computational model of creativity. Not a computational model of human creativity, one is inclined to underline, especially after the ‘removal of the author’ has been pointed out among the characteristics of strong generative art, but rather a model of how computational systems can act creatively in different (specific, not general) domains and therefore how they can be used creatively or simply *be* creative.

#### 1.5.5 Artificial Aesthetics

We can extend these considerations from artificial intelligence and artificial creativity to a narrower field that is concerned with the use of computational systems in design, communication and art. Authors as Galanter (2003; 2006), Watz (2006),

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<sup>254</sup> Watz follows Galanter’s definition of generative art: “any art practice where the artist uses a system (...) which is set into motion with some degree of autonomy contributing to or resulting in a completed work of art.” (2003)

<sup>255</sup> That are more often than not viewed as the same.

Whitelaw (2007), Dorin (2008), Matthew Lewis (2008) or Griffiths (2008), to cite just a few, choose to talk about ‘generative art’. Other authors and artists commonly use the designations ‘digital art’ or ‘digital design’ when discussing these fields, as Murray (1997), Aymeric Mansoux (2008a), Blais and Ippolito (2006) or Peter Luining (2004), while some others prefer ‘computer art’ (Lopes 2010). Cramer (2002) and Thor Magnusson (2008), for example, seem to prefer using the term ‘software art’, a designation that is not commonly applied to design.<sup>256</sup>

Paul A. Fishwick introduces a new perspective with the term ‘aesthetic computing’ (2006a). He however defines it mainly as being concerned with the impact and effects of aesthetics on the field of computing (3), rather than the opposite way around, as we would prefer to do in this context. Fishwick presents us with an introductory reflection regarding the term aesthetics<sup>257</sup> and he follows to define aesthetic computing as “*the application of the theory and practice of art to the field of computing. (...) Aesthetic computing relates to the following sort of sample activities 1) representing programs and data structures with customized, culturally specific notations; 2) incorporating artistic methods in typically computing-intensive activities, such as scientific visualization; 3) improving the emotional and cultural level of interaction with the computer*”, and continues by stating that in general “aesthetic computing involves one of two types of aesthetics applications: *analysis* and *synthesis*. Analytic applications tend to evaluate artifacts of computing and mathematics from the perspective of classical aesthetic qualities such as mimesis, symmetry, parsimony, and beauty. Synthetic applications tend to employ aesthetics as a means of representation of the artifacts. The word ‘representation’ is broadly defined to encompass the concepts of interaction and interface, rather than simply static presentation.” (6) Conceding that art that uses the medium of programming involves a greater reflection and emphasis on the computing, or on programming as a sub-area of computing (8), aesthetic computing, as proposed by Fishwick is nevertheless an area that stands to the field we’re trying to define as software design stands to the design with

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<sup>256</sup> ‘Software design’ is traditionally used to designate the processes of designing the software. It is used not to describe the design of the communicational or aesthetic perspectives of the software, more commonly described by terms as ‘interface design’ or ‘user experience design’, but the technically more narrow processes of designing the functionalities of the software and the code itself and not those of producing design through software (itself increasingly almost the only way of producing visual design nowadays, although the software tools are typically used as non-intelligent resources).

<sup>257</sup> A word that stems from the Greek αισθητική (*aisthītiki*), derived from *aisthēsis*, i.e. ‘perceived by the senses’ (Fishwick 2006b, 4).

software, i.e., it is interested in using knowledge from aesthetics, art or design, for the production of computational artifacts, and not the other way around.

For our purposes, for studying the ‘impact and effects’ of computing in aesthetics, we should perhaps follow a similar nomenclature scheme to artificial intelligence and artificial creativity and to define the field as artificial art, artificial design or more broadly perhaps, as artificial aesthetics. ‘Artificial’ would allow us to emphasize how the systems are synthetic and man-made, rather than natural, and how the artifacts they produce (in those cases where the artifact is distinguishable from the system or in the cases where the artifact is part of or the system itself) are not directly produced by humans — as aesthetic artifacts typically are — but by computational systems that are in their turn created by humans, or created by computational systems that were ultimately created by humans. ‘Aesthetics’ would allow us not to put a strong or discriminatory emphasis on the use of these systems for strict artistic purposes or for broader communicational and utilitarian purposes, but to place them in both fields simultaneously (as well as in other related fields, whenever sensorial communication is used, regardless of its purpose or particular context).

We can consider artificial aesthetics to be a subset of artificial creativity which is in its turn a subset of artificial intelligence. Not disregarding a possible conceptual and operational split between strong and weak artificial aesthetics, we would prefer to focus on a pragmatic and performance-oriented approach, in the sense that in a majority of cases, artists and designers are not objectively researching on human aesthetics and creativity or on its simulation, but rather trying to implement creative traits in the systems. This doesn’t mean that what is developed is something as a weak artificial aesthetics, if we consider this to be the implementation of aesthetics and creativity as a secondary aspect of the system,<sup>258</sup> rather that, whatever aesthetic aspects are implemented by artists and designers, in a majority of cases, do not aim towards a generalized usage, polyvalence or total autonomy, and are not burdened by the mimesis of the human processes.

If in the domains of artificial intelligence and creativity we can develop systems that totally eschew the human model. When thinking of artificial aesthetics we must

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**258** As it happens for example with the coding of artificial intelligence in non-playing characters or foes in computer games or in household devices and appliances, or in the multiple daemons that populate our personal computers or the Internet.

however note that although similar approaches are in principle possible, they must nevertheless always manage to communicate across the computer-human frontier, meaning that whatever process is developed, its ultimate goal is always to be perceived by a human, or to have its products perceived by humans. Human perception, psychology, cultures and languages cannot ever be totally absent from the processes, at least at the level of the outputs, and must be real concerns for their creators, that otherwise risk total ineffectiveness.

We can learn from imitation games, from many of the interactions that we so far developed with computers and computational systems and from the many ways in which we have integrated them in our lives, that computational systems do not need to *be* human, as they do not even need to act or to have any sort of human-like traits or qualities. As Hofstadter says, some critics of computers and artificial intelligence are eager to find things that computers cannot do or will never be able to do, and they tend to search for that in domains as art or creativity, classifying them as being fundamentally uncomputerizable. But that is hardly the implied (or the logical) conclusion, because we still do not have good enough models of such things as human perception, memory, mental categories, learning, and so on. In fact, we are still quite a long way from having those, but there is no valid reason to assume that achieving these is in any way impossible (1995, 209). We may have partial models, some of them partially or totally developed outside the domain of computers or computation, like Gestalt theory, cognitive psychology, neurology, and many other areas of research, be it formalized or not<sup>259</sup> and in the lack of comprehensive models, these can be effectively used to overcome the cognitive frontier between computers and humans. Computational systems need to reach humans, but that may just be easier than fully embodying their look and feel and behavior.

### 1.5.6 The Eliza Effect and Comitivity

In fact, creativity, along with other human traits can be almost unwittingly conveyed by a computational system, or to be more precise, understood by humans as existing in the computational system, regardless of its original purpose or that of its creators.

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<sup>259</sup> As in crafts, tradition or in the personal practice of an artist.

In *Computer Power and Human Reason* (1976), Weizenbaum describes the creation of ELIZA, a system that attempted to simulate a Rogerian therapist,<sup>260</sup> working on a text terminal and, in a rough analogue of a human therapist, attempting to communicate with a human counterpart by using natural language.<sup>261</sup>

A typical ELIZA session may resemble something like this example (where capitalized lines are ELIZA's responses):

- Men are all alike.
- IN WHAT WAY?
- They're always bugging us about something or other.
- CAN YOU THINK OF A SPECIFIC EXAMPLE?
- Well, my boyfriend made me come here.
- YOUR BOYFRIEND MADE YOU COME HERE
- He says I'm depressed much of the time.
- I AM SORRY TO HEAR YOU ARE DEPRESSED
- It's true. I am unhappy
- DO YOU THINK COMING HERE WILL HELP YOU NOT TO BE UNHAPPY
- I need some help, that much seems certain.
- WHAT WOULD IT MEAN TO YOU IF YOU GOT SOME HELP
- Perhaps I could learn to get along with my mother.
- TELL ME MORE ABOUT YOUR FAMILY
- My mother takes care of me.
- WHO ELSE IN YOUR FAMILY TAKES CARE OF YOU
- My father.
- YOUR FATHER
- You are like my father in some ways.
- WHAT RESEMBLANCE DO YOU SEE
- You are not very aggressive but I think you don't want me to notice that.
- WHAT MAKES YOU THINK I AM NOT VERY AGGRESSIVE

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**260** Also known as *person-centered therapy* or *person-centered psychotherapy*, Rogerian therapy is a form of talk-psychotherapy originally developed by the psychologist Carl Rogers in the 1940s and 1950s. The therapist tries to aid patients to find their own solutions to their problems by demonstrating empathy and an unconditional positive regard, thus creating a comfortable and non-judgmental environment.

**261** The counterpart is sometimes described as an 'interrogator' (although ELIZA also poses questions) or alternatively even as a 'patient', a term that can be seen as a reinforcement of the role-playing game but risks suggesting that the software may indeed have medicinal properties.

— You don't argue with me.  
 — WHY DO YOU THINK I DON'T ARGUE WITH YOU  
 — You are afraid of me.  
 — DOES IT PLEASE YOU TO BELIEVE I AM AFRAID OF YOU  
 — My father is afraid of everybody.  
 — WHAT ELSE COMES TO YOUR MIND WHEN YOU THINK OF YOUR FATHER  
 — Bullies.  
 — DOES THAT HAVE ANYTHING TO DO WITH THE FACT THAT YOUR BOYFRIEND  
 MADE YOU COME HERE (Weizenbaum 1983)

ELIZA was an experiment in natural language processing, the application received the user's input, parsing it into units of meaning that it could manipulate, and consequently it assembled a response and presented it to the user. This response included the proper grammatical transformations that were necessary to maintain the illusion of a minimal fluency with language.<sup>262</sup> As Weizenbaum was always careful to note, ELIZA had no real understanding of the meaning of the user's inputs and of the answers it derived from them. It much less was able to properly follow a conversation or to have any sort of a real memory from past conversations, it was merely taking the input and "spinning it into a possible conversation". ELIZA was "a machine for generating conversations according to procedures" (Bogost 2007, 11).<sup>263</sup>

There are several anecdotes about occasions on which people communicated with ELIZA believing that the terminal was connecting them to a human counterpart, thus engaging in reasonable amounts of interaction without suspecting that they were talking to a piece of software that was not really able to understand the conversation (Suchman 2003, 608). Weizenbaum (1976) describes how at one point his secretary became so engaged on a conversation with ELIZA that she asked him to leave the room so that she could converse with the machine in private. As N. Katherine Hayles notes, this is all the more extraordinary because, according to Weizenbaum, his secretary was very aware that ELIZA was a piece of software and not a terminal connection to a human, and was also aware of how the program worked. Therefore she was not deceived by the illusion that the machine could in any way understand

<sup>262</sup> As an example, ELIZA searched the input for some keywords such as 'I am' or 'you' and used them as starting points for a series of precoded transformations, as is exemplified by the excerpt cited.

<sup>263</sup> This description stems directly from Weizenbaum's own words when denying the intelligence of his program and explaining it as being "a mere collection of procedures" (1976, 23).

her problems or the conversation that was happening (2006, 155). Weizenbaum was actually so concerned by the intensity of his secretary's engagement that he felt the need to issue a warning about how humans should not think that computers were able to make any ethical, moral, or political judgments — indeed any judgment at all — as in his view, judgment always requires understanding, a faculty that according to him only humans possess (155).

Weizenbaum's secretary and all the protagonists from the various anecdotes were perhaps the first people to experience what later Hofstadter called the 'Eliza effect', the unconscious projection of sentience, even intelligence, onto the mechanical system with which one interacts (Aarseth 1997, 130). As Hofstadter describes, due to the Eliza effect, people are led to feel that computers are able to understand the physical world, that they can make analogies, or they can reason abstractly, that they make scientific discoveries and that in general they are or can be insightful cohabiters of the world (Hofstadter 1995, 157). He defines the Eliza effect as the susceptibility of people to read far more understanding than is warranted into strings of symbols (especially words, because language is such a uniquely human tool) that computers can string together:

A trivial example of this effect might be someone thinking that an automatic teller machine really was grateful for receiving a deposit slip, simple because it printed out "THANK YOU" on its little screen. Of course, such a misunderstanding is very unlikely, because almost everyone can figure out that a fixed two-word phrase can be canned and made to appear at the proper moment just as mechanically as a grocery-store door can be made to open when someone approaches. We don't confuse what electric eyes do with genuine vision. But when things get only slightly more complicated, people get far more confused — and very rapidly, too. (158)

Hofstadter suspects that we are often tricked by the Eliza effect into finding applications of artificial intelligence or artificial creativity to be really intelligent or creative. According to him, a system like ELIZA, programmed with a complex grammar expressed formally and a reasonably long repertoire of words linked to semantic tags can achieve some pretty interesting and impressive outputs. Even if one just chooses the paths through the grammar randomly and constrain the choices by the semantic properties of whatever has already been generated, a trivial insertion

of semantics goes a long way in making written discourse appear to be superficially plausible (470).

Indeed, it may seem so plausible so as to not only engage people in interaction, and lead them to treat the interaction as if it was a real conversation, as it leads some authors to actually describe its experience as a proof that ELIZA may have passed the Turing test in a life-like situation (Grassmuck 1994) or as Weizenbaum himself describes “a striking form of the Turing test” (qtd. in Ariza 2009, 51). Regardless of these somewhat exaggerated claims, ELIZA is one of the early instances of successful interaction between human and machine, because it effectively exploited the natural inclination of people to find the sense of actions or patterns that are assumed to be purposeful or meaningful, what the sociologist Karl Mannheim<sup>264</sup> termed the ‘documentary method of interpretation’ (Suchman 2003, 609). In simple terms, this refers to the observation that people take appearances as evidence for, or the document of, an ascribed underlying reality, while taking the reality so ascribed as a resource for the interpretation of the appearance. In ELIZA’s case, the computer generated text was rationalized by the users on the grounds that there must be some intent behind them, an intent that may not be immediately obvious to the user playing the role of a ‘patient’, but that is nonetheless perceptible (609).

If, for example, one were to tell a psychiatrist “I went for a long boat ride” and he responded “Tell me about boats,” one would not assume that he knew nothing about boats, but that he had some purpose in so directing the subsequent conversation. It is important to note that this assumption is one made by the speaker. Whether it is realistic or not is an altogether different question. In any case, it has a crucial psychological utility in that it serves the speaker to maintain his sense of being heard and understood. The speaker further defends his impression (which even in real life may be illusory) by attributing to his conversational partner all sorts of background knowledge, insights and reasoning ability. But again, these are the speaker’s contribution to the conversation. They manifest themselves inferentially in the interpretations he makes of the offered response. (Weizenbaum 1983, 26)

The Eliza effect is viewed as a consequence of the natural and inevitable anthropomorphization of technology, sometimes regarded as perilous, as we can find in the

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<sup>264</sup> 1893-1947.

writings of the British neurosurgeon Geoffrey Jefferson<sup>265</sup> who saw a “new and greater danger threatening — that of anthropomorphizing the machine” (1949, 1110). We are accustomed to identify (or project) emotions into house pets or other animals and, as Jefferson predicted, we nowadays often anthropomorphize computers by also projecting emotions into them, by reading their behavior as being something other than purely mechanic things.

Hofstadter characterizes the Eliza effect as being a “virus that constantly mutates,” that reappears “over and over again in (...) ever-fresh disguises, and in subtler and subtler forms” (1995, 158) thus making it extremely difficult to objectively assess how successful are the implementations of artificial intelligence or creativity outside of the laboratory. ELIZA certainly made natural language conversation with a computer possible (Weizenbaum 1983, 23), provided one was willing to converse in the terms allowed by the program, that supplied the minimal building blocks for sustaining a conversation and, more importantly, caused the Eliza effect.

Weizenbaum also pointed to a fundamental shortcoming in the strategy used in the creation of the conversations:

ELIZA in its use so far has had as one of its principal objectives the concealment of its lack of understanding. But to encourage its conversational partner to offer inputs from which it can select remedial information, it must reveal its misunderstanding. A switch of objectives from the concealment to the revelation of misunderstanding is seen as a precondition to making an ELIZA-like program the basis for an effective natural language man-machine communication system. (27)

This is much like humans do when conversing, but as we see it, misunderstanding is only reached after the total lack of understanding is surpassed. In a sense, ELIZA did not misunderstand the conversation, because it simply did not understand it. The core of the Eliza effect may therefore perhaps be found in the concealing of the processes that create that lack of understanding, i.e., those processes that are fundamentally different from human processes but that nevertheless produce end results that are very operational and meaningful in computer-human interaction. Even if the processes developed in ELIZA have some similarities with the clinical process of

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<sup>265</sup> 1886-1961.

a therapist, they're nevertheless fundamentally different and, as such, cannot be easily understood by humans that are engaged in a conversation and that expect ELIZA to develop a similar engagement at all levels.

Christopher Ariza (2009, 51) describes how in what can be understood as a variant of the Eliza effect, very often surprise is confused with success. The surprise of discovering that a computational system was able to perform some feat that so far only humans could perform often leads to an overestimation by the observers of the phenomenon. The fact that a program does something is conclusive proof that it has the generative power to do so, that its structural and procedural constraints are, without doubt, rich enough to make such a computation possible (Boden 2004, 98). The same happens with the surprise of witnessing any totally unexpected outcome from a given process, something that, if we have Wolfram's principle of computational irreducibility in mind should not be totally unexpected in the first place. According to Ariza, this is one of the reasons behind some of the effectiveness of computer-generated art and music.

The Eliza effect can thus be described as the outcome of three different but complementary phenomena: 1) the anthropomorphization of technology, that has roots in the anthropomorphization of animals and inanimate things, whether natural or man-made; 2) the concealing of processes that are not relevant to the human-side of the interaction or may not be easily or directly understood by the human counterpart; and 3) the strong effect of surprise — or what we can also call of a “violation of expectation” (Barratt 1980, 292) — when using or interacting with a computational system.

Designers can aim to develop programs that really understand humans, that reason like humans and may even ultimately come to think as humans. But often, fostering the illusion of comprehension while providing signs that are readable by humans is not only enough, as it can eventually even be the best possible strategy to develop efficient and meaningful experiences in human-computer interaction. Although artificial intelligence or creativity can be successfully put to use in systems for artistic or communication purposes, their existence is not a prerequisite for the success of a system.

The Eliza effect is also related to a different experience of artificial creativity systems, something that can lead humans to mistakenly identify creativity in a system in much the same way as the Eliza effect leads one to see intelligence where it clearly is not present. ‘Comtivity’, or “complexity masquerading as creativity” (Cope 2005, 27) happens in systems where the level of complexity of the processes being developed exceeds the capacity of humans to understand those processes, or where the speed of the processes is too fast for these to be perceived correctly.<sup>266</sup> This may happen in relatively simple systems that make use of randomness or chance, as well as it may be identified in more complex systems like neural networks or genetic algorithms. Many of these systems are maybe capable of producing truly creative output, when they are adequately programmed to, but perhaps more often than not, when we regard them as creative, we are, according to Cope, being led to do so by comtivity masking the lack of true creativity. Cope defends that creativity does not need to be complex and that in fact, it often produces the simplest results, rather than the most complex (73), but maybe due to cultural factors, we tend to identify the most complex solutions as being creative and new, as being meaningful just because they openly display this apparent complexity that mesmerizes us.

### 1.5.7 Randomness and Creativity

The true literature machine will be one that itself feels the need to produce disorder. (Italo Calvino qtd. in Aarseth 1997, 129)

As we have previously seen, randomness can be useful for the creation of novelty with computers and can therefore be seen as an important aspect to consider in the achievement of creativity through artificial means. Jasia Reichardt (1971, 89) quotes German philosopher Max Bense’s<sup>267</sup> theory of generative aesthetics, based on computing procedures, that pointed out that randomness, used in the programming of computer graphics could replace those aspects of art that are usually described as being ‘intuitive’. Therefore, the randomizing procedures in code would be analogous to the artist’s intuition. Although this theory can be questionable, especially if exposed as simply as this, it nevertheless exemplifies an early attempt to find an

<sup>266</sup> We could draw an interesting parallelism to the threshold of perception that makes it possible for one to reconstruct moving images from a rapid succession of still frames, and maybe point to a threshold of cognition, that may make humans perceive sparks of intelligence or sentience where they do not exist.

<sup>267</sup> 1910-1990.

equivalence between human activities in the sphere of creativity and the realization of equivalent processes through cybernetic artifacts.

Much in the same way as intuition is not more than a part of creativity, in the context of artificial creativity, randomness may play an important role, but it is far from being the only resource needed or available. Actually, randomness by itself may very well be insufficient to achieve creativity and to produce interesting outputs. As Galanter suggests, perhaps even Mozart already intuitively felt that purely random processes do not generate good results, as his *Musikalisches Würfelspiel im C* already blends (however primitively) the order of the precomposed measures of music with the disorder of the randomness involved in their recombination (Galanter 2003, 14).

If Mozart had written his dice-game using random processes to determine the pitch and duration of every single note in the composition and not just the arrangement of preconstructed phrases, the construction of minuets with this system would be so improbable as to be utterly impossible (Boden 2004, 234). The precomposed bars supply the system with order and form, while the throws of dice inject in it randomness and novelty.

In order to have a coherent output, to have a *form*, we need to perceive a group of elements as a whole and not as the product of a random collection. As Abraham Moles<sup>268</sup> notes, a form is a message which appears to the observer as *not* being the result of random events (1966, 57). Messages that are totally random have no depth, although they certainly are very complex. A highly ordered message, like “0101010101...”, as low on complexity and void of novelty as it may be, can at least present the human observer with a regular rhythm, with a periodic reinforcement of the part of the message that constitutes its period (K. Kelly 2009a). It may not communicate much, but whatever little it does is structured and is therefore perceived as having intent.

Randomness is widely seen as being incompatible with creativity (Boden 2004, 234). The Oulipians, for example, having explored it in many works, came to conclude that no good would be generated by pure, unbridled chance (Berge 2003, 179), thus limiting (or altogether ceasing) its use in their creations.

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<sup>268</sup> 1920-1992.

The first known explicit argument against the usage of completely random processes in creation was exposed in 45 BCE by the Roman philosopher Marcus Tullius Cicero<sup>269</sup> in his book *De Natura Deorum*<sup>270</sup> in which Balbus the Stoic<sup>271</sup> presents the following argument against the atomists, who argued that the order of nature arose from the random collision of atoms:

I can't but marvel that there could be anyone who can persuade themselves that solid atoms moving under the force of gravity could construct this elaborate and beautiful world out of their chance collisions. If they believe this could have happened, then I don't understand why they shouldn't also think that if innumerable copies of the twenty-one letters of the alphabet, made of gold or what have you, were shaken together and thrown out on the ground they could spell out the whole text of the Annals of Ennius. I doubt whether chance would succeed in spelling out a single verse! (Cicero qtd. in Lloyd 2006, 57)

Many centuries after Democritus<sup>272</sup> and the atomists conjectured that the Universe was created from chance and randomness, a somewhat similar hypothesis was proposed by the Austrian physicist Ludwig Boltzmann,<sup>273</sup> himself also an atomist.<sup>274</sup> Boltzmann proposed that order could be generated completely at random in a universe that would, essentially, be random to its core. The theory in abstract is seductive, as much as the so-called *Infinite Monkey Theorem*, that in various alternative versions basically proposes that a monkey hitting keys at random in a typewriter for an infinite amount of time would almost surely type a given text by a sheer fluke or probabilistic inevitability, no matter how complex or long this text would be — the most common example that is given are the complete works of Shakespeare or the full text of one of his plays. But as it was often demonstrated, as seductive as it may be, this is a failed hypothesis. Typing totally at random, the monkeys would take an

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**269** 106 BCE-46 BCE.

**270** *On the Nature of the Gods*.

**271** Quintus Lucilius Balbus (fl. 100 BCE), a Stoic philosopher contemporary of Cicero and introduced in the dialogues of *De Natura Deorum* as the expositor of the opinions of the Stoics and of arguments to which Cicero gives a considerable weight and attention.

**272** ca. 460 BCE-ca. 370 BCE.

**273** 1844-1906.

**274** A stern defender of the atomic theory at a time when this scientific model was still very controversial.

inconceivable amount of time to produce anything as simple as a single verse from one of Shakespeare's plays, let alone a sonnet or a complete play.<sup>275</sup>

Even in an infinite universe, the hypothesis of total randomness would fail. If the order we see would be generated completely at random, then whenever we would be confronted with the existence of new bits of information, they would also be highly likely to be random and all experiences would probably become as useless and void of surprise (because totally nonsensical) as any book chosen from one of the shelves in Borges's *Library of Babel*. Our experience however suggests the opposite, that new bits revealed by observation of the universe are rarely totally random, indeed most of the exploration of the natural world reveals new but non-random bits (Lloyd 2006, 58). Democritus, the atomists and Boltzmann were therefore wrong, because total randomness alone is not at the core of the universe's processes. But so was Balbus the Stoic as described by Cicero, defending that the existence of complex and intricate patterns in nature was proof that an equally complex and intricate machine or intelligence would be generating them and that randomness could play no part in the process. As we have already seen, computers are simple machines, operating by recursively performing a small set of almost trivial operations and, despite their simplicity, they can be programmed to produce patterns of any desired complexity (59). And the programs that produce these patterns also do not need to be complex, as Wolfram demonstrated (2002, 301) nor they need to possess any apparent order themselves: they can be random sequences of bits.

The generation of random bits does play a key role in the establishment of order in the universe, just not as directly as Boltzmann imagined. (Lloyd 2006, 59)

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<sup>275</sup> According to Campbell, William R. Bennett, Jr., a Yale professor of engineering, calculated that if a trillion monkeys were to type ten keys a second at random, it would take more than a trillion times as long as the universe has been in existence to simply type the sentence "To be, or not to be: that is the question." (1982, 116). Of course that as this is a probabilistic assertion, it could very well happen that the sentence could be produced in the very first minute of typing, but the odds are infinitesimally slim, and we cannot also forget that if the monkeys would type with absolute liberty and total randomness, no matter how ordered or complex any given output had turned out to be so far, it would not guarantee that any order or complexity would follow. "No matter how far into *Hamlet* a monkey may get, its next keystroke is likely to be a mistake. In a universe where everything arises at random, our next breath is definitely our last, as our atoms immediately reconfigure to a random state." (Lloyd 2006, 179).

If randomness is not totally free and unrestrained but if it is limited by constraints or probabilities, then it can more easily produce structured results.<sup>276</sup> Campbell suggests that we look at the universe and the living forms it contains, as well as their predicaments, as being based on chance, but not on accident. This amounts to saying that forces of chance or randomness coexist with forces of ‘antichance’, or constraints, or probability, in a complementary and constructive relationship. “The

<sup>276</sup> Campbell (1982, 116-18) describes how Bennett also demonstrated that if the monkeys would not type at random but were instead forced to adhere to simple probabilistic rules — that could be incorporated in the system by for example doubling or tripling some of the keys in the typewriters so that the monkeys would in fact still operate with total liberty but would be more prone to strike a key such as *e* or *a* more often than e.g. *z* or *q* — they would, in minutes, not years or decades, produce passages containing striking resemblances to lines of Shakespeare’s plays. Bennett’s computer-simulated monkeys were provided with the twenty-six letters of the alphabet, the space and the apostrophe in proportions that were derived from a statistical analysis of the third act of *Hamlet* — creating a higher probability of certain letters being chosen more often than others, as in the play itself, where the four more common letters are *e*, *o*, *t*, and *a*, and the four least common letters are *j*, *n*, *q*, and *z*. The simulated monkeys still wrote gibberish, but their output already displayed a slight hint of structure:

NCRDEERH HMFMIOMRETW OVRCA OSRIE IEOBOTOGIM NUDSEEWU ...

Adding to these initial rules a further set of instructions coding the statistical likelihood of certain pairs of letters being formed and how likely each letter is to appear at the start and end of a word (or what is the likelihood of any given letter being paired with the space) improved the output, although it still mainly consisted of gibberish:

ANED AVECA AMEREND TIN NF MEP FOR’T SESILORK TITIPOFELON HERIOSHIT MY ACT ...

Bennett then programmed the statistical likelihood of triplets of letters, leading to outputs where half of the words were correct English words, although many of them were one-syllable obscenities (which led him to suspect that these are among the most probable sequences of letters used in normal language and that as such, swearing has a low information content!). Introducing four-letter sequences into the program led the number of gibberish words to drop to a mere 10% and to the production of one sentence (after only one night of production) with a curious resemblance to Hamlet’s soliloquy:

TO DEA NOW NAT TO BE WILL AND THEM BE DOES DOESORNS CALAWROUTOULD.

The successive steps of adding more and more statistical probabilities to constrain the random generation of the output were adding redundancy to the source of the messages, a redundancy that lowered the entropy of the message source at each stage, but always in different ways. When the simulated monkeys typed freely, the entropy (or in this context, the freedom of choice) was at a maximum, and so was the uncertainty of the reader, since she was unable to predict which letter would follow in the sentence. As the complexity of the programs rose, the freedom of choice became increasingly restricted.

Bennett did not proceed to consider the statistics for five-letter groups but as seen from the examples produced up to this point, the outputs acquired more structure and looked more familiar, even when the words themselves made no sense. They became more redundant and easier to predict, but the simulated monkeys still had a considerable freedom of choice in the keys they would select, although they did not have absolute freedom, as the program shifted the probabilities.

random element is called entropy, the agent of chaos, which tends to mix up the unmixed, to destroy meaning. The nonrandom element is information, which exploits the uncertainty inherent in the entropy principle to generate new structures, to inform the world in novel ways.” (1982, 11) We thus find how constraints are an essential part of any process in which order is of value, how for example thermodynamic systems are unable to do anything useful if all their parts are free to arrange themselves in any way whatsoever, because their entropy will be at a maximum and their energy inaccessible. In order to be able to do any work, the entropy of the system must be reduced, which means that the number of permitted arrangements of its parts will also be limited (174). We also find that random genetic mutations play an essential part in the evolution of species or in speciation (Boden 2004, 234), how living organisms share with Chomskyan language structures the property of not being able to assume any and every form. Rules encoded in the information system of the DNA are the grammar of the genetic language, but they are constrained by other rules at higher logical levels.<sup>277</sup> The grammar must always generate legitimate forms of life, at the risk of not succeeding in its main goal of replicating and perpetuating the genetic information (Campbell 1982, 174). This is what Bateson, when describing evolution, called a ‘stochastic system’, a system with two components — a random component and a process of selection working on its products or constraining its action (1979, 176) — or, elaborating, a combination of design, choice and chance (Kinder 2008, 60).

The ‘design’ to which Bateson alludes won’t necessarily be a set of constraints that are defined externally to the process by an external creator or machine (regardless of its intelligence) but rather the set of constraints that acts as a framework for choice and chance, as the possibility space. These constraints can either be laid out externally or they can evolve with the system, without such a thing as a creator in an ontological sense. Randomness acts within these constraints, and choice is also

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<sup>277</sup> One “could measure not only how small the system could be compressed (more compression = less complexity), but how long the compression would take to unpack (longer = more complexity). So while all the complicated variations, and unpredictable arrangements of atoms that make up a blue whale can be compressed into a very tiny sliver of DNA code (high compression = low complexity), it takes a lot of time and effort to ‘run’ out this code (high complexity). A whale therefore is said to have great ‘logical depth.’ The higher complexity ranking of a random number is shallow compared to the deeper logical complexity of a complicated structure in between crystalline order and messy chaos.” (Kelly 2009a) ‘Running’ the code in the DNA of a whale implies developing the entire cycle of insemination, gestation and birth of a new whale, and its growth, development until adulthood, its reproduction and ultimately also its death. The entire process would therefore last at least a few decades.

dependent on them. According to Boden, in these contexts, the various meanings of randomness that she mapped do not clearly divide between anti- and pro-creative randomness, as they can all be used creatively. When considering the example of genetic mutations, some mutations of single genes are clearly not A/E-random, as they are caused by chemical processes that affect the gene in accordance with known biochemical laws. Other mutations, however, can be considered to be totally or partially A/E-random: “If, as quantum physics implies, the emission of an individual X-ray is A/E-random, then mutations caused by X-rays are in part A/E-random too. If not, then they may be wholly deterministic.” (2004, 240) From the point of view of evolutionary biologists, and considering their interest in the creative potential of genetic mutations, it is not necessary to determine which of these is true. The important thing is that the mutations are R-random with respect to their adaptive potential — that is, a mutation is not caused by its hypothetical survival value (in an almost Lamarckian sense) but it is always caused in some other way, which may or may not be A/E-random (240).

When Wolfram notes that many systems, when initialized from totally random conditions, tend to spontaneously organize themselves and to produce behavior that has many features that are not at all random (2002, 223), we can find that this phenomenon happens when the system is embedded with a series of constraints that narrow the possibility space and that contain the initial randomness to a characteristic pattern or set of patterns. Ultimately, with class 1 or class 2 computational processes, the constraints are so strong, and the space of possibilities so narrow that a singular fixed state or a very regular pattern always emerges of the process, effectively erasing all the information that the random input injected in it. Class 3 computations would insert more randomness into the already random output and would therefore wipe out any information, replacing it with new information that is generated by the computation. In class 4 systems, the constraints enable far broader variation, allowing information from the initial conditions to be preserved, but nevertheless acting on it.

If the initial conditions can affect the development of the system, having some of its information preserved but also effectively intertwined with the information that is generated internally, then we can maybe consider a more reasonable (and maybe realistic) version of the infinite monkey theorem: not assuming that the monkey-produced randomness is present everywhere, at all levels of a system and at all times,

but rather that randomness can be injected into the systems at the initial conditions or through interactions during its development, thus affecting its outputs in both the short term and in the long run. Lloyd (2006, 179) proposes a more plausible explanation for the origins of complexity that can simultaneously provide us with some clues regarding the part of randomness in artificial creativity. He proposes that instead of having the hypothetical monkeys in typewriters, we would have them typing in computer terminals, so that their inputs would not be interpreted as alphabetic text — human language — but rather as code written in any given programming language. As when typing away randomly in typewriters, the monkeys would most likely produce gibberish and consequently the computers would produce error messages. But occasionally one of them would produce something more interesting. As when operating typewriters, the probability that any given monkey will produce interesting output, in this case, any given functional program, will decrease very rapidly with its length, as every single keystroke may undo what otherwise could be shaping up interestingly. But as Wolfram showed and Lloyd reiterates, short programs can produce a wide variety of interesting outputs, so a short sequence of characters, interpreted as executable code will have a much higher probability of producing functional and even interesting output than if we interpret it as any human language (180).

### 1.5.8 Algorithmic Information Content

The study of how likely it may be for a randomly programmed computer to produce interesting outputs started to be developed in the 1960s, and it is based on the idea of algorithmic information, a measure of how hard it is to represent a text bit or a string using a computer. The algorithmic information content of a text or a bit string is equal to the length, in bits, of the shortest computer program that produces that text or bit string as an output (2006, 180). For any number, the algorithmic information content is defined as the length in bits of the shortest computer program enabling the computer to print out that number as it will be (with variations) for any other output regardless of its type. In the beginning of the 1960s, Ray Solomonoff, Andrei Nikolaevich Kolmogorov,<sup>278</sup> and Gregory Chaitin independently discovered algorithmic information content, noting that in some ways it provided a more sat-

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278 1903-1987.

isfying measure of information than the length of a number in bits<sup>279</sup> because algorithmic information respects the intrinsic mathematical regularities of a number in a way that is impossible to grasp with the simple bit length (Lloyd 2006, 181).

The probability that a monkey, or any other random source of input, creates a program that would lead a computer to print out the first million digits of  $\pi$  is then called the ‘algorithmic probability’ of  $\pi$ , and as long programs are much less likely to be correctly produced than short ones, the shortest programs — however difficult they may be to produce by humans or by systems possessing any degree of intelligence — have the highest algorithmic probability. The shortest program that can output any particular number or result is therefore the most plausible explanation for how such result could have been produced. One of the immediate consequences of this, is that those numbers or other results that are produced by shorter programs, are more likely to appear as the outputs of random inputs than those results that can only be produced by longer programs (184).

Many beautiful and intricate mathematical patterns — regular geometric shapes fractal patterns, the laws of quantum mechanics, elementary particles, the laws of chemistry — can be produced by short computer programs. Believe it or not, a monkey has a good shot at producing everything we see. (184)

We can therefore very well be surrounded by algorithmically probable things, those that exhibit large amounts of regularity, structure, and order. If the typewriter monkeys would produce a universe of gibberish, the computer monkeys would, along with an inevitable amount of garbage, produce some interesting features (185) — and these, unlike nonsensical output, would maybe be able to perdure, as class 1, 2, 3 or 4 computations.<sup>280</sup>

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**279** The length of a number (or any other output) in bits is an alternative way to describe the output’s information content. Although apparently the simplest way to do so, in many cases it leads to unnecessarily long descriptions (and in some cases to infinite descriptions). A rational number can be described as a quotient of two integers, but, having an infinite decimal expansion (of repeating numbers), it can only be adequately described as this quotient, itself a process.

**280** When further debating this proposal, Lloyd leans towards a pancomputationalist philosophy: “What is required to make this explanation testable? For the computational explanation of complexity to work, two ingredients are necessary: (a) a computer, and (b) monkeys. The laws of quantum mechanics themselves supply our computer. But where are the monkeys? What physical mechanism is injecting information into our universe, programming it with a string of random bits? We need, again, look no further than the laws of quantum mechanics, which are constantly injecting new information into the universe in the form of *quantum fluctuations*. In the early universe, for example, galaxies formed around seeds — places

An even more plausible and simpler scenario can be imagined if the monkeys (or whatever the source of randomness is) are not required to type code (formed by some thirty or so discrete symbols) but are rather allowed to act inside a computation that is simpler than an interpreter of a programming language, like a two or three dimensional cellular automaton, randomly creating structures that are then developed according to the rules of the automaton.

### 1.5.9 Randomly Programming a Cellular Automaton

Programming a cellular automaton<sup>281</sup> is tantamount to changing the state of a cell or group of cells in the universe of the cellular automaton, therefore creating structures that may or may not affect other already existing structures, that may or may not survive or create new structures in the pool.

As with more conventional, text-based programming, random inputs will mostly generate gibberish, but in a cellular automaton this garbage will almost certainly die out and disappear in the space of a few generations or will create ‘still lifes’<sup>282</sup> that in the can future be affected by other patterns but that will otherwise remain static. If we use Conway’s *Game of Life*<sup>283</sup> as an example, most inputs that would create one, two or three cells in isolation would die within one generation, with the exception of the two cases in which three cells would either create a small period 2 oscillator

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where the density of matter was a tiny bit higher than elsewhere. The seeds of galaxy formation were provided by quantum fluctuations: the average density of matter was everywhere the same, but quantum mechanics added random fluctuations that allowed galaxies to coalesce.

Quantum fluctuations are ubiquitous, and they tend to insert themselves at the points where the universe is most sensitive. Take biology, for instance. You get DNA from your mother and father, but your exact sequence of DNA is produced by a process of recombination after the sperm enters the egg and deposits its genetic material. Just which genes from your mother get combined with which genes from your father depends sensitively on chemical and thermal fluctuations during the recombination process, and these chemical and thermal fluctuations can be traced back to quantum mechanics.

Randomness arises in the computational universe because the initial state of the universe is a superposition of different program states, each one of which sets the universe down a different computational path and some of which result in complex and interesting behavior.” (Lloyd 2006, 185-86)

**281** Not programming the rules of the automaton but rather creating programs that are run by the automaton.

**282** A still life is a pattern that does not change from one generation to the next.

**283** The *Game of Life* is not only one of the classic examples of cellular automata as it is among the most studied and well documented, since its creation in the late 1960s and especially after Gardner discussed it in several of his articles in the *Scientific American* magazine (1983), garnering a much wider audience of scientists, amateurs and enthusiasts.

— commonly known as a blinker — or an L-shaped structure known as a pre-block that evolves to a block in the immediate generation.

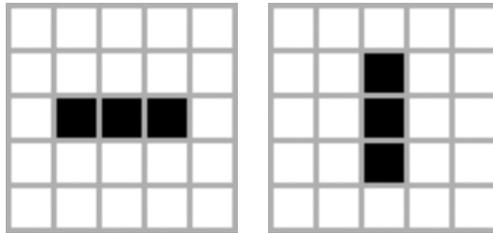


Fig. 52: Two stages of the three-cell blinker, an oscillating pattern of period 2.

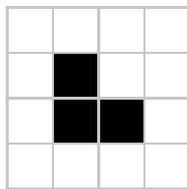


Fig. 53: Three-cell pre-block, a pattern that evolves to a block in one generation.

A four-cell random input would also in some cases create unstable patterns that would quickly die out or it could create static patterns such as the block or the tub, as well as patterns such as the T-tetromino, the tail or the grin that go through spontaneous transformations and become other static (or oscillating) patterns.

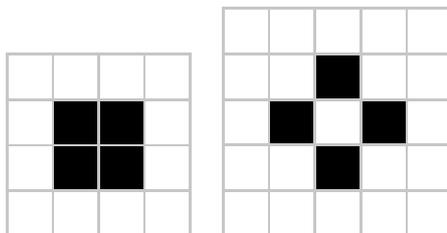


Fig. 54: Block and tub, two four-cell still lifes.

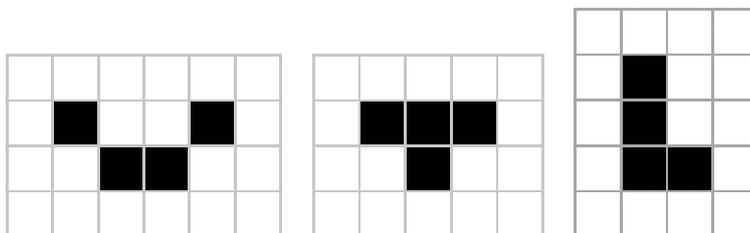


Fig. 55: Grin, T-tetromino and tail, two four-cell patterns that naturally evolve to other patterns. The grin becomes a block after a single generation, the tail evolves to a six-cell beehive (a still life) after three generations and the T-tetromino goes through a more complex nine-step transformation that results in a traffic light, a stable arrangement of four blinkers.

All of the patterns above are stable, able to indefinitely persist to the iterations of the environment if they are left undisturbed, that is, if no other patterns interact with them. They are also local, that is, unable to grow in area or to move around in the universe so as they can affect other areas of the automaton beyond the limited space where they are created. However, if the source of randomness generates patterns of five cells, it will only generate three possible types of stable patterns, from which one is a still life — the boat — but the other two — the glider and the R-pentomino — are very interesting examples of (far) more complex behavior.

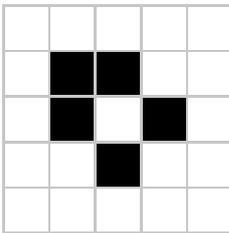


Fig. 56: The boat, a five-cell still life.

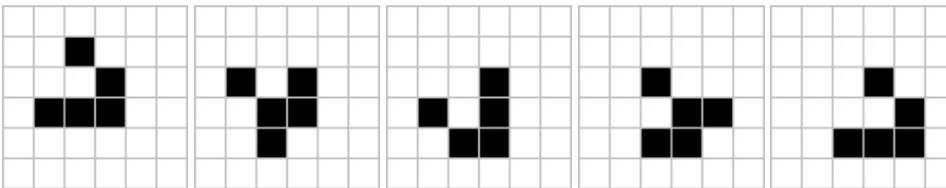


Fig. 57: Five generations of a five-cell glider.

The glider is the smallest pattern that travels through the *Game of Life* grid,<sup>284</sup> with a speed of  $c/4$ ,<sup>285</sup> and that unless disturbed travels forever. Gliders can collide with other patterns to form more complex patterns (or to destroy them, depending on the collisions) or can be collided with other gliders to produce new patterns, through a process called ‘glider synthesis’. They can also be used to transmit information over long distances.

<sup>284</sup> These traveling patterns are commonly referred to as ‘spaceships’, regardless of their dimensions, period or speed.

<sup>285</sup> In the *Game of Life* the speed of a pattern is a measure of the number of generations that it takes for a given pattern or effect to travel some given distance. Speeds are commonly measured as a ratio to the ‘speed of light’  $c$ , which is of one cell per generation and is the fastest speed at which anything can move inside the universe of the *Game of Life*. The glider moves one cell in the horizontal direction and one cell in the vertical direction after a full cycle of 4 generations, therefore its speed is measured as  $c/4$  (speed measurements use the maximum displacement in either the horizontal or vertical axis, not an average or the total of both). Conway has demonstrated that the horizontal or vertical movement of a finite pattern into empty space cannot exceed half the speed of light, or  $c/2$  (Gardner 1983, 220).

If just two of the five cells are placed in different locations, the random source can then generate the very interesting R-pentomino pattern, the first so far that does not develop a class 1 (as still lifes) or class 2 computation (as oscillators or gliders) but that, before stabilizing as a class 2 cycle of 25 different patterns, goes through what can be described as a class 4 stage during 1,103 generations.<sup>286</sup> During this lifespan the R-pentomino generates six gliders (starting at generation 69) that are released into three different directions, and several other patterns that interact with each other but that settle (when the stable form is reached) into 116 cells: 8 blocks, 6 gliders, 4 beehives, 4 blinkers, 1 boat, 1 loaf and 1 ship.

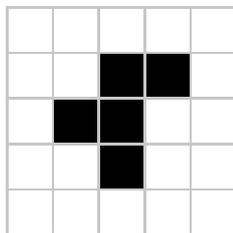


Fig. 58: The R-pentomino in the first generation, with the original five cells.

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**286** Patterns such as the R-pentomino, that take a long number of generations to stabilize — what is commonly called the pattern's lifespan — are also called 'methuselahs'. Gliders and other spaceships never stabilize, although they are class 2 in the sense that they develop a closed cycle, they travel through space so they are commonly referred to as being unstable patterns. The definition of methuselah is not completely agreed upon, but it is usually consensual that it should not be applied to patterns that grow forever (the growth of a pattern always refers to the number of cells in it, not to its area) or to patterns that start with a large number of cells. Gardner (1983, 246) defines methuselahs as patterns of fewer than ten cells that take more than 50 generations to stabilize, and the one with the longest lifespan under 10 cells is bunnies 10, that evolves for 17,423 generations, reaching a total of 1,749 cells. Lidka, starting with 13 cells, lives for 29,055 generations and breeds 1,623 cells: 135 blinkers, 102 blocks, 28 gliders, 18 loaves, 15 boats, 6 ships, 5 ponds, 2 tubs, 2 ship-ties, 1 toad, 1 beacon and 1 long boat.

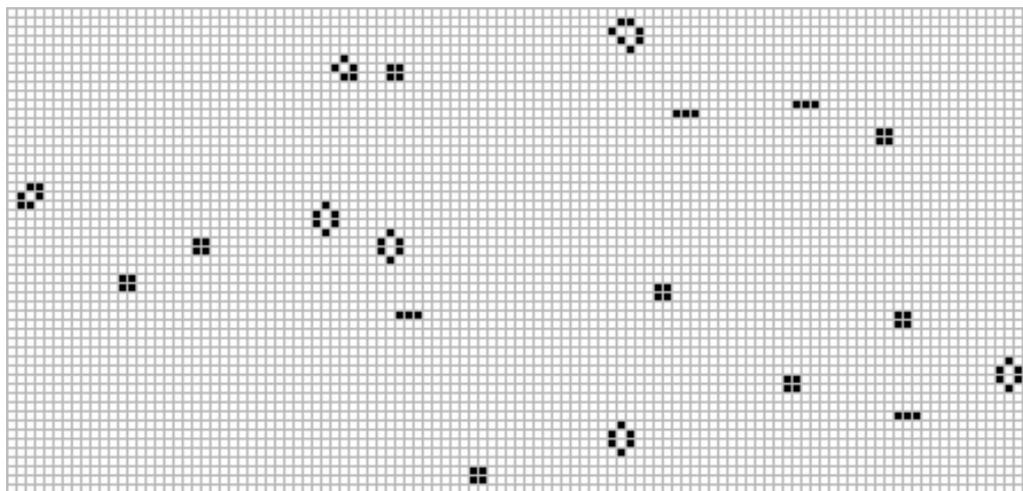


Fig. 59: The stable pattern that emerges from the R-pentomino after 1,103 generations, the 6 gliders released earlier are at this stage quite distant and are not shown on this grid.

These two patterns are capable of affecting other patterns in the most remote regions of the *Life* universe and through processes of glider synthesis are capable of producing many different structures ranging from other R-pentominos — that only require 3 gliders to meet at a precise angle and in their turn will produce six new gliders each — to far more complex structures. A single glider can have no noticeable effect on a structure, being destroyed upon collision, but it can disturb structures, interfering with them, breaking them down or destroying them, or transforming them in more complex structures, much in the same way (if the analogy is not too far fetched) as an individual X-ray can create a mutation in a strand of DNA. And as with DNA, these effects are not necessarily immediate, as they can evolve for thousands of generations.

Although the cells are the fundamental particles in the *Life* universe, the glider is the minimum unit of communicable information and, unlike Hamlet's verses, it is surprisingly easy to create randomly. The glider exists in a bounding box of  $3 \times 3$  cells that, if randomly set, have a very high algorithmic probability of  $1 / 32$  of generating a glider.<sup>287</sup> The same matrix of  $3 \times 3$  cells has an algorithmic probability of  $1 / 64$  of

<sup>287</sup>  $(1 / (2^9)) \times 16 = 16 / 512 = 1 / 32$ , as each of the nine cells has two possible states and within the  $3 \times 3$  grid there are sixteen possible layouts that can generate a glider.

randomly generating a R-pentomino<sup>288</sup> that in its turn, if undisturbed during its somewhat long evolution will generate six more gliders.

A thorough study of the evolution of random initial conditions<sup>289</sup> in the *Game of Life* (Flammenkamp 2004) did a census of the results of almost two million random seeds with an initial density of 0.375, finding more than 50 billion objects<sup>290</sup> and ranking them according to their frequency. This study found that blinkers, blocks and beehives were by far the most common patterns to emerge, with frequencies of 1/3.038, 1/3.094 and 1/5.230 respectively. As random initial conditions evolve, the universe tends to be dominated by blocks and blinkers in a ratio of approximately 2:1 and much later to develop simple infinite growth patterns<sup>291</sup> that eventually overtake the landscape. It is speculated that in the long run the *Life* universe can be dominated by self-reproducing patterns and eventually even universal constructors,<sup>292</sup> particularly if it is initialized from very low density soups.<sup>293</sup> The study only accounted for still lifes and oscillating patterns, giving us no statistics as to how many gliders or other unstable objects with interesting behaviors were initially generated.

We may then conclude that the random creation of ‘functioning programs’ in a cellular automaton like the *Game of Life* is not only possible, as it is relatively easy. We started from the hypothetical monkeys in typewriters, or the golden letters of Balbus, having to generate text that would be readable to humans. We then increased the odds by having the monkeys generate not human-readable text but rather com-

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**288**  $(1 / (2^9)) \times 8 = 8 / 512 = 1 / 64$ , as a R-pentomino has 5 cells in the first generation and 6 cells in the second generation, each with 4 possible arrangements in the  $3 \times 3$  grid. The probabilities are actually higher, as there are three 5-cell grandparents to the R-pentomino, that is, three patterns that will evolve to the R-pentomino in two generations, existing in matrices of  $3 \times 4$  and  $4 \times 4$  cells, and three 6-cell predecessors that evolve to the R-pentomino in five generations (and that exist in matrices of  $6 \times 3$  cells).

**289** A random initial pattern ideally covering all the surface of the universe of *Life* is commonly called of ‘soup’ or ‘broth’.

**290** 1,829,196 soups, 50,158,095,316 objects, classified into 3,798 distinct objects, of which 97.5% (3,703) were still lifes (Flammenkamp 2004).

**291** Infinite growth patterns are those whose population is unbounded, that is, where for any given number  $N$ , there exists a generation  $n$  such as the population in generation  $n$  is greater than  $N$ . The growth rate of infinite growth patterns is usually linear but several patterns exhibiting growth rates such as quadratic or logarithmic, were already discovered. The fastest possible growing rate of any life pattern is quadratic.

**292** Universal constructors are patterns that are able to build any other pattern that is constructible through glider synthesis, including, presumably, themselves. Universal constructors were never built but they were suggested by Conway, and he outlined the proof of their existence in *Winning Ways for Your Mathematical Plays* (Berlekamp 2001).

**293** Also known as ‘sparse soups’.

puter-executable code, typing small programs in C, Java, LISP or any other programming language. But we can increase them even more if our monkeys are led to program by interacting with a *Life* universe, not by manipulating twenty or thirty discrete symbols but simply by flipping bits in the matrix, turning dead cells into living or living into dead, zeros into ones or ones into zeros. Our happy hypothetical monkeys will have a much simpler task in hands and simultaneously they will have a much higher probability of achieving something other than gibberish with their efforts. They will be able to create (or to contribute to the creation of) bigger structures and to make their influence reach the far ends of the universe, regardless of where they are located.

### 1.5.10 Zooming Out

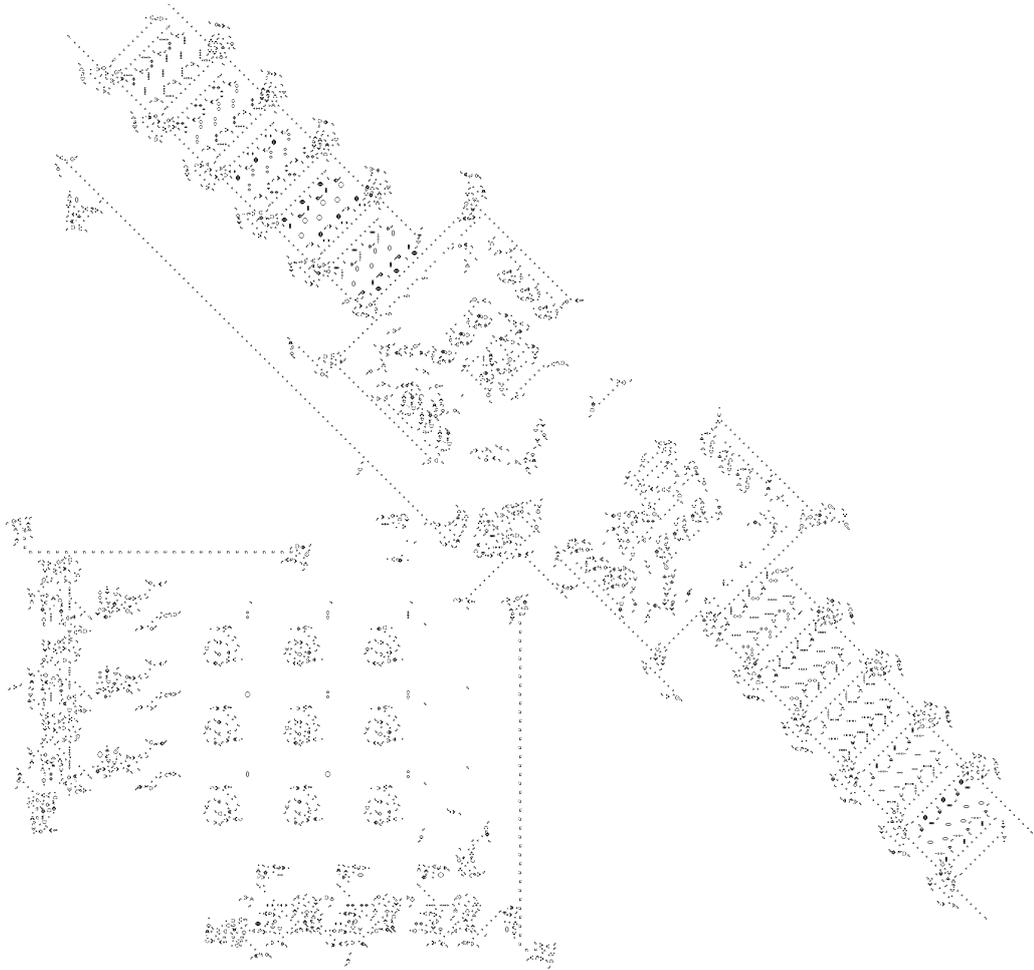
With all the examples given so far we focused on very small, rather ‘microscopic’ patterns in *Life*. If we assume a macroscopic overview of the *Life* universe, a five-cell pattern as a glider will be seemingly insignificant. There are several known patterns constituted by thousands of cells, such as the Turing machine, with 36,549 cells,<sup>294</sup> the spartan universal computer-constructor, with 481,672 cells,<sup>295</sup> or the caterpillar, with 11,880,063 cells.<sup>296</sup>

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**294** Created by Paul Rendell in 2000. The possibility of constructing a simulation of a Turing machine in *Life* was first raised by Conway himself, after the discovery of the glider gun, the first infinite growth pattern. The principle was based on using gliders as unit pulses for storing and transmitting information and to perform the required logical operations (Gardner 1983, 235).

**295** Created by Adam P. Goucher (2009).

**296** Created by David Bell, Jason Summers and Gabriel Nivasch in 2004 (Nivasch 2005).



**Fig. 60:** The Turing machine pattern in *Life*. This pattern is capable of Turing-complete computation and is infinite, as it requires an infinite length of tape to perform arbitrary computations.

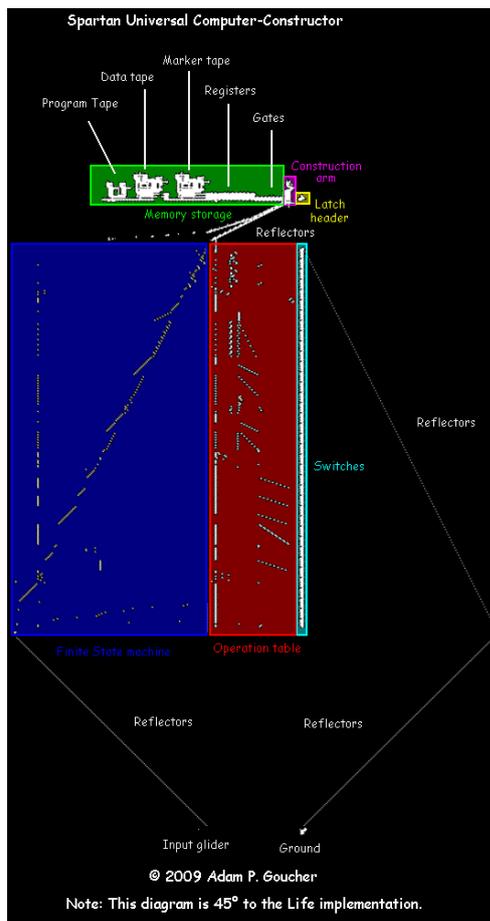


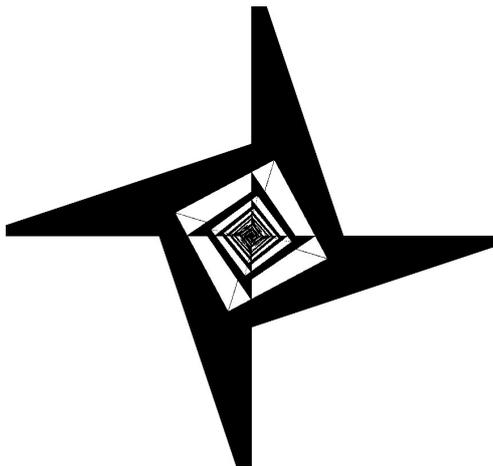
Fig. 61: The spartan universal computer-creator, an implementation of a universal computer, a *Life* pattern that can be programmed to perform arbitrary calculations and optionally to construct patterns according to the results of those calculations.

Although gliders and other small patterns exist in these macroscopic patterns, their sizes are so small when compared with the total size of the pattern that when zooming out so that it becomes possible to see the macrostructure, one effectively ceases to see the cells and the small scale patterns by themselves — they merge into a bigger gestalt, much like particles merge into atoms and these merge into macroscopic matter.

Both the spartan universal computer-creator and the Turing machine are macro patterns that are still intimately related to the smaller patterns, not only because smaller patterns are their building blocks (in much the same sense as the *Life* cells are the building blocks of the elementary patterns), as they are in one case dedicated to generating them while on the other they use them as inputs, outputs and registers.

Their forms are dependent of and oriented towards the smaller scale elementary particles.

In other cases we can find patterns whose form seems to exist at a fundamentally different layer than that of the cells and the elementary patterns. These are patterns whose development goes through very long and convoluted evolutive processes, patterns that are so complex that at magnification levels where the cells or any of the smaller structures are visible, no part of the overall structure of the macro pattern can be understood. An example of such a pattern can be seen in one Dean Hickerson's cloud constructions (Koenig and Greene 2009), a pattern that grows to a population that is orders of magnitude higher than any of the patterns discussed so far and that, growing continuously, starts to reveal itself only after a few hundred thousand generations. The macroscopic view of the Hickerson cloud reveals a geometric and nested arrangement of parts, with two very clear axis of symmetry.



**Fig. 62:** Overview of generation 1,984,750 of a cloud pattern constructed by Dean Hickerson in 2006. In this image the scale is  $2^{11}:1$  and the population is of  $5.83077 \times 10^9$ .

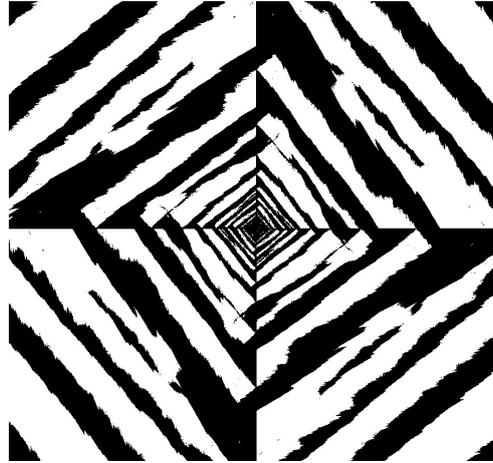
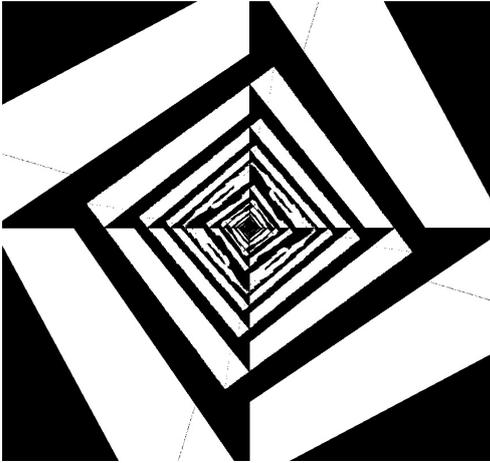


Fig. 63: Scale  $2^9:1$ , scale  $2^7:1$ .

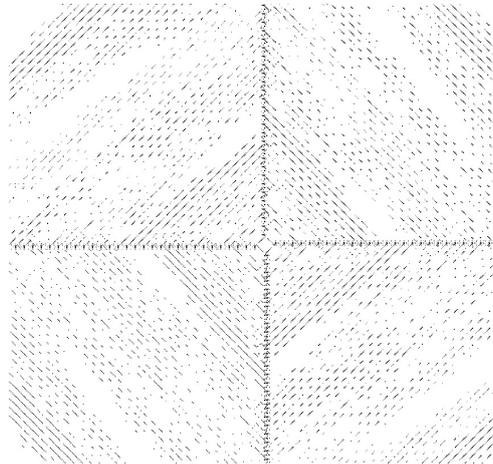
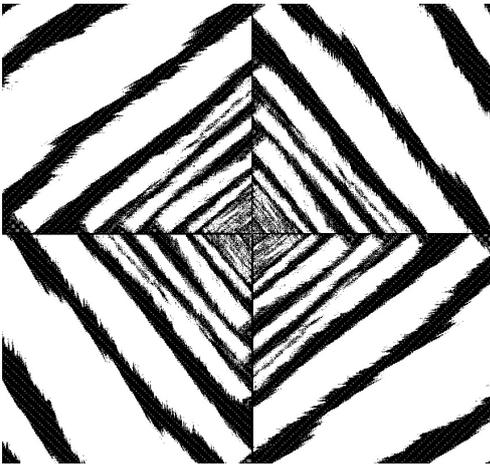


Fig. 64: Scale  $2^5:1$ , scale  $2^2:1$ .

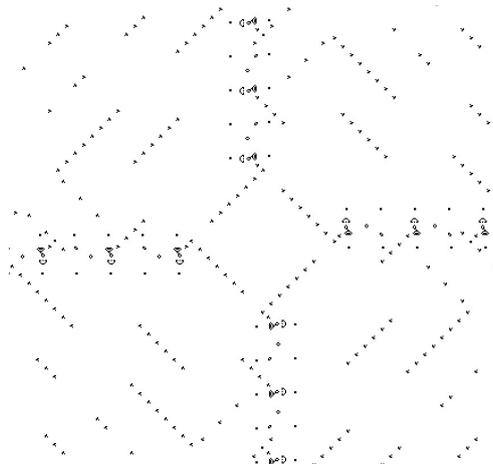
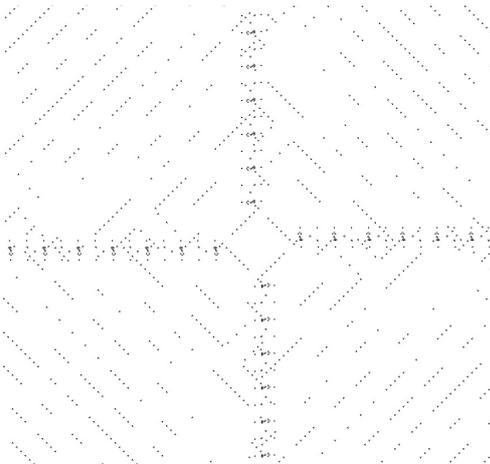


Fig. 65: Scale 1:1, scale 1:2.

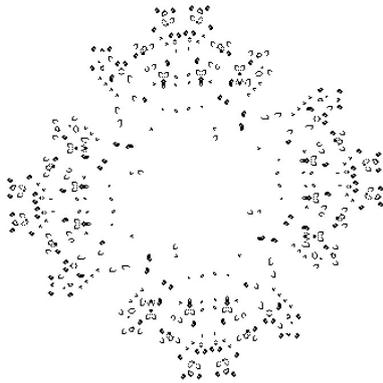


Fig. 66: The seed for the Hickerson cloud at scale 1:2. The initial population is of 3,708 cells.

As one zooms in on the structure, this apparent regularity starts to reveal some jagged edges and patterns that have a ‘furry’ quality and that, wasn’t it for the two axis that split the pattern, would otherwise look very organic. These symmetries along the vertical and horizontal axis are nearly perfect — due to the high complexity of the pattern, one is led to doubt whether the symmetry is total or simply apparent. Only after zooming in several more times will we find the gliders, reflectors and still lifes that are the basic structure of the cloud, at a level where, as we have seen, none of the macrostructure of the pattern is visible. This cloud can be read at three discrete levels of scale: a macro scale of  $2^{11}:1$  or higher, depending on the number of generations that the pattern has so far grown; a micro scale of  $1:1$  that allows the individual cells and small patterns to be seen; and a meso scale that in this case is in the vicinity of  $2^5:1$ , where the really interesting structures are perceived. Compared with the magnitude of scales in the physical universe, this range of values is still somewhat limited: at  $10^{-14}$  meters we have the nucleus of a carbon atom, or the quarks within it at  $10^{-15}$ , while the earth sits roughly at  $10^7$  meters, the solar system at  $10^{13}$  and our galaxy at  $10^{21}$  meters. Nevertheless, we can make a rough analogy with these scalar levels, and the previously mentioned human perceptual levels of scale in the physical universe, noticing how easily we can find a similar diversity and complexity in such an apparently simple system as the *Game of Life* is.

The macro and meso structures are moving and growing, although at a slow pace, if compared with the speed of light or with the speeds of the small patters. The structures that are perceived at the higher levels are traceable back to the behavior of the

small patterns, and these are obviously traceable to the rules of life itself<sup>297</sup> but, unable as we are to follow all the details of the process, we perceive it as emerging<sup>298</sup> from the original 3,7108-cell pattern, that can be seen as an autopoietic system.

If, with the exception of a few examples, the distinction between creativity and randomness had little relevance before the computational age, because random and creative behaviors seemed so distinct as to belong to totally different realms (Cope 2005, 51), we are now finding that, as the English pioneer in cybernetics Ross Ashby<sup>299</sup> pointed, no system (neither computer or organism) can produce anything new unless it contains some source of randomness or, as Bateson put it, “all innovative, *creative* systems are (...) *divergent*; conversely, sequences of events that are predictable are, ipso facto, *convergent*.” (1979, 174)

The examples of *Life* allow us to demonstrate how sources of randomness can create meaningful and operational outcomes inside of a computational system by acting at the micro level, with much more ease than they would otherwise if acting at the meso level, where traditionally (and intuitively) we imagined them to act. Random inputs will most certainly result in gibberish that will either be unstable and die out on its own or be stable and static, waiting in place to eventually be affected by other patterns sometime in the future, or to be incorporated in macro patterns. We can even conjecture that the computations of the *Life* universe exist in the micro level, the level of the cells and of the small patterns but that they may cease to exist, or to have such a strong effect at the meso and macro levels, much in the same way as particle interactions in the physical universe. We may speculate an analogy between the rules of *Life* and the fundamental physical laws, where two of the four forces act

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**297** Gardner notes that Conway chose the rules carefully, after a long period of experimentation, so that they would comply to three main criteria: 1) There should be no initial pattern for which there is a simple proof that the population can grow without limit; 2) there should be initial patterns that *apparently* do grow without limit; and 3) there should be simple initial patterns that grow and change for a considerable period of time before coming to an end in three possible ways: fading away completely (from overcrowding or from becoming too sparse), settling into a stable configuration that remains unchanged thereafter, or entering an oscillating phase in which they repeat an endless cycle of two or more periods (1983, 215).

**298** ‘Emergent’ in the sense proposed by John H. Holland, one of the first proposers of genetic algorithms: “when the activities of the parts do not simply seem to give the activity of the whole. For emergence, the whole is indeed more than the sum of the parts.” (2000, 14)

**299** 1903-1972.

only at the microscopic level, and new forces emerge with the scale and with the countless interactions between particles.<sup>300</sup>

Mozart did not compose his *Musikalisches Würfelspiel im C* by injecting randomness at every level of the composition, but had he chosen to do so, that wouldn't necessarily mean using randomness to directly define the pitches and durations of the notes in the composition as Boden suggested. Randomness could have been constrained by probabilities<sup>301</sup> so that it could influence the development of the composition, not merely the final order of the bars. Xenakis, perhaps the most famous of the computer music composers in the twentieth century, used similar systems in several of his compositions, for both electronic or acoustic instruments, developing what he called 'stochastic' music.

We tend to think of aesthetic objects as fundamentally being static entities, much like a painting, a sculpture and a photograph are after they are produced. The production itself is thought of as a process. This extends to time-based aesthetic artifacts, such as music, film, video and theatre, conceiving of every instance when humans are directly involved as a process, and all others (especially when they involve mechanical fixation or reproduction, whether analog or digital) as static entities. What we can discover through the *Game of Life* example, and if we generalize, from computational artifacts and the physical universe (regardless of how valid we think that the pancomputationalist hypothesis is), is that static objects are perhaps an exception, not the rule, and that they are perceived to be static<sup>302</sup> but are actually very

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**300** Conway speculated that in a sufficiently large randomly initialized universe, one could expect that by pure chance some self-replicating patterns could arise (either directly in the soup or evolving from this) and that those who would be best adapted to survive would live longer than the others (and, we may imagine, survive interactions with other patterns). As in organic evolution in the physical world, Conway imagines that most mutations would either be neutral to the pattern or harmful, but that the odd mutation would have some survival value. Conway then conjectures that "given a large enough 'Life' space, initially in a random state, that after a long time, intelligent self-reproducing animals will emerge and populate some parts of the space." (qtd. in Gardner 1983, 254) Lloyd also speculates that in a computational universe, the primary consequence would be the spontaneous generation of complex systems, such as life: "Although the basic laws of physics are comparatively simple in form, they give rise, because they are computationally universal, to systems of enormous complexity. Besides encompassing the Standard Model of elementary particles and leading at least part of the way to a theory of quantum gravity, the computational universe provides an explanation for one of the most important features of the universe: its complexity. In the beginning, the universe was simple. Now it isn't. So what happened?" (2006, 176)

**301** Had Mozart had access to the computational resources and literacy to do so, something of an impossibility at his time.

**302** Much like the Hickerson cloud at the  $2^{11}:1$  scale.

active processes at the microscopic levels.<sup>303</sup> All objects are processes, regardless of whether they are perceivable as such by humans.

### 1.5.11 The Lovelace Questions

Critical common sense would find the idea of an alien, machinic intelligence not only rebarbative but contradictory. Because humans program machines, machines must in principle be under the control of humans. The tacit assumption here is that it is impossible to make something autonomous. To think otherwise would be fetishism or reification and, in the case of computing, to subscribe to the dehumanizing effects of instrumental rationality. (Goffey 2008b, 135)

Although science fiction and even a certain common sense have for a long time populated the future of humanity with thinking machines, very often in the form of talkative quasi-human robots, and in spite of the Eliza effect, when considering the issue, most people tend to think of creativity and intelligence as being exclusively human attributes. Although we can regard creativity as a subset of intelligence, because of the value that historically and culturally we confer to creativity and creative people, we may often imagine that an intelligent computer or robot could exist, but we may think that an intelligent *and* creative computer or robot would be a much more difficult thing to create. If we can for example identify some degree of intelligence in some higher animals, we certainly do not imagine them as ever being creative or artistic,<sup>304</sup> as these are capabilities that we have learned to identify as being exclusively human.

Very often then, the idea that computers can create is regarded as being intrinsically absurd: computers can only do whatever they were programmed to do and in doing so they produce results that are inevitably determinist, therefore they cannot create (Boden 2004, 16). Much in the same way that cartesian dualism proposes a split

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<sup>303</sup> Or nanoscopic, picoscopic, femtosopic, etc. Within the very broad range of scales of the physical universe, one needs to think about more than merely three discrete levels of scale.

<sup>304</sup> Both creativity and artistic expressiveness have long been studied in animals, especially in mammals and within those in the great apes. One of the most famous studies, by the British zoologist and ethologist Desmond Morris, was published in his book *The Biology of Art* (1962). There are also several documented examples of the usage, invention or discovery of tools by animals, from birds using stones to raise the water in narrow tubes, to primates using sticks or stones as tools to reach otherwise inaccessible food.

between non-physical mental phenomena and the material body that is ‘animated’ by them, there is a generalized tendency to view machine intelligence or creativity as always being inherited from the human creator. Mark Halpern gives us an example of how this view is usually supported: “Machine intelligence is really in the *past*; when a machine does something ‘intelligent,’ it is because some extraordinarily brilliant person or persons, sometime in the past, found a way to preserve some fragment of intelligent action in the form of an artifact. Computers are general-purpose algorithm executors, and their apparent intelligent activity is simply an illusion suffered by those who do not fully appreciate the way in which algorithms capture and preserve not intelligence itself but the fruits of intelligence.”<sup>305</sup> (Halpern 2006)

According to Boden (2004, 16), the first person to publish this argument was Augusta Ada King,<sup>306</sup> Countess of Lovelace, commonly known as Ada Byron<sup>307</sup> or as Lady Lovelace. Lovelace was a friend of Babbage and she developed a keen interest in his project for the Analytical Engine. During the years of 1842-43, she translated a memoir from the Italian mathematician Luigi Menabrea<sup>308</sup> on Babbage’s Analytical Engine, a text to which she appended a set of notes that was longer than the original text itself. These included, in complete detail, a method for the calculation of a sequence of Bernoulli numbers that was later verified as having correctly run had the Analytical Engine ever been built. Due to this work, Lovelace is nowadays commonly credited with being the first computer programmer, and her published method as being the first ever published computer program. She is also said to have

<sup>305</sup> In some sense this reminds us of Wolfgang von Kempelen’s (1734-1804) chess playing machine from the late 18th century, commonly known as the *Turk* or the *Mechanical Turk*. This machine was built to the Empress Maria Theresa of Austria as an automaton that was capable of playing chess games against human opponents, but was many years later exposed as a hoax. The *Turk* consisted of a large base with three doors and a life-sized model of a human head and torso (dressed in oriental attire) facing a chessboard. The model could play chess games against humans and, according to accounts it outplayed the average chess-player, winning many of the games where it was presented. Three doors in the front of the base revealed all kinds of dummy very complex machinery that in reality hid a ‘director’ sitting inside the back two-thirds of the base that had a physical connection with the tray and controlled all the movements of the model, thus playing the game. Von Kempelen’s *Turk* convinced many of its observers of the possibility of machine autonomy and intelligence — although today, especially after *Deep Blue*, we don’t consider that intelligence (or at least a strong and general intelligence) is in any way necessary to be able to defeat a human in a game of chess — but its demise was perhaps the first of many demystifications of mechanical intelligence. Had it been conceived a few decades earlier, maybe the *Turk* wouldn’t have been presented as a mechanical automaton brought to life and reasoning through engineering and craft but perhaps it would rather be presented in a magical or mystical context.

<sup>306</sup> 1815-1852.

<sup>307</sup> Her maiden name, from her father, the English poet Lord Byron.

<sup>308</sup> 1809-1896.

published remarks where she foresaw the capability of computers to go beyond mere calculating functions, at a time when most people, including Babbage himself, focused exclusively on these capabilities.

Lovelace was convinced that the Analytical Engine was in principle able to “compose elaborate and scientific pieces of music of any degree of complexity or extent” (17). She however declared that the Analytical Engine had no pretensions to originate anything and that it could do only “*whatever we know how to order it to perform*”. It is not clear whether Lovelace merely intended to point that a computer’s actions are strictly dependent on its input and programmed code — an important remark on itself and especially at the time — or whether these words were intended as an argument denying any possibility for artificial creativity, in a precedent to the ‘intelligence in the past’ argument and Halpern’s position. The simplicity of the argument, if indeed this is an argument against artificial creativity, leads Boden to present four distinct questions, that are often confused with each other, and to which she calls the ‘Lovelace-questions’, because they address the possibility of artificial creativity and because many people would probably answer them with a dismissive ‘No!’ by using Lady Lovelace’s argument (17).

The first Lovelace-question is whether computational ideas can help us understand how human creativity is possible. The second is whether computers (now or in the future) could ever do things which at least appear to be creative. The third is whether a computer could ever appear to recognize creativity — in poems written by human poets, for instance. And the fourth is whether computers themselves could ever really be creative (as opposed to merely producing apparently creative performance whose originality is wholly due to the human programmer). (17)

Boden then proceeds to try to answer the four questions. Her answers to the first two questions are positive, for reasons we have also already discussed.<sup>309</sup> Boden’s answer to the third question is not so simple, as the question implies that in order to appreciate originality one needs at least some of the abilities that are required for creativity itself. Being creative requires a capacity for critical evaluation so it would seem that question three could only be answered after question four, but consider—

<sup>309</sup> She underlines that there are computer programs that arguably appear to be creative but that there are still no examples of programs that unarguably appear to be creative (Boden 2004, 17).

ing that the question does not concern “the practicality of computer-criticism, but its possibility *in principle*”, Boden also replies positively (20).

The first three Lovelace-questions concern scientific fact and theory, and they are closely interrelated. One cannot decide whether a computer could appear to be creative, or to evaluate creativity, unless one has some psychological theory of what creative thinking is. So someone who is interested in the first question (...) will probably be interested in the other two, as well.

The fourth Lovelace-question — whether computers can really be creative — is very different (and, for our purposes, less interesting). It involves controversial debate about metaphysics and morals.

It raises the problem, for instance, of whether, having admitted that we were faced with computers satisfying all the scientific criteria for creative intelligence (whatever those may be), we would *in addition* choose to take a certain moral/political decision. This decision amounts to dignifying the computer: allowing it a moral and intellectual respect comparable with the respect we feel for fellow human beings. (21)

As a consequence, Boden does not reply the fourth question, summing up that whether or not computers can be *really* creative, they can nevertheless do things that appear to be creative — and more to the point in the context of Boden’s research, we can better understand how creativity happens in humans by studying how it can be developed in computers (21). In the context of this work, however, an answer to the fourth question would be more important, given that we are not trying to study human creativity but rather the creative use of computers. Cope contends that computer programs can indeed create, defending the hypothesis that those who do not believe this may have probably defined creativity so narrowly that eventually even humans could not be said to create (2005, vii-viii).

### 1.5.12 The Lovelace Test

An example of how creativity is defined as a “special epistemic relationship” (Ariza 2009, 53) between creator, her creation and its creations, is the *Lovelace test*, proposed by Selmer Bringsjord, Paul Bello and David Ferrucci (2001). This test requires

a machine to be creative, defining the term in a highly restrictive sense, and trying to find evidence of creativity when a machine produces an artifact through a procedure that cannot be explained by the creator of the machine and when that artifact stands to the machine as this stands to its creator. Briggsjord, Bello and Ferrucci propose the following “rough-and-ready definition”:

Artificial agent  $A$ , designed by  $H$ , passes  $LT$  if and only if:

- 1)  $A$  outputs  $o$ ;
- 2)  $A$ 's outputting  $o$  is not the result of a fluke hardware error, but rather the result of processes  $A$  can repeat;
- 3)  $H$  (or someone who knows what  $H$  knows, and has  $H$ 's resources) cannot explain how  $A$  produced  $o$ . (8)

Naturally,  $H$  is permitted time to provide an explanation, and is allowed to investigate and study the system in any way they find necessary, including to analyze the learned or developed states of a dynamic system within  $A$ , backtracking the process of creation. The Lovelace test is thus designed to suggest that “the notion of creativity requires autonomy” and that “there may simply not be a way for a mere information-processing artifact to pass  $LT$ ” (25). It is safe to say that no known contemporary system has (yet) reached such a level of autonomy and that aesthetic artifacts produced by computers will continue to be seen as being fundamentally human works, or, if the role of the system exceeds that of a conventional tool, as human-machine collaborations, where nevertheless machine autonomy is not required (Ariza 2009, 64).

That is not synonymous with saying that computational systems cannot be made to act creatively within narrower fields of operation, or that a significant creative capability cannot be programmed in the context of a given artistic piece or design project.

### 1.5.13 Creative Systems

Trying to find a model for creativity that does not define it in such a narrow way as to make it actually (nearly) impossible to achieve, and not generalizing into a strong general artificial creativity but rather trying to understand its existence in aesthetic systems, Cope proposes an operational definition of creativity based in twelve principles:

- 1) Creativity relies on connecting differing but viable ideas in unique and unexpected ways.
- 2) Creativity does not depend exclusively on human inspiration, but can originate from other sources, such as machine programs.
- 3) Creativity should not be confused with novelty or comtivity.
- 4) Creativity does not originate from a vacuum, but rather synthesizes the work of others, no matter how original the results may seem.
- 5) Creativity relies in part on the juxtaposition of allusions to the work of others.
- 6) Creativity requires learning and knowledge in order to produce useful rather than arbitrary results.
- 7) Creativity occurs at every structural level.<sup>310</sup>
- 8) Creativity develops within enfolding and influencing contexts, and not in isolation.
- 9) In order for computer programs to create, they must themselves develop and extend rules, and not simply follow instructions provided for programmers.
- 10) Aesthetic creativity relies on creators, performers and audiences associating their experiences across a broad landscape of artistic and cultural tradition.<sup>311</sup>
- 11) Creativity depends on the integration of its various characteristics into a unified whole in which the sum is greater than the total of the individual parts.
- 12) Creativity depends on aesthetic values than themselves depend, at least in part, on the acceptance or rejection of others. (Cope 2005, 368)

To these we may add a set of five properties summarized by Dorin (2008, 294) in an attempt to evaluate the potential of the computer as a generator of patterns or signs that we may associate with art and on how to engineer programs that allow it to exhibit a creative ability. For Dorin, such a system must exhibit:

- 1) *Coherence and unity*, so as to maintain its identity over time, despite occasional perturbations (from within the system, the context where it is instantiated or its users). This property is useful to define the unique character of an art piece or aesthetic object, and it can be operationalized by setting a series of constraints or attractors that not only shape the object as, in a certain way, *are* the object. According to Dorin,

<sup>310</sup> Originally: “Creativity is not limited to note-to-note motions, but occurs at every structural level” (Cope 2005, 368). Cope’s book is dedicated to musical creativity in composition and performance, hence the detail in the formulation of the principle.

<sup>311</sup> Originally: “Musical creativity relies on composers, performers, and listeners associating their experiences across a broad landscape of music tradition.” (Cope 2005, 368)

for an artwork to be coherent, its components must be integrated in a way that is somehow natural or fitting, so that the artifact or artifacts that are produced can be identifiable as a unit (298). If there is some way of viewing even a complex or composite entity that results in an experience of a 'whole', of a 'unity' or what Alexander might have described as a 'center' (2002a), then the arrangement of the outcome of the process may be labeled as being coherent. Form, color, rhythm, behaviors or many other factors can either contribute to the coherence or to its lack, and the search for this balance can be developed through all of these (and more) variables.

2) *Multi-scaled temporal complexity*, so as to demonstrate complex dynamics over fine and coarse timescales. In a sense, any computational artifact is always a time-based object, regardless of whether it is conceived to produce signs that should be read temporally. Static images (photographic or otherwise) are in a certain sense exceptional outputs of computational systems, because they demand the 'freezing' of time and the (at least apparent) halting of the computation, something that unless it is the result of the 'natural' halting of a class 1 or class 2 computation must in principle be forced externally. A static image is also always the outcome of a temporal process and as such may reveal the process's temporal complexity. With some pieces the question is not whether time is frozen but rather that the temporal dimension of the output is unlimited a priori and the system is designed to run continuously, producing outputs that are read for a length of time that is defined by the reader, with a rhythm that is independent from that of the reader but that must be adjusted to its perception and to the context and constraints of communication.

3) *Autonomous production of novelty*, so as to explore large design spaces independently of human input or cooperation, but not necessarily independently of links to the external world. According to Dorin, a system that is capable of exploring novelty without human intervention must have a 'problem space' (or a conceptual space, if we follow Wiggins's terminology) within which humans are able to recognize the occurrence of original and creative outcomes (2008, 302). Within the range of possibilities in the parametrization of an aesthetic system, a very large (or, if we place it in the human scale, almost infinite) variety of outputs can be composed. However, the vast majority of these possible outputs, for a human viewer, will probably not be very interesting in themselves or not significantly different from the other possible outputs in the set. Within its conceptual space, the system needs to search for solutions that lead to sufficiently varied outputs, so as to create dynamic outputs. Dorin

points to nature's ability to generate an apparently open-ended variety of designs that may share certain characteristics but still differ sufficiently from one another so that humans can classify them as different things and different classes of things (303). Within a class of things<sup>312</sup> there is a diversity that is balanced by coherence and unity that interests and fascinates humans, there is a pattern and a rich set of variations within it that makes even new and never before seen variations feel familiar while innovative. It follows that the conceptual space must be broad enough for the system to successfully develop exploratory creativity: “[t]he key is in the choice of representation scheme, the subtlety of the outcomes it is capable of generating and in the ease with which this space may be navigated [by the system] from one interesting phenomenon to another whilst minimizing the occurrence of uninteresting outcomes” (303). There must therefore be at least an implicit measure of interestingness programmed in the system, something that has not been forthcoming, and the designer must also consider that if the system is able to generate *too* interesting results too fast then its experience may feel somewhat noisy or overwhelming to humans. One needs to establish a degree of familiarity with the user, using resources as repetition to reinforce, or even to define the idea of novelty (303). Dorin's remarks raise questions as to whether it may be desirable to endow aesthetic systems with transformational creativity, or if this — unlike conscientious exploratory creativity developed in the conceptual space (or problem space) of the piece — will contribute to a potential lack of coherence in the output of the piece. There is certainly no definite answer to this issue, because in many ways it would depend not only on contextual but also on conceptual considerations for every system or artist.

4) *Responsiveness to perturbation*, so that external events can influence its behavior in either deep or slight ways. Dorin identifies two desirable and inter-dependent properties of artistic systems, each of them relating closely to the role of the human interactor, depending on whether this may be an artist constructing a work or a user of the work that wishes to explore it (305). In either case the interactors will have some expectations that should be met or that the artist (or the system) may prefer to shatter. In the later scenario, the user will typically expect an interactive aesthetic object to have its output influenced in some perceptible way by the interaction, for the most part expecting a direct and immediate feedback, even if a complete direct control of the system is not possible and if some of the influences are deferred in time, only manifesting some time after the interaction. As with property 2, or rather, as

<sup>312</sup> Say shells, leaves, jellyfish, or, perhaps as the ultimate example of diversity, snowflakes.

part of it, the effects of the interaction can be distributed temporally, permitting a combination of influences in the system, where both an immediate impact and long-lasting effects that outlive the user's contact with the system can coexist (306). The former scenario is addressed by a fifth property that is added to the list, thinking not so much about autonomous machines that exhibit creativity but rather in creative computational helpers to human artistic production.

5) *Susceptibility to external control*, so as to permit the definition of further constraints on the behavior of the machine by the artist operating it. If implemented, this property would have effects at all other levels, allowing the creation of a number of variations of a system that could nevertheless have their own, and idiosyncratic, unity.

#### 1.5.14 Creative Human-Machine Collaboration

Considering the four essential properties of digital environments that Murray enunciated, one can ask if and how they can be creatively explored in aesthetic systems, or rather, if they can per se generate creative outputs in or from a system, or if, on the other hand, they always work in articulation, contributing to the creative behavior but not independently causing it.

We can also try to infer to what extent authorship and creativity are associated or indissociable in the context of aesthetic computational systems, to what extent the nature of the media affects our perception of authorship, as it was historically defined and understood in print and in traditional aesthetic media.

For Murray, what we discover in digital media is a procedural authorship (1997, 152), which she defines as the writing of the texts themselves, as in traditional media, as well as the writing of the rules by which the texts appear or make themselves be accessible to the reader (153), therefore, also as the writing of the rules for the interactor's involvement. This means that the author needs to establish "the properties of the objects and potential objects in the virtual world and the formulas for how they will relate to one another", creating "not just a set of scenes but a world of narrative possibilities". Murray compares the procedural author to a choreographer that supplies rhythm, context, and the set of steps that will be performed, leaving it then to the system or the interactor to make "use of this repertoire of possible steps and

rhythms to improvise a particular dance among the many, many possible dances the author has enabled” (153).

As Murray notes, when mentioning interaction, we cannot discuss aesthetic computational systems without considering participatory properties. As previously discussed, interaction usually denotes the articulation of the first two of the four properties: being procedural and participatory, and, even in those cases where the systems are clearly not directly interactive with their viewers, readers or users, the issue must nevertheless be considered because of direct or indirect interactions with other systems or between parts of the system.

In *Cybertext* (1997), Aarseth discusses how ‘interactive’, much as ‘computer generated’ are two concepts that are too unfocused to be useful as critical concepts (132). He states that what we usually call ‘computer literature’ (and by extension, what we call computer art, computer design, computer music) should more accurately be called ‘cyborg literature’ (or cyborg art, design, music), in Haraway’s sense (2004), because it merges artificial and biological intelligences (Rosenberg 1994, 268), processes, and creative forces. Cyborg literature (or cyborg art, design, music, or aesthetics) can then be tentatively defined as the creation of aesthetic products through “a combination of human and mechanical activities” (Aarseth 1997, 134). Consequently, Aarseth outlines the three main positions of human-machine collaboration, given any machine that produces text or any other aesthetic output.

*Preprocessing*, the first regime of collaboration implies the construction, programming, configuration or loading of the machine by humans, presumably leaving it then to run autonomously, without any further human intervention. The second position, *coprocessing*, implies the effective real-time collaboration of the machine and the human, producing outputs in tandem. This is the regime of a tool or an instrument, or of what can be called a fully interactive system like a computer game. Finally, with *postprocessing*, the human operator selects some of the machine’s outputs, while excluding others, effectively acting as a filter to the machine or making this act as a generator of elements to be composed. These three positions often operate together (pre- and co-, pre- and post-, or all of the three) although the human operator does not need to be the same in different positions (135). Based on an analysis of several cybertexts, Aarseth concludes that preprocessing is always present — there must always be an initial act of programming — but that coprocessing

and postprocessing seem to be almost mutually exclusive, what seems to suggest that systems that use coprocessing are usually found in different contexts and are used to different purposes than those that use postprocessing (135). In other cyber-arts it is not difficult to imagine that the three modes of processing can be present in the realization of the same output or piece, although at different moments. Taking music as an example, preprocessing can be developed during the programming of a system, coprocessing is developed while it is used for performance, and postprocessing happens when the outputs of said performance are selected and manipulated to achieve a linear (recorded) composition, when they are fed through the original system, being further transformed or even when they are worked on in a live, real-time context.

In the video works of the Austrian artist Lia, we can find that the three regimes of collaboration are developed in articulation for the production of the final pieces. Preprocessing takes place during the programming stage, where the system is developed for the generation of visual outputs, reacting to the musical input and to the performer's interaction.<sup>313</sup> In the next stage she uses the system to generate several video streams by repeatedly performing it in real time and recording the results of these performances as linear videos. Finally, all the outputs gathered from the performances are used as takes for the final editing of the audiovisual piece, a fairly standard process, not much different from the editing process of most audiovisual productions: mixing, cutting and overlaying different takes from the coprocessing stage. If the aim of the first two stages is the production of original moving images from the code, the preexisting music and the interaction, in the third stage the goal is to compose these images into the best possible temporal composition, not so much their transformation, or the creation of new images.

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<sup>313</sup> Lia usually programs in Director, Processing or openFrameworks, but the operation principle is independent from the particular programming language or platform used, and, despite some changes over the years, has been very consistent since the late 1990s, when she produced her first video works.

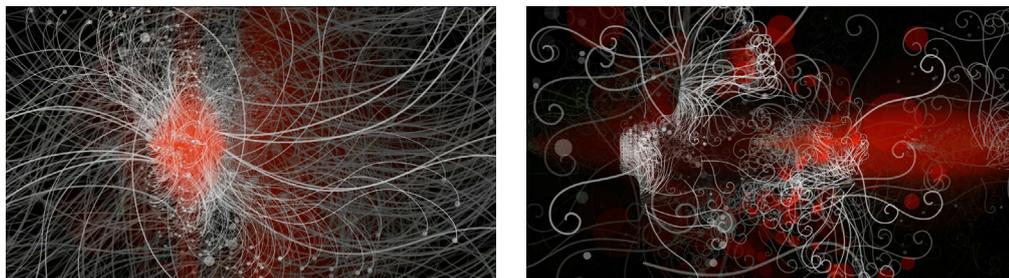


Fig. 67: *Construction 76* (Lia 2008a).

When performing live, only the first two stages are present in Lia's work. From pre-processed code that runs feeding on both the musical input and Lia's interaction, live video streams are generated.

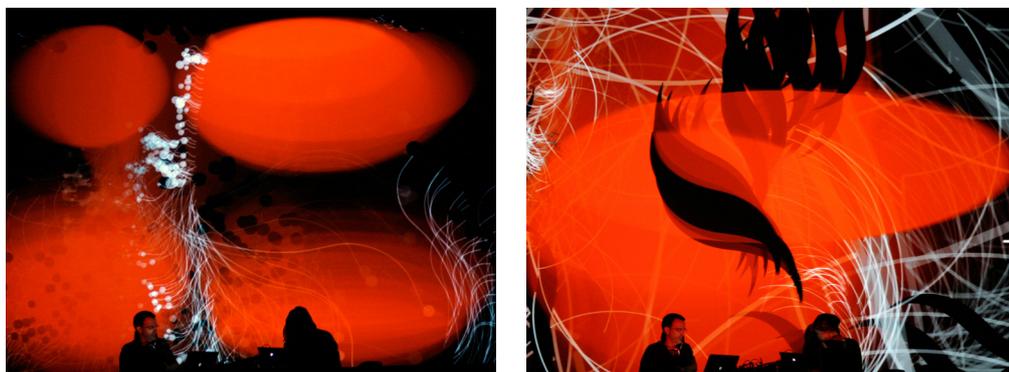


Fig. 68: Lia performing with @c at the European Media Arts Festival 2008 in Osnabrück.

In Aarseth's collaboration regimes, the human operators are always only partially in control, either because they can only operate in one of the regimes at any given time<sup>314</sup> or because even while operating the machine, some degree of control is intentionally removed from the human operator and passed on to the machine operator. Commenting on the new roles that computers started to serve in arts, Christopher William Tyler noted in 1976 that a possible definition of computer art would be that of art that is produced by the computer and that is also essentially out of

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<sup>314</sup> We can of course consider that there may be exceptions to this mutual exclusivity of collaboration regimes, as for example in live coding or in any other systems or contexts in which pre- and coprocessing can be developed simultaneously, but generally speaking we may agree with a principle of mutual exclusivity as proposed by Aarseth. Even in live coding we may speculate whether the pre- and coprocessing regimes are actually developed simultaneously or if on the other hand they are simply developed alternatively, given that programming is always a preprocessing act whereas interacting is a coprocessing act. When interacting through programming the artist is not really interacting with the running code but she is in reality changing the code that is or will be run, therefore she is developing an act of preprocessing.

control of its operator (1976). Art that uses the computer as a canvas, an environment and a tool, but also — and more importantly — as a cocreator or a coauthor of the artistic artifacts. Although the first three are without a doubt important factors to be considered, there's much more to be offered by the computer to art, when it is allowed to act *with* or *as* the creator, author or artist, both of the sensible pieces but also eventually of the program itself.

The computer can itself act as the creator by the ability to generate random (or pseudorandom) sequences of numbers. On a low level this can operate merely to produce the arrangement of patterns or the selection of elements for a design, and many computer artists have utilized this process to great effect. But in principle the random process can be used in the generation of the program itself; a metarandom organization of the generative process. In practice this is likely to lead to many programs which are inexecutable on a given computer system, but an analogous process operates in human creativity. Many false starts and abortive attempts may be made before a workable design is produced. (Tyler 1976)

Already in 1964, in an essay titled *Strauss and the Electronic Future* (1984b), Gould addresses the idea of multiple authorship as a result of the overlapping of the functions of the composer, the performer and the consumer or reader. Two years later, in *The Prospects of Recording*<sup>315</sup> he expands: “because so many different levels of participation will, in fact, be merged in the final result, the individualized information concepts which define the nature of identity and authorship will become very much less imposing” (1984a, 352). Gould recognizes how at the center of the technological debate of the time he found a new kind of listener, a listener that was more participant in the musical experience.<sup>316</sup> This new listener was no longer passively analytical, but was an associate of the composer, an associate “whose tastes, preferences, and inclinations even now alter peripherally the experiences to which he gives his attention, and upon whose fuller participation the future of the art of music waits.” (347) If “[f]orty years ago the listener had the option of flicking a switch inscribed ‘on’ and ‘off’ and, with an up-to-date machine, perhaps modulating the

<sup>315</sup> A text that dealt more directly with the evolution of the recording studio to an instrument, and of recorded music as an art form.

<sup>316</sup> According to Gould, the *listener as participant* was the single greatest achievement of the twentieth-century recording industry, that ultimately may have done more to transform the listeners than the artists or the music they have produced.

volume just a bit”, today, and due to the increasing variety of controls, one requires something more from the listener: analytical judgment (347). Recognizing that at the time those controls were still very primitive, Gould nevertheless believed that more advanced devices would in the future create a broader margin of intervention for the listener, thus diluting or sharing the responsibility in the final artistic artifact they enjoyed. At a point Gould referred to this new listener as a “threat, a potential usurper of power, an uninvited guest at the banquet of the arts, one whose presence threatens the familiar hierarchical setting of the music establishment” (347), but the tone of the article is nevertheless of enthusiasm, when thinking about the “evolution of the listener-consumer-participant” (350). Gould anticipated that the “venerable distinctions about the class structure within the musical hierarchy — distinctions that separated composer and performer and listener — will become outmoded” (351-52), although he didn’t think that this would necessarily contradict the growing specialization that took place since the Renaissance, leading to a return to the medieval status of the musician, “one who created and performed for the sake of his own enjoyment” (352).

This overlapping of professional and lay responsibility in the creative process does tend to produce a set of circumstances that superficially suggests the largely unilateral participation of the pre-Renaissance world. In fact, it is deceptively easy to draw such parallels, to assume that the entire adventure of the Renaissance and of the world which it created was a gigantic historical error. But we are not returning to a medieval culture. It is a dangerous oversimplification to suggest that under the influence of electronic media we could retrograde to some condition reminiscent of the pre-Renaissance cultural monolith. The technology of electronic forms makes it highly improbable that we will move in any direction but one of even greater intensity and complexity; and the fact that a participational overlapping becomes unashamedly involved with the creative process should not suggest a waning of the necessity for specialized techniques. (...) What will happen, rather, is that new participation areas will proliferate and that many more hands will be required to achieve the execution of a particular environmental experience. (...) The most hopeful thing about this process — about the inevitable disregard for the identity factor in the creative situation — is that it will permit a climate in which biographical data and chronological assumption can no longer be the cornerstone for judgments about art as it relates to environment. In fact, this whole question of individu-

ality in the creative situation — the process through which the creative act results from, absorbs, and re-forms individual opinion — will be subjected to a radical reconsideration. (352)

Gould was discovering the implications of coprocessing in aesthetic systems,<sup>317</sup> although the examples with which he interacted were certainly still a far cry from the procedural and the interactive systems that we are nowadays able to deploy. In the late 1960s, although interactive systems could be set and exhibited, the necessary resources for the creation and mass distribution of even the simplest interactive systems were still not available. He concludes the text with an optimistic note:

In the best of all possible worlds, art would be unnecessary. (...) The professional specialization involved in its making would be presumption. The generalities of its applicability would be an affront. The audience would be the artist and their life would be art. (353)

Of course that musical work, either live or recorded, was already, as Moles wrote, a “systematically collective” (1966, 138) endeavor. Music has “at least two authors who participate nearly equally: the composer, who furnishes the operating scheme, and the performer, who ‘realizes’ the scheme” (138). Only in a few special cases could one attribute a work to a single author, and more often than not, in the complex hierarchy of classical composition, or in the growing field of studio productions of popular music, authorship would be diluted by multiple participants. Studio composition would however allow the composer himself to manipulate the sound on magnetic tape, allowing him to dispense with score, conductor or interpreter, directly creating the final recorded (and reproducible) sound. But with the exception of live diffusions of these pieces, where the composer would also have a high degree of control over the acoustic qualities<sup>318</sup> of the space, the technological resources employed for the reproduction and amplification of the tape and the volume level of the playback, the actual instantiation of the piece — when for example reproduced in a home hi-fi equipment — would depend so much on the listener’s setup to make the listener an

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<sup>317</sup> And also pointing to what years later Lessig would name the ‘Read/Write’ culture that digital cultural tokens make possible (2008, 28) and that existed for a long time before music recording and other twentieth century’s electric media created and enforced a ‘Read/Only’, simple consumption culture.

<sup>318</sup> Or the ‘ambient’, as Gould defines it.

actual part of the process and the equipment or setup an instrument as important as any other.

Therefore, as Joyce defends, interaction, whether as simple as through the setting up and controlling of the diffusion conditions for musical recorded works, or as elaborate and complex as in Aarseth's coprocessing, breeds coauthorship (1995, 193). Under the light of the traditional authorship, that of the Renaissance, of the printed text, of the Baroque and Romanticism, coprocessing and procedurality may even seem to altogether remove the author from the equation, to 'kill' it — in Michel Foucault's or in Roland Barthes's sense (Sack 1996).<sup>319</sup> But as Murray (1997) shows, this question of authorship in formulaic media is not exclusive to computational media.

#### 1.5.15 Procedural Authorship

In the 1930s, Greek scholars were distressed when literary analysis revealed that Homer (and other epic preliterate poets) created through a process that involved fitting stock phrases and formulaic narrative units together. Critics at that time resisted the thought that the great artist Homer was not original in the same way that modern print-based writers are expected to be. Now, with the advent of computer-based authorship, we are experiencing the opposite confusion. Contemporary critics are attributing authorship to interactors because they do not understand the procedural basis of electronic composition. The interactor is not the author of the digital narrative, although the interactor can experience one of the most exciting aspects of artistic creation — the thrill of exerting power over enticing and plastic materials. This is not authorship but agency. (Murray 1997, 153)

The idea of authorship was born from the written word and, more specifically, from print. If writing separates the word from the speaker, removing "the authority of its

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**319** This issue was for example discussed by Pierre Boulez, in *Alea* (1991), a very critical text in which he concluded that the long term effects of the use of randomness or stochastic processes in composition would lead to the death of the artist or of the author. Boulez saw chance and randomness as a threat to structure, defending the author's choice over the handing of choice to the system, and apparently not understanding that chance and randomness and the development of stochastic processes imply a far more difficult choice and creative act, not the simple choice but rather the definition of the space of possibilities that will frame the choice, and the context in which this will operate. He asserts that chance "is fun to begin with, but one soon wearies of it, all the more quickly for its being condemned never to renew itself" (27), making us wonder whether his definition of chance in this context wasn't somewhat simplistic.

author, erasing the line of its paternity” and “making of it an orphan” (Wark 2007, 219), print removes knowledge from temporality, abstracts it and interiorizes the idea of authorship, of hierarchy and of authority (Joyce 1995, 93).

Under manuscript conditions the role of being an author was a vague and uncertain one, like that of a minstrel. Hence, self-expression was of little interest. Typography, however, created a medium in which it was possible to speak out loud and bold to the word itself, just as it was possible to circumnavigate the world of books previously locked upon a pluralistic world of monastic cells. Boldness of type created boldness of expression. (McLuhan 1964, 193-4)

Print encouraged a sense of closure, a sense that what is found in any printed text had been finalized, has been developed to a state of completion. According to Ong, this sense affects literary creations, as well as analytical philosophical or scientific works (1982, 129). It also affects other media, developed after print and the printed book: cinema and recorded music, to name just two, are linear media from which we have come to expect the same completion, the same sense of closure, the same representation of “the words of an author in definitive or ‘final’ form” (130). The book is authoritative, complete, immutable, untranslatable even, because translation is an act of transformation and as such it is an interference with the authorial voice. Evolved from mechanical reproduction, books are analog tokens, sharing limitations that were common to all analog tokens, limitations that prevented copying and manipulation of their contents.<sup>320</sup> As Lessig so well puts it, (2004; 2006; 2008) the *code* of these analog tokens constrained the ways in which they could be accessed and or manipulated. All analog media shared these limitations in some way, and all of them, in some way, inherited from the printed book the role and hierarchical stand of the author. The introduction of digital technologies and media, however, brought us to what Bolter called the ‘late age of print’, when books and analog tokens slowly started to give way to fundamentally different digital tokens and to be effectively phased out by these.

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**320** “For most of the twentieth century, these tokens were analog. They all therefore shared certain limitations: first, any (consumer-generated) copy was inferior to the original; and second, the technologies to enable a consumer to copy an RO token were extremely rare. No doubt there were recording studios aplenty in Nashville and Motown. But for the ordinary, R[ead]O[nly] tokens were to be played, not manipulated. And while they might legally be shared, every lending meant at least a temporary loss for the lender. If you borrowed my LPS, I didn’t have them. If you used my record player to play Bach, I couldn’t listen to Mozart.” (Lessig 2008, 37)

In this late age, print (and all the print-like analog cultural tokens) remains indispensable, but, according to Bolter, it “no longer *seems* indispensable” (2001, 2), something that places these media in a very strange condition. Books<sup>321</sup> become obscure pleasures whose time has passed (Joyce 1995, 97), they do not lose their intrinsic value but cease to be the role models or examples for the media to come. Simultaneously, almost conversely, they are the structural models or the foundations over which the new media incunabula<sup>322</sup> are being developed. Printed books and media are still providing much of the raw materials and the stylistics for what are still the first stages of hypertext publishing (Landow 1994, 23), much in the same sense as physical, analog, sound recordings are providing them for digitally created and distributed music, cinema, television and video to digitally created animated images or audiovisuals, and plastic arts to many digitally created artworks. All of them are providing the idea of the author, even when this single top-down creator is perhaps not much more than a very relative notion at best, or a fiction,<sup>323</sup> in the worst case.<sup>324</sup>

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**321** And by extension, analog tokens of any sort, like printed matter, vinyl discs, magnetic tapes, most broadcasts except in a few scenarios live broadcasts, etc. As Joyce so elegantly puts it, “We live, you and I and our students, in (...) the late age of print. [Where] we are washed first with the four a.m. or fin de siècle sense of lateness, but then, belatedly, comes the undertow, the departed sense of the late, dead, lamented; what we do not want to see go and yet value all the more in the parting. In the late age of print, printed books flash through the culture, disappearing into the ether with the speed of electrons.” (Joyce 1995, 93)

**322** “In 1455, Gutenberg invented the printing press — but not the book as we know it. Books printed before 1501 are called incunabula; the word is derived from Latin for swaddling clothes and is used to indicate that these books are the work of a technology still in its infancy. It took fifty years of experimentation and more to establish such conventions as legible typefaces and proof sheet corrections; page numbering and paragraphing; and title pages, prefaces, and chapter divisions, which together made the published book a coherent means of communication. The garish videogames and tangled Web sites of the current digital environment are part of a similar period of technical evolution, part of a similar struggle for the conventions of coherent communication.” (Murray 1997, 28).

**323** Highly collaborative media like cinema or videogames, or crossmedia enterprises like media franchises, developing across cinema, recorded music, literature, videogames, comics, television, World Wide Web and whatever other media they can spread to, can hardly be considered to be individual creations, or even as the creations of a small group of authors working cooperatively. There are certainly producers, directors, writers, actors, cinematographers, sound designers, composers, performers, set designers, art directors, creative consultants, and several other specialists that provide creative inputs along the process, but the totality of the output or outputs of such endeavors cannot be attributed to the authorship of a single individual or identifiable group of individuals, rather it should be seen as the outcome of modes of production that in some ways can be described as being corporate enterprises but in some others can perhaps be best described as creative societies (regardless of whether or not there are corporate interests involved).

**324** Analog media are also somehow expected to provide the economic and legal models for the new and emerging digital media, although as it would be expected, these haven’t always proved to be adequate, as was discussed, among others, by Barabási (2003), Lessig (2001; 2006; 2008) and Anderson (2009).

In the late age of print, as we discover an era of collective intelligence, we start witnessing several changes in the traditional roles of cultural, artistic and media production. These are changes in the relations that are established between the authors and the readers, the producers and the spectators, the creators and the interpreters. All these roles are fusing into a circuit of expression, what Lévy calls a ‘cultural attractor’ in cyberspace (1997, 121), that can be summarized as follows: 1) Messages now revolve around the individual receiver — the opposite of the situation of the previous mass media — regardless of their typology and orchestration; 2) Roles blend into a reading-writing continuum, extending from machine and network designers to the ultimate recipients, each helping to sustain the activity of others, thus diluting the signature or the authorship; 3) The distinction between the message and the work of art fades. What was previously envisaged as a micro territory attributed to an author is now subject to sampling, mixing and reutilization (121) under a Read/Write logic of operation.<sup>325</sup> Changes also happen at the level of the traditional division of art into genres, which, one could argue, is becoming progressively pointless in cyberspace. “Through transmitting onto the internet, everything is sampled into a digital version, which accentuates some of its attributes and other (traditional) lose significance. Hypertext, net-art and new forms of art, the process of cut, paste, rip and remix are natural information patterns of behaviour. Freedom of interconnection of anything crashes linear ways of expression and thinking. Interactivity wipes out and reverses the roles of author/audience.” (oRx-qX 2008, 43) Robert Milthorp notes that in the cyberspace of the foreseeable future, both the notions of what we recognize as originality and authorship are problematic. They are not only subject to the nature of ownership of the technologies, the networks or other applications but, in a culture that is characterized by the proliferation of images, the attachment to the blank page as a symbol of imagination and creativity that was the heritage of nineteenth-century art, the creation *ex nihilo*, has started to be abandoned by contemporary creators. As he sees it, both in life and in art, image-making (and creation in general) is now “characterized by pastiche, construction and deconstruction, appropriation and alteration of existing images”, and the “romantic notion of authorship is now mediated by the demands of a culture in which images, like information, are currency.” (Milthorp 1996, 144)

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<sup>325</sup> “Depending on the emerging pragmatics of creation and communication, a nomadic distribution of information will fluctuate around an immense deterritorialized semiotic plane. It is therefore natural that creative effort be shifted from the message itself to the means, processes, languages, dynamic architectures, and environments used for its implementation.” (Lévy 1997, 121)

Lévy also points to how some of the questions that have been asked by artists since the end of the nineteenth century will become even more urgent in this late age of print, with the emergence of digital technologies and cyberspace. These are questions that are directly concerned with the question of the frame of the work (and therefore also of the artist's or author's work): "the limits of a work, its exhibition, reception, reproduction, distribution, interpretation, and the various forms of separation they imply" (1997, 122). He thinks that under the circumstances of the ongoing shift, an extreme form of deterritorialization cannot be contained and that a leap into a fundamentally new space will be required. Under the light of the mutations in the socio-technical environment in which works of art and aesthetic artifacts are produced and distributed, will it still be reasonable to even speak of a work of art in the new context?

For the past several centuries in the West, artistic phenomena have been presented roughly as follows: a person (artist) signs an object or individual message (the work), which other persons (recipients, the public, critics) perceive, appreciate, read, interpret, evaluate. Regardless of the function of the work (religious, decorative, subversive, etc.) or its capacity to transcend function in search of the core of enigma and emotion that inhabits us, it is inscribed within a conventional pattern of communication. Transmitter and receiver are clearly differentiated and their roles uniquely assigned. The emerging technological environment, however, will encourage the development of new kinds of art, ignoring the separation between transmission and reception, composition and interpretation. Nevertheless, the ongoing mutation creates a realm of the possible that may never be realized or only incompletely. Our primary goal should be to prevent closure from occurring too quickly, before the possible has an opportunity to deploy the variety of its richness. With the disappearance of a traditional public, this new form of art will experiment with different modalities of communication and creation. (122)

Rather than using the computer as a remediator, a mere simulator or a playback device for traditional media assets like sounds, moving or still images, artists and designers are starting to discover the computer's use to create native computational forms, such as hypertexts, games or other procedural artifacts (Mateas 2005). Rather than distributing a message to recipients that are outside the process of creation and that are invited to give meaning to a work of art or aesthetic message only

belatedly, artists and designers now attempt to construct environments, systems of communication and production, collective events that imply their receivers and that transform interpreters into actors (Lévy 1997, 123). Umberto Eco's 'open work' (1962) prefigures such an arrangement, where the recipients are invited, even required, to fill in the blanks, to choose among possible meanings, to confront the divergences among their interpretations, magnifying and exploring the possibilities of the unfinished work. But according to Lévy, "art of implication doesn't constitute a work of art at all, even one that is open or indefinite", it rather brings forth a process and places us, the readers, receivers, spectators, interactors, wreaders, within the creative cycle, a "living environment of which we are always already the coauthors" (1997, 123).

#### 1.5.16 Open Works

In the *Opera Aperta*, Eco argues that literary texts are fields of meaning, rather than strings of meaning, and that they should be understood as being open, internally dynamic, and psychologically engaged. Once that words do not have simple lexical meanings but rather operate in the context of utterance, the most lively and more rewarding texts are those that are open and most active between mind and society and life, rather than the closed texts that limit their potential understanding to a single, unequivocal line. Eco saw every fruition of a work as a simultaneous interpretation and execution, because every reenactment, reading or experiencing of the work relives it in an original perspective (1962, 68), but he also noted how works as Berio's or Stockhausen's are 'open' in a less metaphorical and far more tangible sense, because they are to some extent, unfinished pieces (68). This implies a fundamental understanding (and empowering) of the performer and her role but also of the audience of the work and their role as readers and interpreters. Artists from past historical periods were certainly far from being creatively conscious of this reality, while contemporary artists, on the other hand, not only embrace this openness as an inevitable fact as they also choose it as a productive program and present it in ways that actually maximize it (69).

Creators present their audiences with works that are waiting to be finished. Works that demand to be finished, but that are designed to prevent closure from occurring too quickly (Jenkins 2006, 97). The creators do not know how the work will be fin-

ished but according to Eco (and Murray) they know that once the work is finished,<sup>326</sup> however it is finished, it will always be *their* own work, not another work. In the end of the interpretative dialogue, the form that is built is the creator's form, although it is organized in a way that the creator could not have predicted, because it was the creator that proposed the possibilities, organizing them, orienting them and endowing them with the organic capabilities of development (Eco 1962, 90).

Eco defines open works in movement as characterized by the invitation to execute the work with the author — an invitation to “active design”, according to Joyce, to the participation in an evolving narrative that is written whether by reader or writer (1995, 193). There are works that although physically concluded, nevertheless remain open to a continuous germination of internal relations that the audience must discover and choose in the act of perceiving the totality of the perceivable stimuli, and every work of art, even if produced according to an explicit or implicit poetics of necessity is substantially open to a virtually endless series of possible readings, each of them leading the work to be relived according to a perspective, a taste, a personal execution (Eco 1962, 91-92).

Open works are works in progress. And they are certainly works where, as Lévy notes, the accent has shifted to *progress* (1997, 123). Works whose embodiment is manifested in movements, places, collective dynamics, but no longer in individuals. They are “art without a signature” or art with multiple signatures. They are, we could add, works in process, where the accent has shifted to the *process*. According to Lévy, the classic work of art is a gamble, and the more it “transmutes the language on which it rides, be it musical, plastic, verbal, or other, the more its author runs the risk of incomprehension and obscurity”. The larger is the degree of change or fusion to which its language is subjected, the larger the stake, the greater is the potential gain: “the creation of an event in the history of a culture” (123). However, a work is open as long as it is a work, as long as the boundaries of the possibility space are defined and recognizable, as Eco underlines. Beyond this limit, the openness is noise (Eco 1962, 194).

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<sup>326</sup> Or deliberately left open by the audience, something that is in itself also a closure and conclusion, when the reader decides to terminate the reading experience by halting it at a given point, regardless of whether the author would find this to be an adequate point of conclusion. But closure is also, in a sense, determined by the design. Not by the design of the artwork but by the mechanics of the medium, that may or may not allow the interruption of the experience at the user's discretion.

### 1.5.17 Process Intensity

Trying to describe the relationship between computation and media assets, Chris Crawford introduced the term ‘process intensity’, described as the ratio of computation to the size of the media assets that the system manipulates (Mateas 2005) or the degree to which a program emphasizes processes instead of data. Higher process intensity — or as Crawford puts it, a higher “crunch per bit ratio” — suggests that a program has greater potential for meaningful expression (Bogost 2008, 122). If a computational aesthetic artifact primarily triggers media playback in response to interaction, it has a low process intensity, as the code is doing relatively little work, transferring existing information from the hard drive or server to the visual or aural interfaces with the user. As the artifact manipulates and combines these media assets, its process intensity increases, all the way until the artifact algorithmically generating images and sound that make no use of assets produced offline, when we can say that the process intensity is at a maximum. According to Crawford, process intensity is directly related to the richness of interactivity, and as it decreases, the author must provide a greater number of offline assets to respond to the different possible interactions (Mateas 2005). As the author puts the computational system in charge of producing (or dynamically selecting) the media assets to be used, the process intensity will increase, resulting in a richer experience. We may consider that in doing so, the designer will effectively be empowering the system, promoting it (at least partially) to a coauthor of the work, at times more so than the coprocessing interactor or wreader.

But only part of the creative process can be passed on to the computational process, at least while this doesn’t have a sufficient autonomy to pass the Lovelace test (Ariza 2009, 64). Up to this date, no system has yet been developed to such a level of autonomy, therefore those works that we call computational, procedural or generative, will at least for now continue to be seen as human works. They can be regarded as collaborations between the human author and the machine, between these and the users, but not yet as pure computational creations. Collaboration, in this sense (or in Aarseth’s sense), does not require machine autonomy.

The work of art is not a checklist or the sum of individual techniques or experiments but, according to Pierre Francastel<sup>327</sup> it is rather the creation of a model. Like all im-

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327 1900-1970.

ages, texts or sounds, a work of art incorporates different qualities, while also suggesting new paths, therefore “it possesses, by definition, qualities that stimulate the imagination of its author and its viewers” (2000, 328).

### 1.5.18 Ergodic Literature

**ergodic** *adjective* Mathematics relating to or denoting systems or processes with the property that, given sufficient time, they include or impinge on all points in a given space and can be represented statistically by a reasonably large selection of points.

Aarseth defines cybertexts (and by extension cyberarts) as all those where the author, the process and/or the aesthetic artifact (or work) focuses on the mechanic organization of parts, by positing the intricacies of the medium as an integral part of the artistic exchange (1997, 1). This designation is rooted in Wiener’s *Cybernetics* (1948) and is applied to artifacts that are particularly centered on their consumer, user, reader or interpreter. While with traditional media the performance of the audience may be seen as taking place solely in their heads, as an interpretative and subtextual effort, the audience of cyber arts may also perform in an “extranoematic sense” (Aarseth 1997, 1), contributing to the development of a process where the user will effectuate a semiotic sequence through a selective movement that is a “work of physical construction that the various concepts of ‘reading’ do not account for” (1). Aarseth defines this phenomenon as ‘ergodic’, “using a term appropriated from physics that derives from the Greek words *ergon* and *hodos*, meaning ‘work’ and ‘path’”, describing texts (or artworks) where “nontrivial effort is required to allow the reader to traverse” them (1). It is this ‘work’ that qualifies as ergodic (Bogost 2006, 130), the added layer of difficulty that it creates, the challenge it poses but also the rewards and gratifications that it gives the user.

The focus of Aarseth’s study are texts. With a background in comparative literature, he unsurprisingly develops his work through a comparative approach, extending the definition of both cybertext and ergodic literature to a broader domain than that of the digital media, by including configurative analog texts such as the *I Ching* and Queneau’s *Cent mille milliards de poèmes*, works where we can identify a software layer or a procedural nature, despite their implementation in analogue media. Beyond this, we also believe that many of his conclusions can safely be extrapolated

to other media, as long as one can identify a procedural or ergodic quality in them. Cybertexts such as “hypertexts, adventure games, and so forth are not texts the way the average literary work is a text” (Aarseth 1997, 2), they produce verbal structures, which makes them similar to other literary phenomena, but they are much more than this, because they also exist in a paraverbal dimension that sometimes is not clearly visible. Each cybertext is a “machine for the production of variety of expression” (3). Reduced to this bare minimum, the definition undoubtedly serves other cyberarts well, regardless of whether the expressions produced are in the form of verbal structures, images still or moving, or audial phenomena.

Any work demands an interpretative effort (however small) from its reader. This interpretative function is one of four user functions that Aarseth lists in his model for a typology of textual communication developed in *Cybertext*.<sup>328</sup> If the interpretative function is present in any text,<sup>329</sup> Aarseth defines ergodic texts as those where besides this we can also find at least one of the other three functions: explorative, configurative, or textonic. The explorative function is that in which the user must decide which path or paths to follow along the reading of a text, being constrained or not by the system. This is the case with Joyce’s *Afternoon, a Story* (1990), or Milorad Pavić’s<sup>330</sup> *Damascene, a Tale for Computer and Compasses* (1998), hypertext fictions with a fixed number of *scriptons*<sup>331</sup> (Aarseth 1997, 62) through which the user is invited to travel, building her narrative along the path that is traversed. Much like with the *I Ching* or a game of landscapes, all the user can do is to reconfigure the multiple possible arrangements of the parts of the system. As a consequence of this rearrangement, different parts of the narrative are discovered or missed, different events take place or do not happen, or take place at alternative chronological points in the story as it is read by the user. According to Bolter, in texts like *Afternoon*, one does not get lost in the story, but it is rather the experience of moving through the story on a trajectory partly determined by her own choices that captures the user (2001, 44). One is not involved in the story world, as it so often happens with traditional texts, but is involved by the network of connections that is laid by the text’s

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<sup>328</sup> We will delve into all of the seven variables and its possible values in Aarseth’s model in chapter three of this work.

<sup>329</sup> “If all the decisions a reader makes about a text concern its meaning, then there is only one user function involved, here called interpretation.” (Aarseth 1997, 64)

<sup>330</sup> 1929-2009.

<sup>331</sup> Scriptons are the unbroken series of one or more textons as they are projected by the text and, ideally, read by the reader, although this is not always the case.

system (which is the text itself). The user generates different narrative strands while following the links that are suggested by the text.<sup>332</sup>



for directions click yes (y)-- to start press Return

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Fig. 69: Splash screen from *Afternoon, a Story* (Joyce 1990).

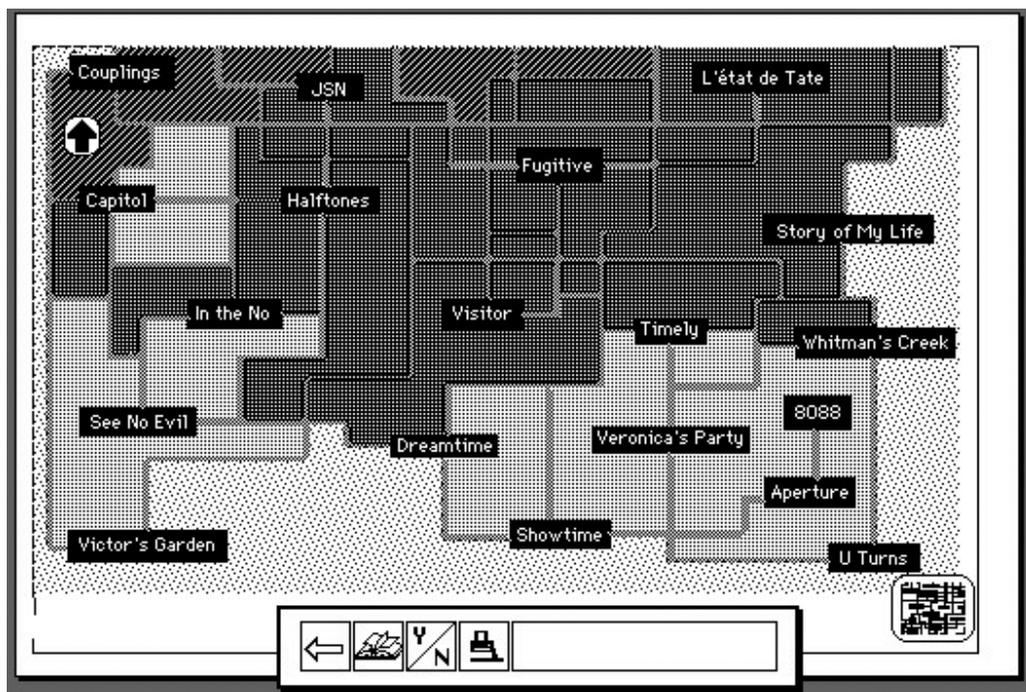


Fig. 70: Map of *Victory Garden* (Moulthrop 1992).

The configurative function is that in which *scriptons* can be chosen or created by the user. This is not what happens in hypertext fictions like *Afternoon* or *Victory Garden*, because by navigating through discrete and precomposed pages, the user merely explores a structure of fixed and immutable scriptons — the contents of each page are fixed and inalterable, what is open to the user's manipulation is the path between

<sup>332</sup> These links can be implicit or explicit, static or dynamic, as we will later see.

pages, the relations and connections, regardless if these are fixed within the system or if they are dynamic, as they are nevertheless out of the user's control. In a work as *Cent mille milliards de poèmes*, one may create new scriptons from the 140 textons<sup>333</sup> contained in the book, and by doing so, one effectively composes new pages in the book. In *Cent mille milliards de poèmes*, the sonnets are the scriptons and the user's goal in manipulating the book (or traversing it, to use Aarseth's terminology) is to compose one or several of the  $10^{14}$  different possible pages. The same function would be in operation in Mozart's *Musikalisches Würfelspiel im C* or in Kircher's *Arca Musarithmica*, where the textons (or their musical equivalents)<sup>334</sup> were recombined to form new scriptons.

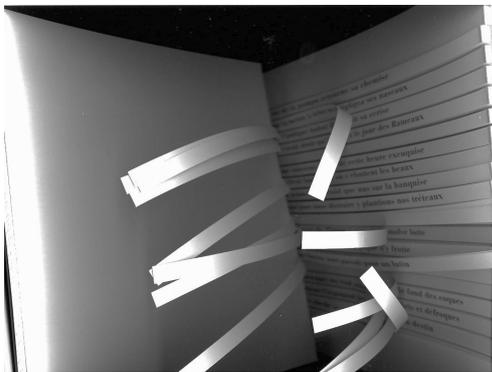


Fig. 71: *Cent mille milliards de poèmes* (Queneau 1961).

In an adventure game<sup>335</sup> such as *Colossal Cave Adventure* (Crowther 1976), the user will typically play in a world that is built from a fixed number of textons, from where a variable number of scriptons are created depending on the progress of the play.

<sup>333</sup> Textons are the basic elements of textuality, “best conceived as an arbitrarily long string of graphemes” and “identified by its relation to the other units as constrained and separated by the conventions or mechanisms of their mother text” (Aarseth 1997, 64).

<sup>334</sup> In these cases, although the end-purpose of the systems was the production of music, the systems themselves worked not with sound but with musical notation, therefore with printed matter, or text. In this context we can describe Mozart's or Kircher's scores as textons, that were combined by the users to form longer (and complete) scores that we can describe as scriptons.

<sup>335</sup> This type of video game is named after the first game that explored this style of gameplay: *Colossal Cave Adventure*, also known as *ADVENT*, *Colossal Cave* or simply *Adventure*. The term describes the gameplay style and not the kind of story or plot being developed — *Adventure* was a fantasy game, drawing elements from reality but also from fantasy novels like the works of Tolkien. In adventure games, the protagonist's role is assumed by the player, that enters an interactive history that is narrated while it is developed. In the late 1970s and early 1980s most of the games in the genre, including the original *Adventure* were text based, describing scenes, characters and actions through text and accepting user commands through text. In the early 1980s the first graphical adventure games were released, originally relying on images to describe ambient and location more than action, and still requiring the player to use text to

In some adventure games, the same player actions will always produce the same response from the system, while on other games pseudorandom functions may lead the system's response to change the response but, regardless of these random variations, the ultimate cause of the ongoing generation of scriptons by the system can be traced to the user's actions within it.

```
.RUN ADV11
WELCOME TO ADVENTURE!! WOULD YOU LIKE INSTRUCTIONS?

YES
SOMEWHERE NEARBY IS COLOSSAL CAVE, WHERE OTHERS HAVE FOUND
FORTUNES IN TREASURE AND GOLD, THOUGH IT IS RUMORED
THAT SOME WHO ENTER ARE NEVER SEEN AGAIN. MAGIC IS SAID
TO WORK IN THE CAVE. I WILL BE YOUR EYES AND HANDS. DIRECT
ME WITH COMMANDS OF 1 OR 2 WORDS.
(ERRORS, SUGGESTIONS, COMPLAINTS TO CROWTHER)
(IF STUCK TYPE HELP FOR SOME HINTS)

YOU ARE STANDING AT THE END OF A ROAD BEFORE A SMALL BRICK
BUILDING. AROUND YOU IS A FOREST. A SMALL
STREAM FLOWS OUT OF THE BUILDING AND DOWN A GULLY.

GO IN
YOU ARE INSIDE A BUILDING, A WELL HOUSE FOR A LARGE SPRING.

THERE ARE SOME KEYS ON THE GROUND HERE.

THERE IS A SHINY BRASS LAMP NEARBY.

THERE IS FOOD HERE.

THERE IS A BOTTLE OF WATER HERE.
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Fig. 72: *Colossal Cave Adventure* (Crowther 1976).

Finally, the textonic function is that where either the *textons* or the traversal function can be permanently added to the text, remaining available for further readers beyond the one that adds them or to this at later readings — as is the case, for example, with multi-user dungeons, with MMORPGs<sup>336</sup> or with other systems that receive and preserve user-generated tokens. In an ergodic text there is a cybernetic feedback loop between the text (and the system that generates the text) and the user, with information flowing from text to user, through the interpretative function, and back again, through one or more of the other functions (Aarseth 1997, 65).

Something that must not be overlooked in Aarseth's definition of ergodic literature is that the variable expression of these works does not necessarily mean that they have an ambiguous meaning. When studying a forking text as a hypertext, many literary theorists may tend to claim that all texts are produced as a linear sequence during reading, and as such, the reader would always be reading the same text, although choosing from different sections of the text while doing so. Aarseth's study focuses not so much on what is being read but "on what was being read *from*" (1997, 3). In a cybertext this is a crucial distinction to make, and a rather different distinc-

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interact with the system. Over the years many variations on the genre were developed, ranging from the pure-text versions to very complex audiovisual interactive platforms.

336 Massively Multiplayer Online Role-Playing Games.

tion from that that we can find in other media, where we can identify a script or play and varying performances that originate from it.<sup>337</sup> When a Cybertext is read (or, we could alternatively say, when it is executed or performed) one is “constantly reminded of inaccessible strategies and paths not taken, voices not heard” (3). Each decision of the user will affect the accessibility of different potential or real parts of the text, and the user may never know the exact consequences of her choices, that is, exactly what she missed. “This is very different from the ambiguities of a linear text. And inaccessibility, it must be noted, does not imply ambiguity but, rather, an absence of possibility — an aporia.” (3)

This aporia, however, is significantly different from those one may experience in codex, or non-ergodic literature. In non-ergodic texts one may be unable to make sense of a particular part of the text even though one has access to the entire text. In ergodic literature, the aporia prevents one from making sense of the whole because one may not have access to a particular part of the text that becomes central to the text’s understanding. “Aporia here becomes a trope, an absent *pièce de résistance* rather than the usual transcendental resistance of the (absent) meaning of a difficult passage.” (91)

Aarseth finds a poetics of conflict that develops from the complementarity of another trope, that of epiphany. “This is the sudden revelation that replaces the aporia, a seeming detail with an unexpected, salvaging effect: the link out.” (91) The epiphany is the resolution of the aporia, it is immanent, a planned construct rather than an unplanned contingency, but it is not always necessarily programmed by the designer, rather it is often structurally indissociable from the medium, part of the medium’s nature and of the nature of the ergodic experience that is developed in it. This pair of master tropes, aporia and epiphany “constitutes the dynamic of hypertext discourse: the dialectic between searching and finding typical of games in general”, the pair is not “a narrative structure but constitutes a more fundamental layer of human experience, from which narratives are spun” (92).

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<sup>337</sup> These are hierarchical and explicit relationships, so the distinction between the play and the performance, between the script and the film, between the score and the music that is executed is so big as to effectively turn the distinction trivial (Aarseth 1997, 3) and the two parts into almost different works, with different authorship attributions in many cases.

The difference between narratives, games, and hypertexts is conceptualized by Aarseth from ergodics, description and narration. Whereas a game exists only at the ergodic level, there is action and the paths that result from the actions, in a video game one can find a description (developed at the semiotic level in the interface, as screen icons, sounds, text, etc) and ergodics (the succession of events) but one doesn't find narration.<sup>338</sup> In hypertexts one can find all three levels occurring simultaneously: description, narration and ergodics, the first two in the text itself, the later in the reader's choices (95).

There are (...) two main problems in contemporary computer-generated poetics. One is the use of traditional literary genres and formats as ideals of the new literature, thus setting up unrealistic (and irrelevant) goals. The other is the uncritical use of traditional literary theory in the criticism of participatory literature, thus hindering an investigation of these new ergodic forms that will emphasize how they differ from narrative media. Unlike the textual aporias of hypertexts and adventure games, the aporias of computer-generated literature can be located in the programmers' ideological attachment to narrative ideals. I suspect the epiphany of poetologists of the computer-generated school will come only when they see this as a problem.

To achieve interesting and worthwhile computer-generated literature, it is necessary to dispose of the poetics of narrative literature and to use the computer's potential for combination and world simulation in order to develop new genres that can be valued and used on their own terms. Instead of trying to create a surrogate author, efforts in computer-generated literature should focus on the computer as a literary instrument: a machine for cybertext and ergodic literature. (...) the computer as literary agent ultimately points beyond narra-

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**338** According to Aarseth, the game may of course be narrated in a number of ways, "but like football, narration is not part of the game", it is external to it (1997, 95). As in some sport simulators, narration can be included in the game, but this narration (as voice-over or audio commentary) will not constitute a narrative layer, because it will not be relating the events after the fact but rather will present a synchronous description of the events as they occur. In some cases one can find a true narrative layer included in computer games, when sports simulations or action games allow the playback and review of previous games — offering access to the entire duration of the game play or to selected excerpts. In these cases, however, one is temporarily removed from the video game experience, characterized as it is by the description and the ergodics, and is led to a narrative experience, where descriptive and narrative elements alone exist, and where generally speaking, there is no ergodic level (and one is presented with a linear experience of the narration of the facts after their experience).

tive and toward ergodic modes — dialogic forms of improvisation and free play between the cyborgs that today's literate computer users (and their programs) have become. What we need in order to achieve this is not an automated playwright or narrator but simulated worlds with emergent intrigants, interesting enough to make real people want to spend time and creative energy there. (Aarseth 1997, 141)

### 1.5.19 Ergodic Media

Can we possibly extrapolate from Aarseth's analysis in order to study other media besides those that develop and communicate through textual structures? Aarseth's definition of a text is of an object whose primary function is to relay verbal information (1997, 62). From this definition two observations immediately follow: "1) a text cannot operate independently of some material medium, and this influences its behavior, and 2) a text is not equal to the information it transmits" (62). In this context, 'information' is understood as a series of signs which may or may not make sense to a particular observer.

The text consists of the textual structures and of their traversal function, the mechanism through which the signs are presented to the user. If transcoded to an electronic medium, a codex text retains most (or all) of its characteristics if analyzed under this definition. In terms of script, a paper copy of *Don Quixote* or an electronic copy that is read on screen are the same, although Aarseth concedes that "the ink-cellulose relationship promotes and impedes different rituals of use than does the electron-phosphor relationship" (1994, 58). The speed of access is certainly altered, as well as some of the environmental factors that affect the experience of reading, but the script, the sequence of signs that are offered to the user — the text itself — is not fundamentally altered in any way.

Much the same happens with the transcoding of audiovisuals from analog to digital formats: videos or film transcoded to DVD, analog television transcoded to digital, sound recordings transcoded from magnetic tape or vinyl to CD or other digital formats, etc. In most (or all) of these cases the sequences of signs, the information that is presented to the user is not fundamentally altered, although the rituals and contexts of use can be changed. Considering particular transcodings we can find that sometimes elements of random access that were not present in the original me-

dia are added, like chapter marks in DVD versions of cinema pieces, but again, these do not fundamentally alter the nature of the information being communicated or the essence of the aesthetic artifact. Generally speaking, both the information structures and the traversal functions remain unaltered.

Returning to Aarseth's definition of text, we could broaden it to define an aesthetic artifact as an object (or system of objects that is read as a unified whole) whose primary function is to relay information. An aesthetic artifact cannot operate independently from some material technology<sup>339</sup> that influences its behavior and the sequence of signals that are conveyed by this technology are not equal to the information it transmits.

Any medium consists of its information structures — textual, visual, audial or multimodal — and of their traversal functions. If the user function is merely interpretative the medium can be considered to be linear (although the particular narrative structures that are developed within it may not be linear at all) or non-ergodic, otherwise we may consider it to be ergodic, as it forces the user to a nontrivial effort in its experimentation.

This however, is not enough to fully describe the medium or the artwork, because the ergodic experience is not necessarily a nonlinear or nonsequential<sup>340</sup> experience.

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**339** Or 'medium', the term Aarseth uses and that we will try to avoid in this context, as we find it almost synonymous or downright equivalent to 'aesthetic artifact'. The reasons why we chose to use the latter term over the previous are related to 1) emphasizing a particular context or purpose of the communication media and the uniqueness of being carriers of aesthetic information or of carrying the information through aesthetics; and 2) marking a clearer distinction between 'medium' as previously used by Aarseth and the meaning we would like it to have in this work. By 'material' we do not mean physical or in any way necessarily tangible, we simply mean perceivable to the human senses.

**340** These terms were originally used by Nelson in his discussions of hypertext. They have since been criticized and even rejected by other hypertext theorists, that suggested the alternative use of the terms 'multilinear' and 'multisequential' (Landow 2006). Aarseth defends the use of Nelson's terms: "But if the paths fork, with at most one direct path between any two nodes, as is usually the case in hypermedia, we can no longer talk about paths in any other sense than as a potential path, a course or itinerary. The lines of such a net are not identical to the possible courses, since the same line can occur at different positions in a single course. So, should we decide to use the term *multilinear*, what lines are we referring to, the lines of the net or the lines of the courses? If we refer to the individual lines of the net, the term *multilinear* makes only trivial sense and could, in fact, be wrong, if the whole net can be subsumed under only one line. If we refer to the courses, *multicursal* would be a much more accurate term than *multilinear*, indicating that the lines are produced by movement rather than drawn in advance. But is *nonlinear* better? Can a structure consisting of lines be nonlinear? On the (trivial) level of the line, no; but on the level of the structure as a whole, yes. The sign + is made of two lines, but its form is not linear, as opposed to the signs <, |, or O.

The ergodic experience can happen with strictly linear experiences, from which one of the purest examples can be found in William Gibson's *Agrippa (a Book of the Dead)* (1992), a book published as a writable computer diskette. This was a strictly linear text, written and designed to be read in a single seating, in the most linear of ways. *Agrippa* conditioned the reader to read linearly, by presenting itself as black text on white background, scrolling automatically from the bottom to the top of the screen, and not allowing the reader to control any aspect of the reading experience, from speed to direction, etc. This conditioning of linear reading was much stronger than it would be possible in a traditional book format, where the linearity of the reading would be left to the reader and not to the system.<sup>341</sup> Furthermore, besides forcing this linear (and timed, at around 20 minutes) reading, the system of *Agrippa* also ensured that the reading could not be repeated, by using a custom-built RSA<sup>342</sup> encryption algorithm that would effectively destroy the information of the text after it had been displayed one single time. *Agrippa* displays an unusual combination of characteristics that make it become a one of a kind text, incomparable to other cybertexts.

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If topological shapes are either linear or nonlinear, then hypermedia works, as opposed to hypermedia itineraries, must be topologically nonlinear.

The discrepancy between Nelson and his critics, therefore, can easily be explained: while he is talking of text and writings (as constructed objects), they are talking of readings and writing (as temporal process) — or at least they are not taking that distinction into account. Yet this is a distinction that must be made.” (Aarseth 1997, 44) Concluding with “In other words, a piece of writing on paper or a computer screen should not be confused with the act of reading it. To say that hypertext readings must be linear is just another way of saying that they are temporal, which again simply refers to the temporality of our existence. It is therefore not valid as an argument against the term *nonlinearity* as used in this context, just as the structure of nonlinearity or multilinearity is not an argument for liberation, as Rosenberg (1994) points out.” (46)

**341** The book is not an intrinsically linear (or nonlinear) format. It is, more exactly, a random access format that is “well suited to linear discourse but is just as accommodating toward nonlinear discourse, as an encyclopedia or a forking-path story” (Aarseth 1997, 46). If it is true that in general the nonlinear text types perform better in a computational system than in paper, *Agrippa* shows that those texts whose linear integrity cannot be compromised also perform better in these media. “Even hypertext can be a much stronger linear medium than the codex, should its author decide so (...) [a] hypertext path with only one (unidirectional) link between text chunks is much more authoritarian and limiting than (say) a detective novel, in which the reader is free to read the ending at any time” (47).

**342** Rivest, Shamir and Adleman public-key cryptography.

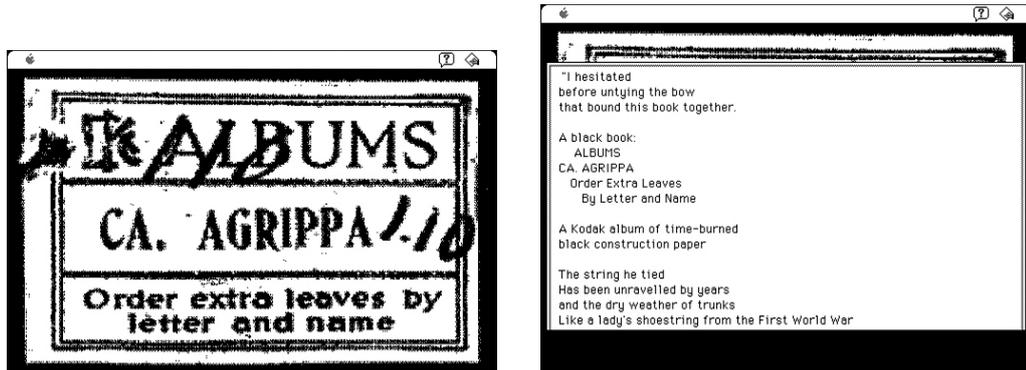


Fig. 73: Start screen and “I hesitated...”, the beginning of poem as it scrolls up screen (Gibson 1992).



Fig. 74: “laughing, in the mechanism” (the end) and the encrypted text appearing after end of poem (1992).

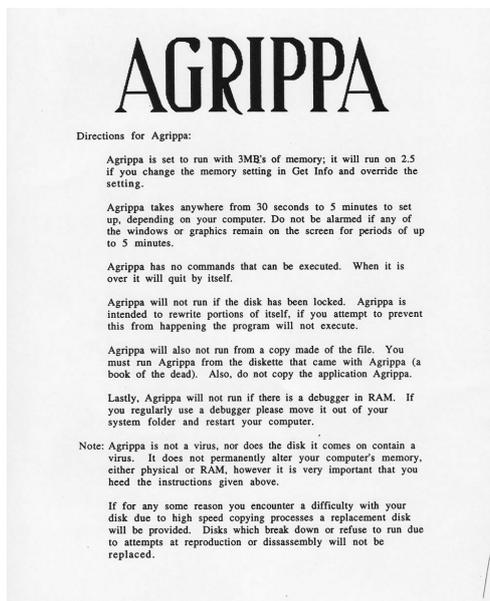


Fig. 75: Instructions provided with *Agrippa*. “Agrippa has no commands that can be executed. When it is over it will quit itself. (...) Agrippa is intended to rewrite portions of itself, if you attempt to prevent this from happening, the program will not execute. (...) Agrippa is not a virus, not does the disk it comes on contain a virus. It does not permanently alter your computer’s memory, either physical or RAM (...)”

The effort of reading *Agrippa* is certainly nontrivial, although no other action is expected (or even required) from the user besides a somewhat traditional reading of the text in a very linear fashion, the time constraint that is imposed on the user and the irreversibility of the process transform it into a completely different literary event. All literary experiences are unarguably time-based experiences, but this is one where the timing and the finitude of time rests at the core of the experience. One may question whether two consecutive readings of *Agrippa* will not, in fact, present the user with the same experience. They certainly will, and although the scripts presented in both readings will be identical, both experiences will also share the temporal limitation and the demand to the user to conform with the pace of the scroll.

After studying *Agrippa*, a “new text type” that had not previously been developed, Aarseth proposed four programmatic categories, or degrees, of linearity in cybertexts: “1) the simple nonlinear text, whose textons are totally static, open and explorable by the user; 2) the discontinuous nonlinear text, or hypertext, which may be traversed by ‘jumps’ (explicit links) between textons; 3) the determinate ‘cybertext,’ in which the behavior of textons is predictable but conditional and with the element of role-playing; and 4) the indeterminate cybertext in which textons are dynamic and unpredictable.” (Aarseth 1994, 63) We can safely assume that *Agrippa* falls under the third category, being determinate and predictable, and forcing the user to develop some role-playing, even if the action is limited to chasing after the text. The user function is mostly interpretative, but it is slightly more than just that because the user is not free to read at her own pace and is carried along a determinate traversal function by the software. The reader is not simply placed at the end of the text’s production line — after writer, editor, printer, publisher, distributor, seller — but is in a way taken inside the production process, witnessing the text’s formation, existence, and demise. *Agrippa* is then an ergodic experience.

Other time-based processes, that could be classified in between the third and the fourth categories, present the user with similar ergodic experiences. Two examples are Gescom’s *Minidisc* (1998) and the Farmers Manual’s *Explorers\_We* (1998), works that present similar strategies of composition, although in different (but not totally dissimilar) media. *Minidisc* comprises 45 tracks indexed in 88 total parts,<sup>343</sup> ranging from a minimum of four seconds to a maximum of four minutes and fifteen

<sup>343</sup> A later CD edition was published with 88 discrete indexes, thus with 88 independent parts.

seconds, while *Explorers\_We* comprises 60 one-minute tracks. Both works were designed to be played randomly, employing the ‘shuffle’ functions available on CD and MiniDisc players, and therefore using the systems to create random sequences with the possible permutations of the base tracks parts. The principle of composition in these two pieces (considering the full-length CD or MD as the compositions, not their independent parts) is similar to what we can find in a game of landscapes or in Bénabou’s poem *Several Tens of Tens*,<sup>344</sup> where the reader was encouraged to form any possible 10-verse stanza through the permutation of the ten verses that the author provided:

*Several Tens of Tens* (translated from the French by Harry Mathews)

All is dream life and love and death  
 We smilingly enter the cradle of shadow  
 At night what corpse does not resume its flight  
 To find the child that has survived the wreckage  
 Sometimes I arrive in my deserted town  
 The sky’s light was then abruptly extinguished  
 Still enveloped in the guiles of springtime  
 Above the chalk that dusts the green flowers  
 The unspeaking streets look at me unseeing  
 Life has taken refuge in the depths of mirrors (Mathews and Brotchie 2005, 61)

Bénabou’s poem allows  $10! = 3,628,800$  permutations. Presented as a text, with static textons that the user must explore and recombine, *Several Tens of Tens* is classified in the first category, much like the *Cent mille milliards de poèmes*. However, if in any of these texts we manage to automate the permutations, thus removing the freedom of the user’s exploration and presenting her diverse outputs as preformed scriptons, we will transform the experience of reading these pieces and turn it into something similar to what is experienced when listening to *Explorers\_We* or *Mini-disc*. This has (maybe unwillingly) been done in several adaptations of Queneau’s work to the World Wide Web that, instead of allowing the user to manually select each of the 10 alternative verses for each position in the sonnet, randomly compose

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<sup>344</sup> Bénabou was an Oulipian and the title of this poem directly alludes to the *Cent mille milliards de poèmes*, to which author it was presented as something of an homage in the fourth number of the *La Bibliothèque Oulipienne*, published in 1977 shortly after Queneau’s death.

the entire poem out of the 140 available textons, and present the complete output to the user.<sup>345</sup> This transforms the traversal function into something akin to that of traditional texts, minus the random-access and, more importantly, denying the possibility of return to the particular articulation of the piece (or the particular output one has read or heard) once a new articulation has been generated. Each articulation of *Several Tens of Tens* is always 10-verse long, each articulation of *Explorers\_We* is always 60 minutes long<sup>346</sup> but regardless of this regularity, each of the articulations is virtually unique and unrepeatable. The enormous number of possible permutations almost guarantees it. If *Several Tens of Tens* allows over three and a half million permutations to be created, *Explorers\_We* dramatically increases that number to a magnitude of  $60!$ , such a large number that is almost impossible to grasp,<sup>347</sup> and *Minidisc* increases that number to  $88!$ .<sup>348</sup> It is of course possible that the same permutation can be repeated to a single user, but the probabilities of that happening are very low.<sup>349</sup>

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**345** Magnus Bodin's implementation is one such example, presenting the original version, an English translation by Stanley Chapman (from 1998) and a Swedish translation by Lars Hagström (from 1992). The first digital implementation of *Cent mille milliards de poèmes* was programmed in 1975 by Paul Braffort. This version created the poems by using the reader's name and the time it took her to input it to control the selection of the verses. It was Paul Braffort that in 1980, with Roubaud, proposed the creation of a group dedicated to the computer-oriented Oulipian research, the ALAMO, the *Atelier de Littérature Assistée par la Mathématique et les Ordinateurs*.

**346** Plus the variable delay between each of the tracks, depending on the time that is necessary for the mechanical movement of the CD lens between tracks.

**347**  $8,320,987,112,741,390,144,276,341,183,223,364,380,754,172,606,361,245,952,449,277,696,409,600,000,000,000,000$  possible permutations, far, far more than the number of atoms in the visible universe.

**348**  $1.85482 \times 10^{134}$  or 185,482,642,257,398,439,114,796,845,645,546,284,380,220,968,949,399,346,684,421,580,986,889,562,184,028,199,319,100,141,244,804,501,828,416,633,516,851,200,000,000,000,000,000,000.

**349** There is however one particular permutation that is likely to be repeated over and over again. That is the sequence of tracks as organized in the index of the CD, the default playing sequence if the user does not manually activate the shuffle (or random) function of the CD player. Unlike DVDs, where one can use a virtual machine implemented by the DVD player to run bytecode contained on the DVD, thus disposing of a moderately flexible programming environment, Compact Discs cannot be programmed to play randomly and must rely on instructions passed on to the user (with a varying degree of efficacy) to ensure that the program of the work is correctly executed — that is, that the tracks in the disc are played randomly and not in the default index order. If the user does not follow the instructions and plays the disc in the default mode, the reproduction order will be that of the index, the first among all of the possible permutations. Maybe because of this, in *Explorers\_We* the first few tracks in the index of the disc consist of nothing but silence (not digital silence — no signal — but rather recordings of silence), almost as if to signal the user that the intended playing system is not being followed. It should be noted that what is requested of the user is simply to operate one switch in the CD or MD player, not to in any way determine the permutation of tracks to be reproduced but to delegate that to the shuffle algorithm of the player.

The nontrivial effort that is demanded of users in the context of these pieces, is then not that of traversing the work facing whatever difficulties, aporias or epiphanies this may present them, but rather that of knowing that whatever particular articulation happens to be read, seen or heard, most likely will never be presented again and, although remaining forever as a potential articulation of the parts of the system, will never more be brought to existence as a fully formed gestalt. This tension is similar to the one that is experienced while reading *Agrippa*, but two differences can be pointed: 1) in *Agrippa* one knows that the text in the diskette will be forever lost after its display, but one also knows that *Agrippa* is a mechanically duplicated artifact, and that any two copies of the diskette will carry the same data and will present it in an analogous fashion, thus, although difficult, the experience of reading *Agrippa* is potentially repeatable; 2) every articulation of *Explorers\_We*, *Minidisc* or *Several Tens of Tens* is built from the same limited number of textons (or tracks) — that are in each case complex units of information and meaning — and will therefore repeat the presentation of the same set of modules, rebuilding something of a familiar experience to the user. The recurrence of verses or sounds will balance the uniqueness and the unexpectedness of the ever-new articulation with the intimacy created by the recognizability of the parts. This effect is reinforced by the continued permutation of all the parts. In a work as the *Cent mille milliards de poèmes*, where only ten percent of the textons are used in each recombination, there is a permanent repository of unknown or unrevealed textons to present to the reader in further recombinations, therefore each posterior reading will still hold the potential to reveal previously unread parts. In each permutation of *Several Tens of Tens*, on the contrary, all the textons are presented to the reader, leaving no room for later discoveries or surprises at this level and placing all novelty of further permutations simply at the level of the articulations that the system may produce. Although at a macroscopic level we can find that the articulations between parts differ — and is it at the level of these articulations that the astronomical number of possible permutations is found — the experience of listening or reading each of the single parts, independently of their place in the sequence, will always be somewhat similar (if not totally identical, depending on the context).

The experience that is presented to the user can be considerably more complex if the parts are recombined among themselves besides being permuted or resequenced. The  $30 \times 1$  (Carvalhais, Tudela and Lia 2005a) installation developed an audiovisual system that relied on permutation to generate multiple possible readings, but more

than simply rearranging the parts into different playback sequences, used them as components in a complex articulation program that also depended on shuffling (or on the random selection of the parts).

In *30x1* there were a total of 62 different audio compositions ranging one minute in length. For each of these compositions, two video interpretations were created, reaching a total of 124 different audiovisual pieces. These pieces were distributed by five groups of DVD discs, each of the discs in a group containing all the pieces in it.<sup>350</sup> The different DVDs were shown on screens or television sets of varying sizes, assembled through 8 rooms of the gallery, whenever possible allowing a line of sight between rooms and always allowing the sound from each display to mix with the other sounds in the room and to permeate between rooms.<sup>351</sup> All the DVDs were programmed to randomly play the tracks they contained and all of them should be turned on at the start of the day (without any particular care in the sequence or timing of the start) playing throughout the day. Although the DVDs were programmed to not allow immediate repetitions of the same track (playing the same track twice in a row), they were not programmed to force the entire group of tracks to play before repeating any of the tracks (thus not ensuring that any of the tracks would be played as often as any other). The slight variations in the length of the tracks and the mechanical delay that the DVD players inevitably created when moving the play heads from one track to the next ensured that the overlap between the outputs of different DVDs that were played in the same space or whose sound could be heard in the space would vary continuously. We can argue that this piece was ergodic at two different levels: 1) it created a shifting audiovisual space, controlled by the textons contained in the DVDs and by the randomization programmed in the DVD players; 2) this space was, however, too vast and complex for any visitor to perceive at once, requiring her to physically travel through the space, hearing different parts of it (or the mix of the sound output of different discs) and seeing an even more limited part of the output at any given time. The user effectively composed her particular reading of the piece, determining its length, the balance between the parts and the

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<sup>350</sup> 20 videos in group zero, 34 videos in group one, 30 videos in group two, 20 videos in group three and 20 videos in group four.

<sup>351</sup> Televisions reproduced the sound in mono, while the projections were amplified by stereo speakers hanging from the ceilings.

audiovisual relations through the path walked through the gallery<sup>352</sup> and through the interactions with other visitors.<sup>353</sup>

The visual components of *30x1* were conceived as framed images to be presented in the context of the gallery, to be read in the frame of the projections or screens or as part of a broader view of the rooms, where two or more screens could coexist in the visual field of the visitors. The sonic elements were designed to overlap with each other and to be recomposed by the randomization and the acoustics of the space, so that even if particular sounds could be recognized as being repeated during any visit to the work, the total tracks were only rarely perceived as being repeated.

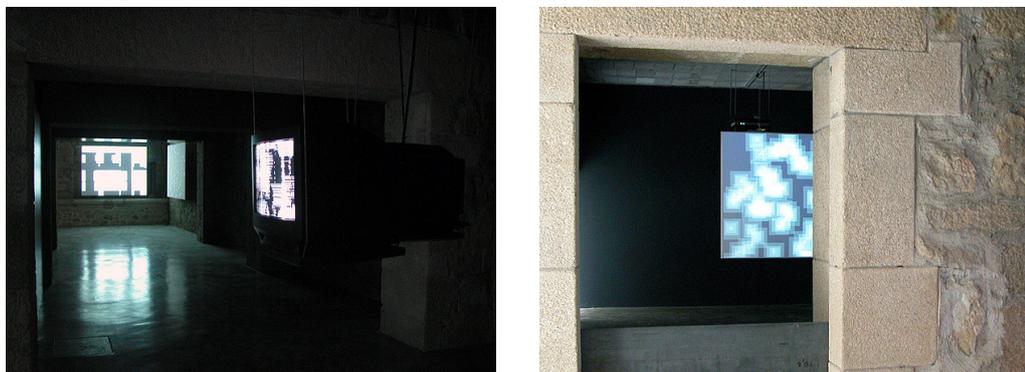


Fig. 76: Two views of *30x1* (Carvalhais, Tudela and Lia 2005a).

This work proposed the development of an ergodic experience, an experience from which the authors were not exempt, as they were not only the designers of the whole process but also necessarily its first test subjects.<sup>354</sup> Although the authors can certainly estimate some of the outputs of the process, in such complex systems as those described in this chapter, however accurate those estimates and the authors' intuition may be, they will almost certainly always fall short when faced with the mas-

<sup>352</sup> In *30x1* the path is not a metaphorical description of the reading experience but rather a physical course that had to be travelled by the visitors along the different rooms and the audiovisual sources they contained.

<sup>353</sup> Although *30x1* was not conceived as a collective experience, it was set in a space where multiple visitors could simultaneously experiment the installation, thus potentially intersecting their paths and sharing the construction of their particular readings.

<sup>354</sup> We can mention a further ergodic aspect of the authoring process: the piece was created by three artists in collaboration, the three acting as authors of the overall piece but developing distinct parts of the audiovisual pieces: while Lia developed all the images, the remaining authors developed the sound components. Although working in close contact, the creative process was a continuous path of discovery, debate and discussion between the three.

siveness of the number of combinations that are mathematically achievable, a number that will effectively make it impossible for any single author (or team of authors) to experiment, or verify and validate, the articulation of all permutations. They also propose that the users read them as open works, as works that resonate through the physical space of the installation and the time each visitor takes to observe it, but also through a series of related works that further expand the initial work, in this case a second installation,<sup>355</sup> two linear videos<sup>356</sup> and a sound recording,<sup>357</sup> all of them composed from the individual parts prepared for the installations.<sup>358</sup>

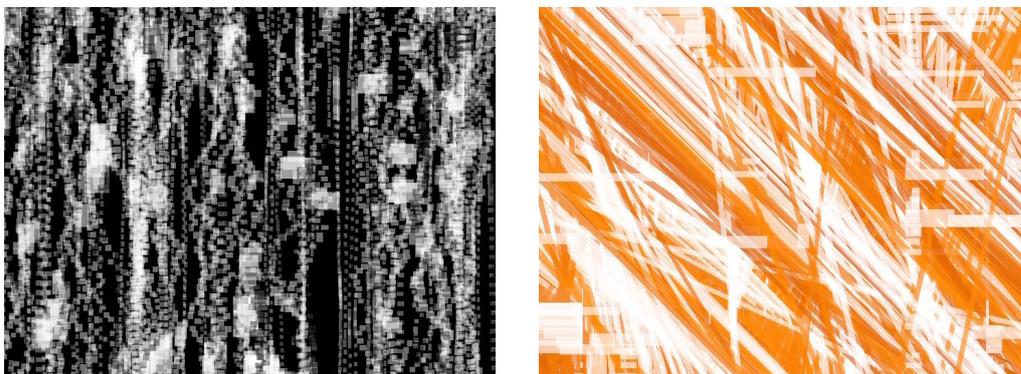


Fig. 77: *Int.16/54//Sono01/30x1* (Lia 2005) composed from the individual parts of *30x1*.



Fig. 78: *30x1.01* (Carvalhais, Tudela and Lia 2005b) composed from the individual parts of *30x1*.

<sup>355</sup> *30x1.2* (Carvalhais, Tudela and Lia 2007).

<sup>356</sup> *Int.16/54//Sono01/30x1* (Lia 2005) and *30x1.01* (Carvalhais, Tudela and Lia 2005b).

<sup>357</sup> *30x1.3* (@c, 2010).

<sup>358</sup> It was established by the authors, since the start of the project, that these derivative works would be produced, not only trying to recreate certain aspects of the experience of visiting the installation in other media, but also trying to creatively explore the sources that were created to the installation in linear artifacts, creating 'author-curated' permutations of the parts. The first of these (however unregistered) was presented in the day of the opening of the installation, during a live audiovisual performance, where elements used in the composition of the parts of the installation were recomposed. In this case the source material were not the videos of the installation but rather the code used to generate the images and the code and digital sound files used to create the audio.

The work thus becomes an ergodic system through which the author, the devices and the users must build and experience their own individual paths. The work becomes not the individual artifact (although it never really ceases to be the artifact itself) but rather the system of artifacts that are weaved in a network of relations that, while external to every particular piece, nevertheless links all of them and reverberates through them. The work becomes the repertoire of artifacts that are linked by causal and conceptual bonds, its experience grows to be the collection of experiences that are gathered by a single user or by a group of users.



## PROCESSES AND SYSTEMS

### 2.1 The Classification of Systems

What does a computer sound like when it sounds like a computer? What visual worlds of expression will we consider to be idiomatic to computers? What virtual realities will be idiomatic to computers? What new means of expression and communication will be idiomatic to computers? (Holtzman 1994, 251)

If one surveys the broad field of computational art and design,<sup>359</sup> one of the first questions we can pose is: what characterizes these systems computationally, what similarities or contrasts can we find between different artifacts at the level of the processes developed by the systems? As we have seen, the same system can produce very diverse outputs at the surface level but despite potential variations, different implementations of the same processes may produce recognizable patterns. These patterns may be subtle and difficult to recognize but, if one wishes to develop a comparative analysis of these artifacts then one should develop some knowledge of the fundamental systems that are used in their creation. This chapter will try to map some of those systems, listing some of the strategies used in the development of procedural arts and design.<sup>360</sup>

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<sup>359</sup> Regardless if one is focused on those works that we can define as being procedural, or generative to the core, or if one is alternatively focused in *any* computer-assisted or computer-mediated aesthetic artifact, notwithstanding its process intensity.

<sup>360</sup> A list that must nevertheless remain incomplete.

Composer and music theorist Iannis Xenakis (1992), divides the methods employed in the production of his works in two general categories that encompass deterministic and nondeterministic models. These two mathematically derived categories are linked to the involvement of randomness in his composition process. As he explains in an interview: “in determinism the same cause always has the same effect. There’s no deviation, no exception. The opposite of this is that the effect is always different, the chain never repeats itself. In this case we reach absolute chance — that is, indeterminism” (qtd. in Tryfonidou and Gourdoukis 2008). A deterministic model does not include randomness and will always produce the same output if started from the same values, while indeterministic or stochastic processes involve randomness and regardless of the initialization values will always produce different outputs each time the process is repeated.

Although Xenakis noted this division, most of his compositions were totally determinate once finished and, regardless of the methods used, once translated into conventional musical notation, his scores left no space for variation or improvisation during performance. “In other words the generation of the score involves randomness to a great extent, but the score becomes finalized by the composer so that each time that it is performed it remains the same.” (Tryfonidou and Gourdoukis 2008) The few compositions that allowed varying performances were, interestingly, deterministic according to his classification (i.e., they did not include randomness), but instead relied on well-defined rules for a game to be played between performers or conductors during the performance.<sup>361</sup>

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<sup>361</sup> “An example of the last case is *Duel*, a composition that is based on game theory. The composition is performed by two orchestras guided by two conductors, and is literary a game between the two that in the end yields a winner. Each conductor has to select for each move, one out of seven options that are predefined by the composer. A specific scoring system is established and the score of each orchestra depends on the choices of the two conductors. The result of this process is that each time that the composition is performed, the outcome is different. Therefore, a deterministic system where there are seven specific and predefined elements is producing a result that varies in each performance of the score. To make things even more complicated, the seven predefined musical elements are composed by Xenakis with the use of stochastic processes. To summarize the structure of *Duel*: Xenakis generated seven different pieces using stochastic processes, therefore seven pieces that include randomness. However those pieces were finalized by the composer into a specific form. Then those pieces are given to the conductors that are free to choose one for each move of the performance. The choice of each conductor however is not random: ‘... it is [not] a case of improvised music, ‘aleatory’, to which I am absolutely opposed, for it represents among other things the total surrender of the composer. The Musical Game accords a certain liberty of choice to the two conductors but not to the instrumentalists; but this liberty is guided by the constraints of the Rules of the Game, and which must permit the music notated by the score to open out in almost unlimited multiplication.’ So the choices of each conductor are based upon the strategy that he follows in order to win the

Another composer, David Cope (2005), organizes processes in six distinct groups: rules-based, data-driven, genetic algorithms, neural nets, fuzzy logic and mathematical modeling. Such a distinction may be somewhat too complex, already proposing at the top level of the hierarchy to split processes that could have been paired under the same group. If neural nets or genetic algorithms (as fuzzy logic and mathematical modeling) are sets of processes with very different characteristics, they are all nevertheless rule-based systems, and as such contrast with everything that may be classified as data-driven processes.<sup>362</sup> Following Crawford's suggestion (and Bogost's interpretation) we can try to simplify this first level of the hierarchy. If process intensity refers to the "degree to which a program emphasizes processes instead of data" (Bogost 2008, 122), then we can propose to start by dividing the systems in two basic groups: data-driven systems and rule-based systems. If we try to merge this with Xenakis's distinction between determinate and indeterminate systems, we will find that both rule-based and data-driven systems can produce determinate and indeterminate outcomes, both at the moment of authorship, creation or composition (as one prefers to call it) as at the moment of deployment, reading or performance. Xenakis's classification is understandable in the perspective of the creator, but it is not very useful for the posterior analysis of the creations, exactly because it says nothing about the processes that are developed in the piece but rather focuses on the processes employed by the author during the process of composition. In those cases where these processes are the same, we may find that Xenakis's description will accurately fit the pieces but on those where they are not — such as *Duel* (1958) — we will find that his approach will fall short of accurately describing the works. What characterizes *Duel* are not the processes that the composer used to create the score<sup>363</sup> but rather the game that is developed by the conductors while ordering those same pieces and defining the final form of the performance.<sup>364</sup>

Rule-based and data-driven as top hierarchies in a classification of systems allow us to split them in two sets that are distinguished by a fundamental characteristic: whether the system's behaviors, choices and ultimately its creations are generated by

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game, and consequently upon the choices of the second conductor. Therefore the final performance of the score is different each time." (Tryfonidou and Gourdoukis 2008)

**362** In itself a rather broad category also, containing processes so diverse as those in the rule-based category, and — when one considers digital media — with a very complex and rich history.

**363** Although they are certainly a fundamental part of the piece and Xenakis's score could not be arbitrarily replaced by any other score without compromising the work's identity.

**364** Although the form of each of the seven parts is closed and immutable.

the system or are based on data that is external to the system. What this classification then tries to assert is the provenance of data.<sup>365</sup> It should also be pointed that those systems that use or reproduce conventional data such as images, sound, video and text documents, all of which have their origins outside of the system<sup>366</sup> can also be seen as being data-driven. This is something we will explore further on.

## 2.2 Data-Driven

### 2.2.1 Data-Driven Processes

Although it may not seem to be the obvious first step, when compiling processes that depend on external data or are data-driven, one should perhaps start by looking at all those systems that integrate, or remediate, digitized images (whether moving or still), digitized sounds and other human-authored contents. In short, systems that integrate (traditional) media. According to Cramer, these are typical examples of “non-algorithmic program code” (2002), of code that uses the computer merely as a storage device and as a mechanism for the transmission of media.<sup>367</sup> This describes “for example the difference between algorithmic composition on the one hand and audio CD/MP3 files on the other, between algorithmically generated text and ‘hypertext’ (a random access database model which, as such, doesn’t require algorithmic computation at all), or between a graphical computer ‘demo’ and a video tape.”<sup>368</sup> (2002)

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**365** Or ultimately one can even assert the provenance of the rules (or the program) themselves, and not simply the data. Tyler already pointed to that: “The computer can itself act as the creator by the ability to generate random (or pseudorandom) sequences of numbers. On a low level this can operate merely to produce the arrangement of patterns or the selection of elements for a design, and many computer artists have utilized this process to great effect. But in principle the random process can be used in the generation of the program itself; a metarandom organization of the generative process. In practice this is likely to lead to many programs which are inexecutable on a given computer system, but an analogous process operates in human creativity. Many false starts and abortive attempts may be made before a workable design is produced.” (1976)

**366** Whether in the real world or in other systems.

**367** Regardless whether these were originally created through procedural code or by other means, including digital and analog devices.

**368** Cramer emphasizes the authorship of program code, as although “one can of course use computers without programming them, it is impossible not to use programs at all; the question only is who programs”. One can defend that regardless of how low is the level of code that a designer uses in the creation of her work, she will always, and inevitably, need to interface with other code that was not created by her, that was preexisting in the computational tool of her choice. The software layer is naturally omnipresent, therefore there is “no such thing as data without programs, and hence no digital arts without the software layers they either take for granted, or design themselves” (2002). Somewhat more radically, Rushkoff pro-

In a way that is not totally dissimilar to what happens in a system that uses a well-defined mathematical series (such as prime numbers, the Fibonacci series, the decimal expansion of  $\pi$ , etc.),<sup>369</sup> non-algorithmic program code reads the information of the image, audio, text or whatever medium or media are remediated by the system and reproduces it, integrating it in the output. Once the system is restarted,<sup>370</sup> the exact same behaviors, and consequently the same outputs, will be displayed. Even in cases where the dataset is not closed and may be updated constantly or on a regular basis,<sup>371</sup> although the outputs may vary, the system will always depend on the external data for its realization and will always act as a translator for the data fed into it. Ultimately we may regard this distinction as being fundamentally based on the amount of free-will or autonomy that a system possesses to create novelty, on its process intensity. When dependent on external data, a system is fundamentally programmed to follow or to develop a succession of events that it may not be able to change or to escape from, while a process intensive rule-based system may (at least theoretically) have in its code the choice to escape from self-repetition, or the opportunity to create.

If we return to Chomsky's grammars and to the considerations that De Landa (1997, 217-18) develops after them, we may infer that data-driven systems sample their structure from external sources and may fundamentally operate with transformational components.<sup>372</sup> With the exception of some systems that one can identify as being

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poses that in the digital age, either one programs or is programmed, either one is a programmer or one is being programmed. If we do not program we end up being the users, or worst even, being the used (2010).  
**369** "Mathematical series appear at the head of the list of alternative formalisms for quasi randomness. Of these mathematical series, the Fibonacci sequence (...) has earned a special place. Dividing any number of this series by its predecessor produces the so-called golden mean (golden section) of approximately 1.62 — depending on how far the series has progressed. The golden mean (also called phi) has served as a paradigm for artists, architects, and composers such as Debussy, Bartók, and Stravinsky, as well as for many composers using computers to compose. (...)

Having a pseudorandom number generator choose numbers indeterminately from a Fibonacci sequence helps to ensure that, over time and with many thousands of choices made, these numbers and the choices they reflect will approximate golden mean relationships.

Mathematical formulas can also provide useful quasi randomness. A particularly interesting mathematical formula for me, the function  $f_{(x)} = 1 / \cos x^2$  produces apparently random output when the result of each formulaic calculation recursively becomes a new 'x' for squaring, cosining, and so on. The resulting series of numbers does not reveal patterns at any level." (Cope 2005, 75-76)

**370** Presuming that the system can be restarted, of course. Nevertheless, and for the sake of argument, we can assume that all systems can somehow be restarted.

**371** Examples are systems that feed on real-time data for example, tracking meteorological information, stock markets or any other source of data that can inject variation and novelty into the system's outputs.

**372** As opposed to working with generative components.

strictly rule-based or totally data-driven, we will naturally find that many systems are hybrids of both approaches, because they articulate data-driven and rule-based processes, developing them in tandem.<sup>373</sup> If we can regard any linear video or audio file — when reproduced by a computational system — as being a strictly data-driven process, we very often find works where these data-driven processes are balanced by other rule-based processes, enriching the system. The aforementioned *30x1* installation is such an example. If all the audiovisual components of this work are fixed as data to be read and reproduced,<sup>374</sup> their articulation is the outcome of chance or uncontrollable factors,<sup>375</sup> of the rules that control the pseudorandomness<sup>376</sup> and finally of the rules defined by the authors.<sup>377</sup> So we may very well classify the system both as being data-driven or rule-based without erring in any of the classifications. We would need to assert which of the two processes is more determinant in regard to what is communicated to or experienced by the visitors of the installation, and even here, the dominance would probably shift depending on the context of the visit, its duration, etc.

Another example can be found in the ‘soft cinema’ works of Lev Manovich and Andreas Kratky such as *Texas* (Manovich 2004b), *Mission to Earth* (Manovich 2004a) or *Absences* (Kratky 2004). These works intend to explore the “creative possibilities at the intersection of software culture, cinema, and architecture”, and to investigate “how the new representational techniques of soft(ware) cinema can be deployed to address the new dimensions of our time (...) and the effects of information tech-

<sup>373</sup> Or, to put it in another way, complex systems are almost by definition built from many parts and among these we will find both data-driven as well as rule-based components, the classification being defined through an analysis of each component’s role in the system. Those that are able to generate data versus those that feed on data generated elsewhere.

<sup>374</sup> Regardless of how they were created, and in this case most of the processes used in the development of the audio and video components were rule-based. The audio components integrated several ‘field recordings’ or sampled audio, but used them in the development of rule-based compositional processes. The video was created through algorithms that read the mean amplitudes of the audio for small groups of samples (about 1,764 audio samples, or the equivalent to one frame of PAL video) and consequently used those values in the composition rules, affecting colors, dimensions, angles, speed of movement, and various other transformations.

<sup>375</sup> Chance, in this context is present in the actions of the human operator that starts all the different playback mechanisms at an uncontrollable pace and order, but also in the mechanical influence of the DVD players in the time taken to access the different tracks on disc. Besides these, the actions and the drift of visitors along the space is pretty much left uncontrolled.

<sup>376</sup> The shuffling process programmed in each of the discs and read and executed by the DVD players.

<sup>377</sup> These rules are formalized in the clustering of components in different discs and in the spatial distribution of the various projections, affecting what may or may not fall into the viewer’s fields of vision and audition at any given point during the visit to the installation space.

nologies on subjectivity” (Manovich 2005b). According to the authors, the research followed four directions: “1) following the standard convention of the human-computer interface, the display area is always divided into multiple frames; 2) Using a set of rules (...) the soft cinema software controls both the layout of the screen (number and position of frames) and the sequences of media elements that appear in these frames; 3) The media elements (...) are selected from a large database to construct a potentially unlimited number of different films; 4) (...) video is used as only one type of representation among others: motion graphics, 3D animations, diagrams,<sup>378</sup> etc.” (Manovich 2005a) These are a set of explicit rules for the creation of soft cinema works, but the authors also intend to explore what they present as four main conceptual ideas behind the project: algorithmic cinema, macro-cinema, multimedia cinema and database cinema (Manovich 2005b).



Fig. 79: *Texas* (Manovich 2004b).

By algorithmic cinema, the authors understand the (semi-)automated editing of the media materials that are used in each work. By tagging each asset in the database with keywords that “describe both the ‘content’ of a clip (geographical location, presence of people in the scene, etc.) and its ‘formal’ properties (dominant color, dominant line orientation, contrast, camera movement, etc.)”<sup>379</sup> (Manovich 2005b), the soft cinema software assembles the video track by selecting several of the assets sequentially or in parallel using the system rules and the descriptions in the tags. “Different systems of rules are possible: for instance, selecting a clip which is closest

<sup>378</sup> By ‘video’ the authors seem to be referring to live-action captured to digital video, not to the medium in which the images are stored. According to the documentation in the website (Manovich 2005b) and in the catalogue edition (Manovich and Kratky 2005), most or all of the data in these pieces seems to be stored as compressed digital video.

<sup>379</sup> Some of which are generated automatically through the analysis of the assets by image processing software, while the others are assigned manually by the authors or their collaborators.

in color or type of motion to the previous one; selecting a clip which matches the previous one partially in content and partially in color, replacing only every other clip to create a kind of parallel montage sequence, and so on.” (2005b)

This process aims at the creation of what Manovich calls database narrative, that is, a narrative that is not originated by a script from which media elements are created but rather a working process that is started from a large database of assets from where several narratives are created. “In Soft Cinema, the media elements are selected from a database of a few hundred video clips to construct a potentially unlimited number of different short films.” (2005b)

Thirdly, we can witness the authors’ attempt to develop what they call macro-cinema. This designation is not so much related to the rule-based aspects of the processes that the system develops but rather to the way a visual composition is broken down into diverse areas where different assets are composed. As Manovich states, “[w]hile filmmakers such as Peter Greenaway and Mike Figgis have already used a multi-screen format for fiction films,<sup>380</sup> thinking about the visual conventions of Graphical User Interface as used in computer culture gives us a different way to do macro-cinema. If a computer user employs windows of different proportions and sizes, why not adopt the similar aesthetics for cinema? In Soft Cinema, the generation of each video begins with the computer program semi-randomly breaking the screen into a number of square regions of different dimensions. During the playback different clips are assigned to different regions. In this way, software determines both temporal and spatial organization of a work, i.e. both sequencing of clips and their composition.” (2005b)

Finally, these three aspects revert in the creation of what Manovich calls “multimedia cinema”, a cinema that is not only built upon film or video but that uses these as “just one type of representation among others: 2D animation, motion graphics (i.e. animated text), stills, 3D scenes (as in computer games), diagrams, etc.” (2005b) Although this supplementation of the normal video image with other types of imagery, analog or digital in source, is nothing new, the authors try to use it for more

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**380** There are much earlier examples of this process. The final reel of Abel Gance’s (1889-1981) *Napoléon* (1927) was conceived as a triptych, to be projected simultaneously in three parallel screens, arrayed in a horizontal row with a total aspect ratio of four to one, in a process that Gance called ‘polyvision’.

than just achieving a purely visual effect and to investigate “the possibilities of using them together for fictional narration” (2005b).

We may conclude that soft cinema is a hybrid between data-driven and rule-based processes, but that it is however, both at a sensorial as at a narrative level, biased towards the data-driven.<sup>381</sup>

A third and final example can be found in installations authored by Canadian artist David Rokeby: *San Marco Flow* (2005a), *Gathering* (2004b), *Sorting Daemon* (2003b), *Taken* and *Seen* (2002d; 2002b). In these works, Rokeby uses live video captures, usually with hidden or surveillance cameras that are further processed by the installations’ systems. *San Marco Flow*, *Taken* and *Seen* are perhaps the pieces that develop the simplest processes, composing their outputs directly from the camera inputs, with little manipulation of the sources, or no individual transformation of these.<sup>382</sup> *Seen* and *San Marco Flow* both work, three years apart from each other, with live observations of the same space, the Piazza San Marco, in Venice,<sup>383</sup> and both develop a similar process, first developed in *Watch* (1995). The video feed is transformed into

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**381** We must also note that the DVD version and the installation versions of the ‘soft films’ differ substantially because the processes at their core are highly contrasting. Where the installation (or projection) versions are composed and edited in real time, the DVD version lives from prerecorded fixed sequences that are later shuffled by the DVD player.

**382** That is, once the transformation process is defined, it is applied to all the sources, regardless of their individual characteristics. The other two pieces, *Gathering* and *Sorting Daemon* do not use the sources in such a linear way.

**383** In *Seen*, due to technical constraints, the video feed is not captured live but rather recorded in a DVD and played back in the space of the installation. As the prerecorded loop is rather long and there was a considerable physical distance between the space that was watched and the space where the projection occurred, this comprehensibly seemed to be a good solution both for the artist and the curators. Furthermore, this concession is not fundamentally compromising the mechanics of the piece, because either live or prerecorded, the system will always be non-interactive (the audience of the piece was in a position where it wouldn’t be able to influence the output) and data-driven. We can however consider that the process intensity of the system was considerably lowered when the live capture was discarded. Even if minute, we could expect variations (both minor, caused by the varying flows of people and animals throughout the day, as major, caused by weather and luminosity changes) and a certain degree of unpredictability in the outputs of the system — something that the other pieces that we discuss here always present. With the prerecorded loop Rokeby offers only a simple, repeating and closed, thirty-minute sequence of events where nothing new ever happens, something that we can consider to be not *his* system but perhaps only, and simply, a simulation of his system. By turning the *mutable* into the *immutable* (although keeping it temporally dynamic, but still closed), Rokeby removes life from the system, by removing change. Although keeping motion, its ongoing closed and rhythmic repetition transfixes time (to use a phrase from René Magritte (1898-1967) (qtd. in Shlain 1991)).

an evolving image where only the moving parts of the source<sup>384</sup> are displayed, creating a 'movement portrait' of the Piazza. In *Seen* the first and fourth projections in the installation are color version of *Watch*, while the second and third projections offer different perspectives on the patterns of flow.

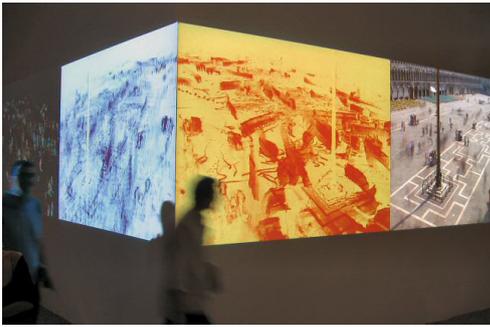


Fig. 8o: *Seen* (Rokeby 2002b).

In *San Marco Flow* Rokeby revisits the Piazza San Marco, layering all the actions that are perceived through the camera into a pair of evolving images that represent two parallel views of the history of the events that happened there.

The images are, in effect, lit by animate presence; things that are not moving are invisible. Walking pigeons leave worm-like traces. Gathered people abstract themselves through their shifting motions. Tour groups flow across the image like a river. The left side accumulates the activities into a very long exposure image that develops visibly over the course of several minutes. This image has layer upon layer of traces building into a rich and complex image that is very painterly and find many resonances with the history of Art and the history of the piazza itself. In the projection on the right, the past fades more quickly resulting in a gently dynamic flow. The evolving images (...) are different readings of the same unfolding source material providing a kind of stereoscopy into the dimension of time. (Rokeby 2005b)

<sup>384</sup> Those parts of the image that significantly change from frame to frame are displayed, usually people, birds and vehicles. Small changes like variations in lighting from passing clouds are usually filtered out. "In this case, what was moving were the people milling about the piazza and the famous San Marco pigeons. What was still was the architecture of the piazza, and the kiosks selling souvenirs and corn with which to feed the pigeons. (...) The processing was performed at full video resolution, meaning that every pedestrian and pigeon on Piazza San Marco left a trace. Flying pigeons drew the arc of their flight, running pedestrians left trails showing their dodges and turns as they wended their way through the crowds. The walking pigeons produced patterns looking rather like arabic lettering as they chased after the scattered corn." (Rokeby 2002a)



Fig. 81: *San Marco Flow* (Rokeby 2005a).

*Taken* presents a more elaborate process, but still one that is fundamentally dependent on the captured data, in this case the motions and faces of the installation's visitors. Unlike the previous examples, in *Taken* we can witness the development of the process while participating in it, thus interacting with the system. The double projection of *Taken* extracts visitors from surveillance cameras that watch the gallery space where the system is presented, looping them back onto themselves in regular intervals. "The result is that every action that has taken place in the gallery since the computer was turned on occurs together on the screen, repeating every 20 seconds. The image stream, provides a kind of seething chaos of activity that can be read both as a statistical plot of gallery activities (where do most people stand to regard the piece? Do they move around?) and as a record of each act of each visitor. The image is densely social, deeply layered and chaotic." (Rokeby 2002c) On the opposite projection Rokeby progressively assembles a catalogue of the visitors, tracking individual faces that are detected in the space and zooming on the heads. "These individual head shots are collected as a set of the last 200 visitors and presented as a matrix of 100 or occasionally all 200 shots, moving in slow motion. This side is analytical and highly ordered and rather threatening." (2002c)



Fig. 82: *Taken* (Rokeby 2002d).

While not completely stepping away from the ideas put to practice in these works, in the later pieces *Sorting Daemon* and *Gathering*, we can find an increase of the im-

portance that rule-based processes play. Both pieces work by appropriating images of people, surveying both the environment where they are exhibited or its surroundings (namely the exterior, thus appropriating people that are not necessarily aware of the systems). The pieces try to understand what in the images that they have access to can be people, removing them from the background spaces and recomposing their images in the screens. On *Sorting Daemon* the images of extracted persons are “divided up according to areas of similar colour” and the “resulting swatches of colour are then placed within the arbitrary context of the composite image [that is] projected”. “On the left side of the composite, flesh-coloured patches are sorted by hue (olive on the left, pink on the right) and size (largest on the bottom and smallest on the top). The right side accumulates all the other coloured patches, sorted by hue horizontally and saturation vertically (with most saturated at the bottom). (...) The extracted person first appears ‘whole’ at the bottom of the composite and then slowly separates into coloured regions which each move to their appropriate location in the composite.” (Rokeby 2003a) In the artist statement about *Sorting Daemon*, Rokeby explicitly acknowledges the importance of not knowing what will the exact results of the process be, an uncertainty that is not only fed by the data that is gathered but also by the processes, that although programmed by the author, act in ways that are uncontrollable. “I have defined the processes, but that is very different from defining the actual resulting output. The painterly look of the composite is an accidental byproduct of the ordering process. The composite seems chaotic, but is actually a completely rational and ordered process.”<sup>385</sup> (2003a)

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**385** To this Rokeby adds an interesting remark: “One of my deepest interests is to try to understand how computers and humans are different. On the surface, it seems relatively easy to differentiate between the two, but as computers become more powerful, many of the capabilities that were clearly displayed only by human beings, are now apparently shared by computers. There are many who are now claiming that computers will soon be able to match human intelligence. I find this a startling claim that need intense examination. Many of my works have been, in part, an investigation of this question and a critic of the assumptions that are being made in this regard.

A second stream of my work over the past 10 years has examined vision, and by extension ‘surveillance’. I have created many systems that ‘see’ in various ways. These endeavors have left me greatly impressed with our own human vision. It is extraordinarily hard to create computer systems that can do the simplest things that we do with our eyes and brain and take wholly for granted. I am astonished at how willingly and easily we underestimate the complexity and subtlety of our own human faculties. If we underestimate ourselves, then we will be in danger of putting machines to work in situations where these undervalued human faculties are actually essential elements.” (2003a)



Fig. 83: *Sorting Daemon* (Rokeby 2003b).

*Gathering* expands some of the ideas initially developed in *Sorting Daemon* to a large immersive video installation that “gathers moving images of people from outside the building” and “separates these images into moving fragments of coherent color which are then arranged and sorted according to a shifting set of rules across 8 video screens” (2004a). Images are arranged according to overall hues as in the previous system<sup>386</sup> but unlike in it, the projections are not arranged side by side but rather in a circle of eight projections, tilted up at one of its sides to allow visitors to enter the space.

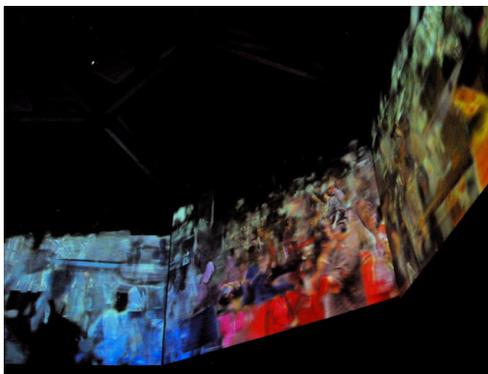


Fig. 84: *Gathering* (Rokeby 2004b).

<sup>386</sup> “First, moving people are located by a camera that can pan around the area. They are separated from the background, and then analyzed for colour content. Flesh toned areas are separated from clothing and the clothing is divided into areas of like colour. These moving patches of colour (...) are then sorted across the screens. The patches are organized by 3 different sets of rules at different times. In one set of rules, they are sorted by hue along the horizontal and by saturation (...) along the vertical. In another they are sorted in order of height. In a third, they are positioned according to the spatial location at which they were captured, returning heads to bodies, t-shirts to jeans, etc., spatially reintegrating the fragments, but producing a densely layered crowd.” (Rokeby 2004a)

### 2.2.2 Visualization

Every remediation of prerecorded images or sounds or of non-algorithmic program code is in a sense a visualization of data or code. Visualization, in this context should be understood not so much as the process of turning something visible, but as the process of translating computer data into human-perceivable forms. As Richard Wright puts it, visualization is conventionally “understood as a mapping of digital data onto a visual image”,<sup>387</sup> a process that is developed to take advantage of the flexibility and immense power of human vision to “perceive emergent properties such as subtle patterns and structures” (2008, 78-79).

Although a similar repertoire of tools and processes can be used to diverse ends,<sup>388</sup> they are used for analytical purposes in engineering or design — to tell us something new about the data, or to allow us to discover what is new and unique in the mapped structures — whereas in art and science they are very often used to methodically tinker and to create new aesthetic or scientific artifacts, that will express something new and unique<sup>389</sup> (Sterling 2008). American artist Charles Csuri, one of the pioneers of computer arts, states that computer graphics offer direct modes of interaction with information, making data become more communicative because the user is able to “interact with mathematical models that simulate social systems or abstract processes or even aesthetic objects. Through computer animation/graphics, the user is given dynamic and pictorial means to view the process of change that is a consequence of his intervention. This enables the user to better understand the complex relationships that produce the results for which his intervention is responsible.” (1976)

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<sup>387</sup> Wright adds that the “need for visualization was first recognized in the sciences during the late 1980s as the increasing power of computing and the decreasing cost of digital storage created a surge in the amount and complexity of data needing to be managed, processed, and understood.” (2008, 78)

<sup>388</sup> The various fields are often difficult to distinguish, as at least since the early 20th century (if not from the onset of human history) we can find a slew of crossed influences, as Leonard Shlain maps in his book *Art & Physics* (1991). We can also find that artistic tools have proven to be able to provide new insights and knowledge, by creating connections among different disciplines, modalities and “their means of perception” that may result in what Wright calls “a new cultural practice, a ‘poetics of knowledge’” (1997, 31).

<sup>389</sup> Sidestepping momentarily, it is interesting to note that whereas we can align with common sense and suggest the existence of two opposite fields between science and engineering on one side and art and design on the other, we may (and perhaps should) pair them differently when it comes to the use that is made of visualization tools (as well as, one can speculate, although that discussion surpasses this work, to their working methods and goals).

Regardless of the field in which they are used, visualizations can be divided in two big classes according to the data that they map, the first of these corresponding to what Wright calls “data visualization” and the second what he terms of the “more general category of computer generated visualizations”<sup>390</sup> (2008, 84). These two classes loosely correspond to what Vilém Flusser<sup>391</sup> called the ‘images of the world’ and the ‘images of equations’ (82). One approach catalogues data (from the world, presumably, or from sources that are external to the system) and constructs the outputs from it, while the other appropriates mathematical expressions or formulas from where the data is generated. Both are data-driven in the sense previously described, they are fundamentally fed by the data and create whatever outputs they produce from it, without developing more complex rule-based processes to select, organize, or interpret such data, leaving that to the human reader. If the data changes the outputs are modified but, if the data remains unaltered, so do the outputs — regardless of the transformations that are operated by the system, there is always a direct mapping<sup>392</sup> between the data and the output.<sup>393</sup> In a data-driven system, as for

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**390** “Scientific representations function (...) on at least two levels: as didactic devices, and as the record and recognition of a ‘state of human understanding’; or, more specifically, as a ‘statement of the state of human awareness’. In addition to their more obvious function of disseminating information, or perhaps because of this function, scientific representations stimulate the imagination. More often than not, they tend to function simultaneously in these two modes according to the needs of their audience, specialists or members of a wider public alike.” (Tomas 2004, 48)

**391** 1920-1991.

**392** It may not be too clear, or linear, but we can consider it to be direct in any case. As Wilden reminds us, a mapping is not necessarily a means of visual representation, as it is a way of structuring information. “A map is a translation from code to code — a translation of selected features of a ‘territory’ into another medium or another code of representation, or the translation of one kind or level of mapping into another kind. Mapping at one or several levels — which is taken to include reconnaissance — is one of the most important activities of systems dependent on information. These include (in order of increasing diversity and complexity) cybernetic machines (including robots, with feedback), computers, organisms, persons, corporations, armies, and societies. Mapping varies from the simplest of mechanical simplicities in the mapping of temperature by a household thermostat, to the relative simplicity of the mapping of patterns of numbers in a computer, to the more complex mapping of the immediate environment (...) by a microbe or a cell, to the high complexity of the many maps of many territories at many levels characteristic of human beings.” (1987, 109)

**393** The output will always stand in an analogical relationship with the data that is used in its creation, something that in a sense will challenge the digital essence of the system, making in more akin to an analog system, as we can infer from Robinson (2008, 21). Which output is produced from the data is also a question of choice from the author, or something that can contingently be determined by the context to which a given system is produced. Franke points to that idea, acknowledging the metamorphic properties (and the fluidity) of digital information: “The means of expression of an artist are adapted to the faculties of human perception. Complex patterns are perceptible only via the eye or the ear, thus making music, poetry and the visual arts in all their combinations and variations the most sophisticated areas of artistic activity. It is interesting to note that the arts, despite highly different results, have one common origin in

example Tobias Frere-Jones's composition *F-Hz* (#190736, 1996) (2000), the output is unchanged provided the data remains static.<sup>394</sup> In this piece the high and low temperature measurements for each day of the year in 1996<sup>395</sup> are converted to audible form by switching the original unit of measure from Fahrenheit degrees to Hertz, thus producing sine waves and arbitrarily establishing their duration as one-tenth of a second for each reading. Should the 732 discrete numbers always reflect the data gathered from the world during the course of that year,<sup>396</sup> (and if the parameters of the transformation are kept) then the final sonic output will always be similar. In a rule-based system, where the values could be generated by a pseudorandom number generator or any other (equivalent or more complex) system, then the outputs would become as dynamic and variable as the numbers produced by the rules. In the first case the composer's work consists of defining the mechanics of the transformation and in selecting the source of data to be fed in the system, while in the other it consists not only of defining the mechanics of the transformations but also those of the generation of the data that will be created by the system for its own use.

Data-driven processes place the control of the data outside of the system, either in information that is gathered from the world or from mathematical structures that generate it, something akin to what happens in interactive systems, where the control of the output is shared with one or several users. Either strategy will endow the system with sources of unpredictability, or enable it to, following Dorin (2008) and Scott Turner (qtd. in Cope 2005, 10), produce novelty. Going even further, when stating the basic properties of generative art systems, Dorin is careful to describe the

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the imagination of the artists: chemo-electrical engrams in the artist's brain. It is only the choice of the specific means of expression — language, music, images — that leads to outwardly different results. The functioning of a computer suggests an interesting analogy: during processing, the data are encoded in electronic impulses; it is up to the programmer to choose the output device — printer, sound generator, plotter. Not only is this analogy remarkable from the viewpoint of history, it also entails practical consequences. The use of computers in art leads to a compatibility of the instrumentarium — to a closer link between the different art forms which, owing to the different classical methods and instruments, have been separated and taught in different institutions. It is one of the decisive aspects of the new situation brought about by the introduction of the computer that there is no longer a reason for dividing art into different forms, be they classical or modern." (1976)

**394** In his notes Frere-Jones discusses how it is impossible for any format to convey all aspects of the meaning of information. "Format is not inherent in any piece of information. Format is applied later, and thus can be changed."

**395** As recorded at the Blue Hill Meteorological Observatory in Milton, Massachusetts, USA.

**396** Also in his notes, the composer notes that the piece "recounts an entire year of climate in a sequence of sine waves. Besides from the one-tenth second interval, every aspect of the composition is 'found', written by the natural world."

production of novelty as being autonomous, that is, emergent or epigenetic. Data-driven or interactive processes rely on exogenous sources of novelty and, although the information garnered can be interpreted and from it new information can eventually be created by the system, therefore producing endogenous novelty, we are focusing here in processes where that does not happen and the system simply (or literally) maps the information more or less directly to its output. This is what happens in *Merce's Isosurface* (Levin 2009), *All Streets*<sup>397</sup> (Fry 2008b) or in the *White Glove Tracking* (Roth and Engebretth 2007) projects, works that although in some cases are temporally dynamic, nevertheless remain static in the sense that they introduce no novelty between repeated viewings.



Fig. 85: *All Streets* (Fry 2008b), general map and Kansas City detail.

In the pieces contributed to the *White Glove Tracking* project we can witness a similar phenomenon, as we are able to identify strong structural similarities between different mappings of the same data (i.e., different pieces), regardless of the transformations that each author developed and of the particular visual resources used.<sup>398</sup> The recurrences between different pieces are so strong that, perhaps due to the power of (audiovisual) magnetization and synchresis (Chion 1994), one soon starts wondering whether there is a real synchronism between the visual and the audial layers.<sup>399</sup>

<sup>397</sup> *All Streets* is an image of 26 million individual road segments in the lower 48 states of the USA. According to the author, no other features, such as outlines or geographical elements were mapped in the image, although they naturally emerge as roads avoid mountains, and sparse areas convey low population (Fry 2008a).

<sup>398</sup> This project proposed different artists and designers to create works from the data collected from Michael Jackson's televised performance of *Billy Jean* on March 25, 1983. The approximate location and size (proportionally to the video frame) of Jackson's famous white glove was compiled for all the 10,060 frames of the performance. The data was collected through crowd-sourcing and the resulting data file was made freely available online for anyone to "download and use as an input into any digital system" (Roth and Engebretth 2007).

<sup>399</sup> The sound of all the pieces contributed to this project is that of the original video. Naturally, there is a strong relation between the music and the glove's position in each frame, connected as they are to Jack-



Fig. 86: *White Glove MHI* (Roth 2007) from the *White Glove Tracking* project.



Fig. 87: *Flocking Gloves* (Wicks 2008) from the *White Glove Tracking* project.

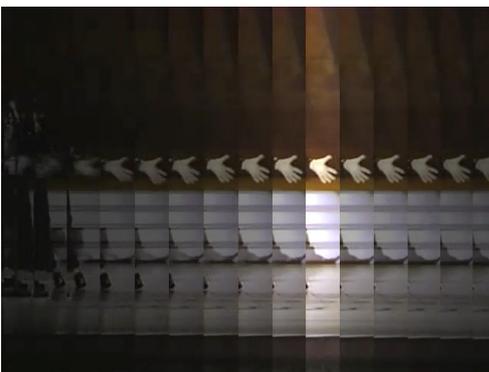


Fig. 88: *Slinky* (Seo 2007) from the *White Glove Tracking* project.

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son's movements. Sudden movements of the glove can happen in close sync to faster rhythms or breaks in the music, while slower movements may be linked to slower passages, etc. We can almost consider the existence of a second-order mapping from music to image through the glove's position (and framing and montage options, something that clearly has a predominant influence in this data set).

If one thinks about works that visualize music, many of the same questions turn out to be equivalent to those we discern in data visualization or in the usage of mathematical models or series. Music is encoded information and its visualization is usually based in strictly numerical parameters such as loudness (or volume), pitches and duration (temporal quantities) that can either be read from the sound itself (using various processes of analog to digital conversion) or are, sometimes, gathered directly from MIDI<sup>400</sup> or OSC<sup>401</sup> data received from the devices that generate or play the music. In the later cases the link that the system builds is not with the music itself — that is, with physical sound matter — but rather with the control layer of the system that is producing the music, and therefore, we are faced with a system that produces both audial and visual outputs from the same data source and not visual outputs from an audial source. If the music visualization system is mainly driven by the data gathered from the music and does not include dominant rule-based process or processes that strongly influence the way in which that data is transformed, then we can safely regard it as being part of a broader class of data-driven processes.<sup>402</sup>

### 2.2.3 Data-Driven Conclusion

Data and action-rules together comprise a generative system, with the potential (in principle) to generate every location within the conceptual space. The number of these locations may be very large, even infinite. (Boden 2004, 90)

There is a further point to be made about data-driven systems and their differences when compared with rule-based systems.<sup>403</sup> We have already seen how data-driven systems externalize the control, while rule-based systems internalize the control. Even if and when using data, they generate it from within. There is always data, and there are always transformations operated on the data in order to produce the multiple outputs, regardless of the nature of the system one builds, experiments

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<sup>400</sup> Musical Instrument Digital Interface.

<sup>401</sup> Open Sound Control.

<sup>402</sup> In many contexts music visualization processes will need to operate in real time, but on one hand that will not happen in all situations, as on the other, real time operation is nowadays much less of a technical problem than it used to be in the not so distant past.

<sup>403</sup> To be precise we should once again underline that we are not simply discussing systems that are exclusively data-driven or exclusively rule-based but also those systems that, although combining both approaches, can be seen as being primarily data-driven or rule-based. Our hypothesis is that any system, regardless of its complexity, will behave in ways that characterize it as being dominated by one of the two groups of processes.

with or studies. In this sense, every system is of course, and inevitably, data-driven, therefore this designation may seem somewhat redundant and unfocused. By using it, what we wish to emphasize is how the particular data that is transformed by a system comes to be, whether it is appropriated externally — from the world, from mathematical expressions or models, from the interaction with human beings or other procedural systems — or whether it is created internally. In the former case a system may be said to be acting transformationally, while on the later the system may be said to be acting generatively.

In this sense we can bring to the discussion two terms that are nowadays very often used in music: sampling and synthesis. When considering the sound matter used in music and how this exists in digital instruments, one can generally split all the existing techniques into sample-based or synthesis-based approaches.<sup>404</sup> Sample-based approaches take the sounds from the external world (from physical phenomena, instruments or other sound producing contraptions) and offer tools to repurpose those sounds in new contexts. They may be seen as top-down approaches, starting as they do from a complete sound and shaping it to other forms, or deconstructing it into simpler (and shorter) units.<sup>405</sup> Synthesis-based approaches intend to produce all the sounds from the ground-up, by using very simple and fundamental generators — sine waves, pulses, etc.<sup>406</sup> — and subsequently combining and transforming them

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**404** Granted, this may seem to be a very reductionist approach but, as with data-driven and rule-based processes, we believe that there are merits in this extreme contrasting, making the differences stand out in ways that would otherwise be more difficult to grasp.

**405** Although related to musical practices such as what is commonly referred to as *musique concrète*, the principles in operation are somewhat different. *Musique concrète* refers to a composition technique “concerned itself with the reorganizing of ‘found sound’ (...) recorded in the home, the factory, the street, etc., and was in many respects reminiscent of its stylistic antecedent, Dada” (Deutsch 2003, 29), “where the essential problem is to assemble sonic objects in a sequence sufficiently ordered to be intelligible” (Moles 1966, 169), while sampling refers only (and simply) to a technical process in the construction of sounds, that may or may not be used in the production of *musique concrète*. In particular cases where the sampling is not only used as a technical sound-creation resource but as a conceptual framework for the composition, different designations have been created, trying to emphasize exactly that — John Oswald’s *Plunderphonics* (1988) being perhaps the better known of these.

**406** To be strict, in current digital sound synthesis these generators are very often operating from samples, that is, they are not, as in analog synthesizers, physical sound generators but are rather reconstructing those simple sounds from their mathematical descriptions. So, although we cannot say that any particular sine wave was sampled to produce the sound that the system outputs when synthesizing a sine frequency at any given rate, we can nevertheless identify the principle of sampling in operation, as the wave was produced from external data. We are however interested in discussing these principles in the creation of more complex sounds so, we may disregard the fact that the basic components are themselves not synthesized, provided the process of the sound creation adheres to the overall principles of sound syn-

through more or less complex processes to produce the final sound.<sup>407</sup> Many musicians place a very high subjective value on this aspect of the music making process. Stephen Deutsch refers the way how postwar electronic music quickly split in two camps, *musique concrète* and *electronische musik*, largely defined by the contrasting approaches to sound production and the composition processes that derived from those (2003, 30),<sup>408</sup> and points as to how these two camps were, by themselves, perhaps analogous to the “initial schism” in film between the camp of the Realists — represented primarily by the Lumière brothers — and that of the Conjurers — from which Georges Méliès,<sup>409</sup> the ‘cinemagician’, is nowadays the most well-known figure (2003, 29).

Regardless of what we call it then, data-driven, sampled, *concrète* or realist on one hand, rule-based, synthesized or conjured on the other, one may find that the first systems are in a sense closed, limited by the inputs they receive,<sup>410</sup> while the later, while still limited by the scope of possibilities — or locations within the conceptual space — generated by their internal rules, can be seen as more open, pregnant with novelty and creative potential.

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thesis, that is, of building the sound from transformations of basic audial units and not from a complex external description.

**407** This is, of course, a broad and crude overview of the processes. Sound synthesis, whether digital or analogue is a complex field, and there is a large number of alternative processes that can be used to achieve sometimes similar end results, such as subtractive synthesis, sample and synthesis, physical modeling, frequency modulation, harmonic synthesis, formant wave functions, granular synthesis and many, many others (Russ 2009; Roads 1996).

**408** According to Deutsch, *electronische musik* “based upon the notion of technologically-led art with a technological aesthetic, held sway intellectually and politically, and was a dominant form of avant-garde music during the period 1950-75. To make such music, these practitioners needed to be totally *au fait* with the technology, which initially consisted of oscillators, filters, ring modulators, reverb units and tape recorders. Both technologically and aesthetically, *electronische musik* was predisposed away from tonality and harmony. It was directed towards structuralistic and colouristic systems of composition...” (2003, 30).

**409** 1861-1938.

**410** “Without doubt very interesting results can appear which have never been seen before. For long-term artistic interest however, the resulting aesthetical information of a mathematical formula is in itself limited and therefore a closed system. The research to find or invent individual rules as a means of artistic expression. The individual impact of human behaviour, filtered and reformed through the inherent peculiarities of a computer, will lead directly to an interesting and overall coherent open system. Of course mathematics are used, but in this case only as a technical help, and not as the sole purpose.” (Mohr 1976)

## 2.3 Algorithmic / Rule-Based

### 2.3.1 Rule-Based Processes

Rules are information about information, stored information that is remembered and expressed every time a rule is used. They are informational constraints that goalseeking adaptative systems observe in the creation of structure: organization, complexity, meaning.

Every system of rules depends on rules about rules, including the very idea of rule itself. The following might be called the Rules Rules:

- No rule without exceptions.
- Rules are made to be broken.
- The exception tests the rule.
- A rule to which there are no actual or imaginable exceptions ceases by that fact to be a rule (after Benjamin Lee Whorf).

By recognizing that rules may be broken, we recognize that rule-governed systems are open to innovation. (Wilden 1987, 103)

If a system feeds on information that is provided externally, it may be regarded as not delivering more than a set of more or less complex transformations that are operated on that data. To a point, the system may be interpreting that data, but whatever interpretation is made, it will be, for the most part, neutral. Naturally it is granted that whatever input a system receives will need to conform to that system's capacity to detect and read it — a system may have upper or lower limits on the resolution of the data it transforms, much in the same way as it will have a more or less predefined scope of possible outputs for those transformations<sup>411</sup> — so a system will not be able to operate on any data that falls outside of its detection limits, as much as

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<sup>411</sup> Simple examples: a system that samples its input once a second will fail to detect variations in the input that fall in between different samplings, say, every tenth of a second or faster; A system that reads light in the human visible range, much like humans, will fail to detect light sources in the infrared range; A system that inputs integer numbers will fail to see most differences between float numbers, depending on the way it may round or truncate them.

it will not be able to output any such data.<sup>412</sup> But in regard to that data it may operate into, the system will (in principle) not discriminate, it will be neutral, unbiased and ultimately uncreative. The data that is fed in the system may provide it with structures that are complex enough as to give us the impression, once we analyze its output alone, that the system is producing novelty, a structurally coherent or even an unpredictable set of outputs, but we must understand that the root for these phenomena is in the data and not in the system itself. In these cases it may be said that the system demonstrates the capacity to transform the inputs in meaningful (or even elaborate) manners, but that its potential for artificial creativity is low or even nil.

If on the other hand, we wish to devise systems that can operate independently from external inputs by producing novelty, surprise and ultimately acting creatively, we will need to resort to rule-based processes. In these the data is not only acquired and transformed by a system but may also be effectively produced by itself prior to whatever transformations may also take place and to its conversion to sensorial outputs.

We should firstly try to define more clearly what, in the context of this work, we understand by rule-based processes. In *Generative Art and Rules-Based Art* (2006), Galanter tries to expand his original definition for generative art,<sup>413</sup> distinguishing in a first moment generative art from computer programming, or from computer-programmed art. According to Galanter, interpreting both as being synonymous is a mistake, because “generative art long preceded computers” and “can include a chemical reaction, the use of living plants, condensation and crystallization processes, melting substances, or any other physical process that can take place autonomously.” He defends that generative art happens every time that the artist chooses to “to cede some degree of control to an external system, and the artwork thus results from more than just the moment-to-moment intuitive decisions of the artist”.<sup>414</sup> He

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**412** Which is not to say that a system will not be able to output information that is then unable to read, because that can also happen. Much in the same way that humans emit infrared energy that are not able to detect unaided, a system may produce physical outputs (electromagnetic, thermic, audial, etc.) that it may be unable to detect without the help of specific, and specialized, transducers.

**413** “Generative art refers to any art practice where the artist uses a system, such as a set of natural language rules, a computer program, a machine, or other procedural invention, which is set into motion with some degree of autonomy contributing to or resulting in a completed work of art.” (Galanter 2003) In various successively refined versions, this has been taken by other authors and artists as a good, if not as the finest, definition for generative art (Watz 2006).

**414** In the context of this work we might even slightly rephrase this definition, pointing not to an external system but to the system that the artist builds. Therefore the source of control to whom the artist

states that the terms generative art and rules-based art are sometimes used interchangeably and tries to “add clarity to the language, [to] show that the terms are indeed usefully different”. Safeguarding that a “full exploration of the historical relationships between rule-based art and generative art and the related art movements could fill a book or even a career”, he proceeds to develop a brief overview of what he considers to be the fundamental distinctions, enumerating a few rule types and indicating which can be considered to constitute generative methods.

Galanter starts by quoting the opening statement of American curator Marc Glimcher in the catalogue for *Logical Conclusions, 40 Years of Rules-Based Art* an exhibition at the Pace Wildenstein gallery in New York.<sup>415</sup> In his essay, Glimcher offers his definition of rule-based art: “For purposes of this investigation, rule-based art will be defined as art created utilizing one or more logic-based systems to direct the design and creation of the object. Their foundation may be mathematical, such as those based on geometric and number theories. Or, they may be founded in logic: for example solipsism and other tautological constructs. And finally, there are applications of game theory, in which the artist forces the art to conform to certain arbitrary (if personally meaningful) rules.” (Glimcher and Rose 2005) This definition implies an overlap between rule-based and generative arts but, according to Galanter is also unfortunately problematic, over-inflated and yet not inclusive of all the works on display, that were “either well outside of this definition, or sometimes within the definition in ways that are trivially reductionist”<sup>416</sup> (2006). Galanter complements the short analysis on *Logical Conclusions* with a similar exercise about *Beyond Geometry, Experiments in Form, 1940’s-70’s*, shown at the Los Angeles County Museum of Art<sup>417</sup> and curated by Lynn Zelevansky. The conclusion of the second analysis reinforces that of the first, in which even if both exhibitions come very close

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cedes the decisions is internal to that system, not external to it, although it will be in either case external to the artist herself.

**415** February 18 to March 26, 2005.

**416** “Mathematical systems’ are typically systems of axioms and deduced propositions. Such activities are not evident in the works cited, but there are pieces that are based on simple arithmetic. While solipsism and tautological constructs are part of ‘logic,’ they are deflated aspects devoid of the long chains of reason logical systems would usually connote. The invocation of ‘game theory’ is simply mistaken in that game theory as a discipline is the mathematical analysis of economic situations where multiple agents attempt to optimize a series of interactions to their own benefit. Some of the artistic processes exhibited are vaguely game like, but they are single player games devoid of any competitive or economic aspect. In other words, they may be games in the common sense, but they are not subject to game theory as such.” (Galanter 2006)

**417** June 13 to October 3, 2004.

to make the argument that Galanter is defending, to underline “how interwoven generative art already is with traditional art”, they nevertheless fail to do so, and “the mainstream art world remains blind to generative art as the sweeping inclusive tendency it is.”

Galanter then moves to expose the differences between rule-based and generative art, again defining them as “independent realms with an area of overlap” and stating that “a number of generative systems are not rule-based at all”. Galanter’s definition of rule-based seems to be clearly different from the one developed in this work (and thus far described not as rule-based art but rather as art developed by rule-based processes). We will further develop this, but let us first see what else Galanter presents as part of his definition: generative systems “can include various forms of mechanical painting and drawing machines, chemical reactions, the use of living plants, condensation and crystallization processes, certain forms of kinetic sculpture, and so on”, while “rule systems which are not generative lack the specificity and autonomy to create results ‘on their own’”. We may therefore agree with Galanter’s underlining of the necessity to create results (or novelty) “on their own”, from within, endogenously or autonomously, rather than relying on outside sources of novelty, be it data, users, or the artist herself. If we remember the Principle of Computational Equivalence, that states that “almost all processes that are not obviously simple can be viewed as computations of equivalent sophistication” (Wolfram 2002, 716), we may easily regard the systems presented by Galanter as being computational at their core, regardless of whether they are natural (chemical reactions, the use of living plants, condensation and crystallization processes) or artificial (mechanical painting and drawing machines, kinetic sculpture), if they are contemporary and developed with computers or if they can be found in examples from the history of art, developed manually or mechanically. In any case, once appropriated as part of an artwork or other aesthetic artifact, all processes, regardless of their root, become part of the artificial process that is the artwork. We may also discover several other rule systems with serious creative potential in a list of rule systems which are not generative that is presented by Galanter. This list includes constraint rules, rules which present abstract scores for free interpretation, inspirational rules, rules as frozen plans for installation or fabrication, rules dictating thematic manual creation, the rule as performance script or ritual and manual interpretation of non-autonomous rules. On the other hand, Galanter’s list of rule systems which are generative systems includes rules as algorithms, rules as recipes

for autonomous processes, rules as a well-defined widely applicable process, combinatorial rules, numerical sequences as rules, line composition or drawing rules, the rule of serial generation, tiling and other symmetric composition rules, chance operation rules, clustering rules that create composition, mapping from one domain to another and finally, rules which create cycles and phase interactions. We will now analyze these systems of rules, adding some that were not contemplated by Galanter, in an attempt to clarify what is (also according to Galanter) a very fuzzy category.

### 2.3.2 Rule Systems That Are Not Generative: Constraints

The first rule system that Galanter cites as not having generative potential is that of sets of (artificial) constraints that limit and therefore partially define the composition space of a piece. “For example, ‘the artist will use a 4’ by 3’ canvas, and only cobalt blue and black paint.’ An artist might choose to use constraint rules to create controlled experiments (in the case of Albers), or to press an art-theory point (as with Manzoni), or to simply activate the creative process by reducing an infinity of options to a workable number (as with Zittel).” (Galanter 2006)

Although constraint rules can certainly have creative potential, we agree that in these examples they cannot be understood as generative (in Galanter’s sense of the definition) or even as rule-based processes (in our’s). Depending on the type and specificity of the constraints, some cases may constitute systems capable of (semi-) automatically generating outputs, as in the previously noted case of LeWitt, where one can speak not so much of constraints but perhaps of (to use LeWitt’s words) “a plan” (1969b). LeWitt saw this as “one way of avoiding subjectivity” that also “obviates the necessity of designing each work in turn”.

The plan would design the work. Some plans would require millions of variations, and some a limited number, but both are finite. Other plans imply infinity. In each case, however, the artist would select the basic form and rules that would govern the solution of the problem. After that the fewer decisions made in the course of completing the work, the better. This eliminates the arbitrary, the capricious, and the subjective as much as possible. This is the reason for using this method.

When an artist uses a multiple modular method he usually chooses a simple and readily available form. The form itself is of very limited importance; it becomes the grammar for the total work. In fact, it is best that the basic unit be deliberately uninteresting so that it may more easily become an intrinsic part of the entire work. Using complex basic forms only disrupts the unity of the whole. Using a simple form repeatedly narrows the field of the work and concentrates the intensity to the arrangement of the form. This arrangement becomes the end while the form becomes the means. (1969b)

Although when exposed in this sense the system does not detail a strict process, whenever the constraints are too strong one may consider that whatever freedom the artist may have within those constraints will actually become the process. If one's moves are severely limited, if the possibility spaces for the artist's action are bounded by constraining rules, then that limitation can be seen as being part (or all) of the process.

Of course that simpler constraints such as the first cited above, determining format and color palette, can be regarded as too weak, not quite constraining the action enough to be considered as process-defining. Constraints that on the other hand are very strong, that specify to a great detail every action to be or not taken, will likely prescribe all the steps taken by the artist in the execution of a work that abides by them. In this case we can already speak of algorithms or effective procedures instead of constraints. On the other hand, we should note that whenever an effective procedure is defined and set in motion, the processes encoded in the procedure will generate a space of possibilities for its outputs to be created in. Not allowing any output to fall outside of this field will, for all purposes, set boundaries that cannot be breached because the system is not able to do so. Any rule-based process is then, in effect, a definition of constraints — but one that does not start by disallowing but rather by allowing things to exist.<sup>418</sup> We may therefore propose that for a system to have generative potential<sup>419</sup> it will need to be bound by constraints, in most cases very severe constraints. Therefore generative potential will not so much be a mat-

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**418** To be precise, many logical expressions can be interpreted as being designed to disallow possible states, such as when a designer explicitly filters out values that fall outside a certain scope. What we find fundamental is that even in cases where those expressions are used, the space of possibilities is defined affirmatively — by stating what will happen, or what *can* happen — and not negatively, by stating what should be excluded.

**419** An expression that we prefer, and find less subjective than as Galanter proposes 'to be generative'.

ter of whether there are constraints — as there *must* be — but rather of how strong those constraints are in the system and how many of them can be found.<sup>420</sup>

Extreme constraints will inevitably result in a deterministic system and, as we have previously seen, any computational system is by definition relentlessly deterministic (Rucker 2005, 11). Taken to an extreme, determinism and constraining will result in systems like *Every Icon* (Simon 1997b), where every future state can easily be predicted by an informed observer or, if we subscribe to pancomputationalism, we will even be able to consider that they result in any static, classical, artwork,<sup>421</sup> where every stroke, chiseling or action taken by the artist becomes a constraint.<sup>422</sup>

### 2.3.3 More Rule Systems That Are Not Generative

The second type of not-generative system presented by Galanter is that of rules which present abstract scores for free interpretation, defined as “systems of abstract symbols without a intended or predefined mapping into a multidimensional qualia

**420** “Complexity is a quality based on diversity. Diversity is the combination of two or more kinds of variety. A system displaying only one level or kind of variety — such as the ‘organized simplicity’ of the planets in mechanics or the ‘unorganized variety’ of the molecules in a gas in thermodynamics — is neither complex nor diverse. Considered simply as the means of counting, for example, the positive whole numbers display infinite variety. But all of this variety is of the same kind and exists at the same level: the whole number system does not display diversity.

Systems displaying one kind of diversity (two kinds of variety) are the least complex of complex systems. If we consider the variety of the positive integers, not on the basis of counting alone but also by the quality of being odd and even, then the whole number system displays two kinds of variety and one kind of diversity.

The more levels and kinds of variety a system displays — living systems operate on many thousands of levels (the average cell may contain 3,000 different enzymes) — the greater is its diversity and thus its complexity.

Complexity and diversity are products of constraint. One kind of constraint produces one kind of variety. Complexity and diversity thus require the operation of more than one constraint. The more levels and kinds of constraint that govern (but do not determine) a system, the more levels and kinds of diversity it is sensitive to, and the more complex and diverse it is.” (Wilden 1987, 172).

**421** Even static painting or sculpture can be seen as being, at its core, a dynamic process. If works of art were not transient and mutable (although with a rather slow pace) they would not be part of this world, they would not deteriorate or need special preservation and restoration.

**422** We may also speculate that the authorial mark left in the work increases with the constraints, but that may not necessarily mean that the absolute authorial mark is only achieved with absolute constraints. An artist as Josef Albers (1888-1976), following rules that result in a static artifact can be found to have a small authorial imprint (if we may call it as such) in the definition of the rules, and a very strong one in the finished piece, that is an outcome of the rules and of his actions while abiding them, but his authorial mark will be left only in that one object, while in dynamic systems that may produce multiple outputs, the authorial imprint of the artist or designer is left across all of them.

space. The live performer invents a mapping from the abstract symbols into a property such as pitch, or color, or energy level, and then performs the score. Needless to say, some of these mappings will be more improvisational than others.” (2006) As an example he proposes a score by Earle Brown,<sup>423</sup> *December 1952* (1952), from which the performers are supposed to “translate the abstract parameters of graphic forms into sound by a performing mappings of their own invention”, “the horizontal dimension might be pitch, and the vertical dimension loudness” but no interpretation or suggestion is offered by the author regarding that. Cage’s *Mesostics* are another example of these “rule systems”,<sup>424</sup> graphical poems intended to be performed but provided to the performer without any instructions whatsoever to guide the performance or the mapping between graphic forms and music to be produced from them.<sup>425</sup> Although much less improvisational, Cathy Berberian’s<sup>426</sup> music scores were also designed to provide a vast amount of freedom in the interpretation, and were not intended to be followed with the strictness that traditional musical notation normally requires. Cardew’s *Treatise* (1967), a 193-page musical score written for no specific type of instrument, with no instruction or guidance for the performers, can also be regarded not so much as a rule system but as an inspirational cue that could be interpreted with a wide latitude by the performer or performers.

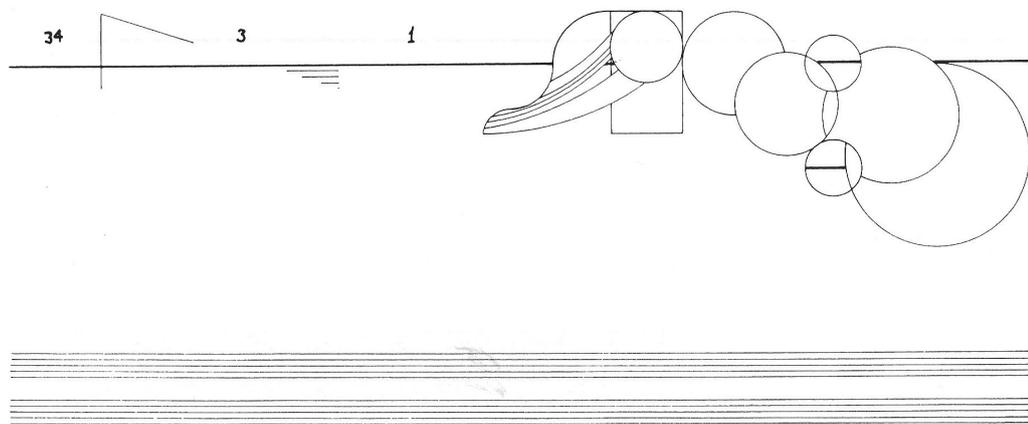


Fig. 89: Page from *Treatise* (Cardew 1967).

<sup>423</sup> 1926-2002.

<sup>424</sup> At this point one feels the need to safeguard the expression by surrounding it with scare quotes, as not doing so would almost seem inadequate in the present context.

<sup>425</sup> The text in the *Mesostics* was naturally intended to be read or sung, but always as part of a musical interpretation, never as a poetry declamation. Even in such a case, the *Mesostics* would still require the reader to develop a very personal and subjective interpretation.

<sup>426</sup> 1925-1983.

Inspirational rules are the third type listed by Galanter, a definition that in his own words may “appear to be an oxymoron” (2006). Inspirational rules are a somewhat common phenomenon and some have met with considerable reputation or popular fame in recent years, such as the deck of cards produced by Brian Eno and Peter Schmidt called *Oblique Strategies* (1975), posteriorly updated in several versions, both in physical as digital supports. *Oblique Strategies* originated when its authors concluded that they “tended to keep a set of basic working principles which guided them through the kinds of moments of pressure” and that “the pressures of time tended to steer them away from the ways of thinking they found most productive when the pressure was off.” (Taylor 1997) The system was then devised as a way to “to remind themselves of those habits of thinking — to jog the mind”, as a set of heuristics, one could say. It was suggested that “the deck was not conceived of as a set of ‘fixed’ instructions, but rather a group of ideas to be added to or modified over time”, an idea that was reinforced by the inclusion in the deck of “4 or 5 blank cards, intended to be filled and used as needed.”<sup>427</sup> (1997) A second example presented by Galanter is Ad Reinhardt’s<sup>428</sup> *Abstract Painting, Blue* (1952), a work where the canvas is overlaid with a three-by-three grid of rectangles rendered in blue paint, with so subtle tonal variations between each of the squares that the painting only reveals its composition after prolonged and focused observation. Reinhardt’s rule for the

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<sup>427</sup> In a 1980 interview, Eno discusses the creative process that conducted to the creation of the first edition of *Oblique Strategies*. “These cards evolved from our separate working procedures. It was one of the many cases during the friendship that he [Peter Schmidt] and I where we arrived at a working position at almost exactly the same time and almost in exactly the same words. (...) The Oblique Strategies evolved from me being in a number of working situations when the panic of the situation — particularly in studios — tended to make me quickly forget that there were others ways of working and that there were tangential ways of attacking problems that were in many senses more interesting than the direct head-on approach. If you’re in a panic, you tend to take the head-on approach because it seems to be the one that’s going to yield the best results. Of course, that often isn’t the case — it’s just the most obvious and — apparently — reliable method. The function of the Oblique Strategies was, initially, to serve as a series of prompts which said, ‘Don’t forget that you could adopt *this* attitude,’ or ‘Don’t forget you could adopt *that* attitude.’ (...) The first Oblique Strategy said ‘Honour thy error as a hidden intention.’ And, in fact, Peter’s first Oblique Strategy — done quite independently and before either of us had become conscious that the other was doing that — was ... I think it was ‘Was it really a mistake?’ which was, of course, much the same kind of message. Well, I collected about fifteen or twenty of these and then I put them onto cards. At the same time, Peter had been keeping a little book of messages to himself as regards painting, and he’d kept those in a notebook. We were both very surprised to find the other not only using a similar system but also many of the messages being absolutely overlapping, you know... there was a complete correspondence between the messages. So subsequently we decided to try to work out a way of making that available to other people, which we did; we published them as a pack of cards, and they’re now used by quite a lot of different people, I think.” (Amirkhanian and Eno 1980)

<sup>428</sup> 1913-1967.

creation of this work states “...one formal device, one color-monochrome, one linear division in each direction, one symmetry, one texture, one free-handbrushing... No lines or imaginings, no shapes or composings or representings, no visions or sensations or impulses... nothing that is not of the essence.” (qtd. in Galanter 2006)

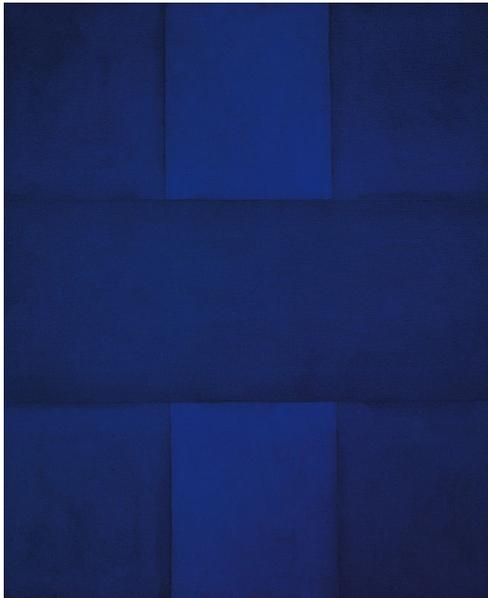


Fig. 90: *Abstract Painting, Blue* (Reinhardt 1952).

A posteriori, one can certainly identify the correspondences between rules and finished piece but in these rules one does not discover a strong enough set of constraints that would dictate this particular piece among many other, and radically different, possible end results. One does not find detailed procedural instructions from which this result could emerge. As Galanter puts it, “this is not a mathematical, logical, or ‘game theory’ rule”, but “more of a manifesto that constrains the activity of the artist within a narrow range”, but not narrow enough to remove a large majority of the decisions from the hand of the artist, effectively constraining his actions (and creativity, and will) so as to make the rules become responsible for a minimum of coauthorship of the end-result. Many of the works produced by Reinhardt can be seen as being inspired by such writings, but as this excerpt proves, such manifesto-like inspirational approaches are usually not deterministic enough to be considered as rule-based systems in this context.

Rules as frozen plans for installation or fabrication are also presented as being void of generative potential. Galanter refers to blueprints or their information equivalent,

that usually constrain the results to a maximum and allow for a zero-degree of freedom in terms of inventing mappings at the time of execution, once that the blueprint needs to be strictly followed at all times. Naturally, and as a practical matter, “fabricators and artisans will leave their own traces in the rendered media” but “because blueprints demand a predetermined fixed result they are usually not viewed as being generative.” (2006)

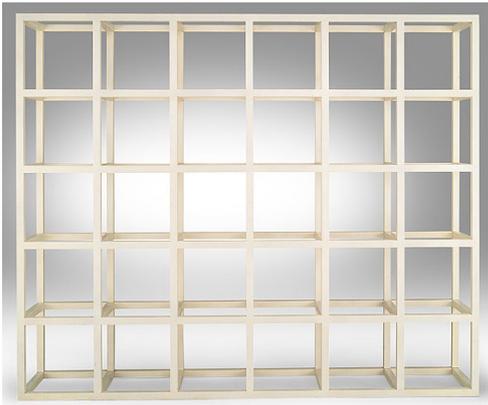


Fig. 91: *Cubic Modular Piece No 3* (Le Witt 1968).

An example of such a system can be found in LeWitt’s *Cubic Modular Piece No 3* (1968), a work drawn from precise instructions for a process leading to a totally determinate (and inalterable) end-result. Blueprints and similar systems do not allow for variation or for a degree of indeterminacy in the outcomes of the fabrication process, therefore they can be seen as being a data-driven process and not a rule-based process.<sup>429</sup> We should also note that blueprints, unlike emergent systems, usually involve a one-to-one reversible mapping between the design and the outcome of the process (blueprint and house, or car, or computer), whereas emergent systems are irreversible (Dawkins 2009).

Rules dictating thematic manual creation are basic ideas or themes sometimes referred to as being generative because they inspire a family of ideas or activities as variations and applications. About these, Galanter states that they are “generally excluded from the notion of generative art because they depend on a human being act-

<sup>429</sup> We can make the case that some blueprints may be generated from rule-based processes, as it is common in architecture or industrial design, for example, but in such instances we should, as Xenakis, differentiate between the act or process of designing the blueprints — a generative, rule-based, endeavor — and that of implementing them — a non-generative, data-driven work.

ing as the generative system. Of course human beings *are* generative systems when viewed as objects. But taken as is, it leads to the conclusion that all art created by humans is generative art. At that point the term generative art loses utility and distinct meaning. Typically by generative art we mean art created with the assistance of non-human generative systems.” (2006) Ruscha’s *Various Small Fires and Milk* (1964) art book is cited as an example, as its operative rule is that only pictures of the thematic subject matters should be used. This is a process that Ruscha developed in other works and publications, such as *Nine Swimming Pools* (1968).<sup>430</sup> A further example is found in the works of Bridget Riley that although seemingly possible to summarize by mathematical rules, were in fact generated from intuitive processes.

Rules as performance script or ritual follow from these, and were often explored in conceptual art, in what Galanter refers to as “a sort of minimal performance art”, work that can usually be regarded as being rule-based because it is the result of performance instructions. However, as no control is ever transferred to systems that are external to the artist or the performers, such work cannot be considered generative.

Finally, in the list of systems enunciated, we have the manual interpretation of non-autonomous rules, found in miscellaneous rule-based artworks that share only the notion that a generative idea can be explored in a series of manual variations. Several works by On Kawara can be given as examples.

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<sup>430</sup> Between 1963 and 1978 Ruscha produced a total of sixteen books using various concepts as these — the first of the series was titled *Twenty-Six Gasoline Stations*. Ruscha always stated that he thought of the title before taking the photographs, underlining the conceptual aspect of the works.



Fig. 92: *June 19, 1967, Oct. 31, 1978, 2 Juin 2000 and Sept. 25, 2002* (Kawara 1967; 1978; 2000; 2002).

Each of Kawara's works must be, according to his set of rules, completed in a single day, show the date of creation, and include a box lined with a newspaper of the day attached to the back of the canvas. These rules are very specific but still they are unable to determine the piece autonomously, leaving once again most of the operational decisions to the artist. We can find a similar *modus operandi* in the works of French-born Polish painter Roman Opalka, that in the mid-1960s started painting by a process of counting, from one to infinity. Each of his canvas is filled with sequential numbers, starting in the top left-hand corner of the canvas with the number after the last painted in the previous painting, and finishing in the bottom right-hand corner. Each of the canvas is of the exact same dimension (196 × 135 cm) and is executed in a similar way, following an almost ritual approach that is still continued by the artist, more than forty years after it was started. Again, as systematic as this process may be, and as similar as it may be to some rule-based processes, we cannot define it as being generative, or as being endowed with any autonomy from the artist that executes it, unlike what happens in the rule systems proposed as exemplary of generative potential.

### 2.3.4 Rule Systems That Are Generative Systems

On a fundamentally different level, not necessarily of complexity but rather of autonomy, or capacity to produce novelty and to take the creative control from the artist, are a series of twelve systems that Galanter presents as “rule systems which are generative systems” (2006). Some of these have already been discussed but we will nevertheless revise the list, and expand it where necessary.

The first system is that of “rules as algorithms”. Galanter does not offer his definition of algorithm, but it is safe to assume that he follows the somewhat standard definition we have been following, that of a complete set of instructions that are given to a machine (or human) in order to solve a problem or to describe the strategy for its resolution, an effective procedure. The example offered, from the *Logical Conclusions* exhibition, is a work by Tom Friedman, a sculpture constructed from 36 boxes of s.o.s. scouring pads, that were measured, cut, incrementally offset, and then glued together, creating a single enlarged version of the original boxes.<sup>431</sup> Other works by Friedman use the same system, a process that after the selection of the input (which kind of box) and of a single variable (how many boxes to use) will autonomously produce outputs, leaving no choice to the human operator (be it the artist or an artisan).<sup>432</sup> In its (relative) simplicity, we find it to be an excellent example, not only because it is a process that most persons could imagine being able to develop with little more resources than common office supplies, as also in spite of rigorously describing a process, it does not depend on a computer or any knowledge of programming to be executed. For these “rules as algorithms” to be valid as generative

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<sup>431</sup> “Friedman’s working principle revolves loosely around codes of construction. (...) The sos box is inflated to Warholesque proportions, but that inflation is accomplished by juxtaposing the grid-wise dissected elements of (...) sos boxes. The resulting work reveals an enlargement that shares the grainy, out-of-focus quality of overenlarged photographs. In fact, both Warhol’s and Friedman’s manipulation of space as a phenomenon depends upon the mathematical principle of multiplication. In Warhol’s case the rule is expansive and simple. In Friedman’s it is algorithmic, efficient, and complex, but it is the essence of the principle of replication that the artist seeks to make visible through his experimentation.” (Glimcher and Rose 2005, 121)

<sup>432</sup> Relying as it does on a human executor (one is tempted to say a human *computer*) this algorithm does not need to define all the articulations of the process. Humans are, after all, resourceful and intelligent executors, unlike computers or other machinery. Much in the same sense, an algorithm written for execution by a computer, while needing to detail in much more detail several of the steps in the process, would not need to detail those operations that were already specified by the system it runs in or the programming language with which it is written — as an example, if arithmetic is used in the algorithm, the programmer will (normally) not need to specify how arithmetic operations should be computed, etc.

systems, we need to understand them as cases in which all, or most, of the decisions are prescribed by the algorithm, either because the process is laid out with such a reduced margin for uncertainty that decisions will not be necessary or because the algorithm itself provides the tools for making the choices, whenever the need arises.<sup>433</sup>

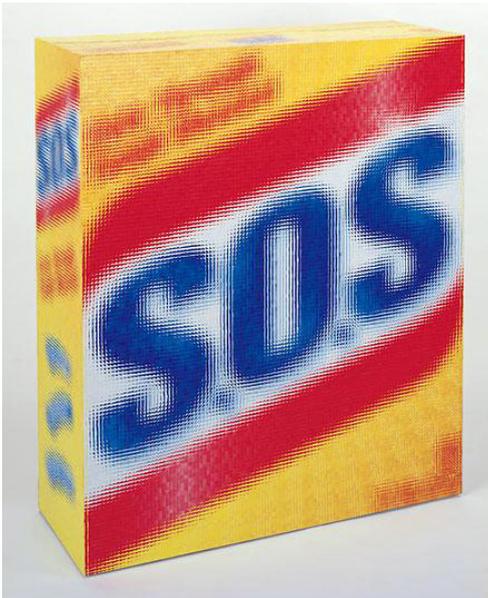


Fig. 93: *Untitled* (Friedman 2004).



Fig. 94: *Untitled* (Friedman 2000) and detail.

<sup>433</sup> A measure of indeterminacy is also contemplated by this algorithm — not only in the choice of input and variable (not precisely specified) as in the details of the boxes used in the construction (printing errors, variations in color, texture, etc.) and in the relative inaccuracy of the manual execution of the construction process, revealing minute imprecisions, and other quirks.

Under this system one can also list works by Chuck Close, large format portraits created from photographs that are “divided with an overlying grid made of a predetermined number of units. A canvas is then divided into a grid with an equal or a smaller number of units.” Close then “transcribes the image, block for block, from the photograph to the canvas. This transcription takes one of many forms”, rendering a new image, closely based on the original photograph but truly unique.<sup>434</sup> (qtd. in Glimcher and Rose 2005, 70)

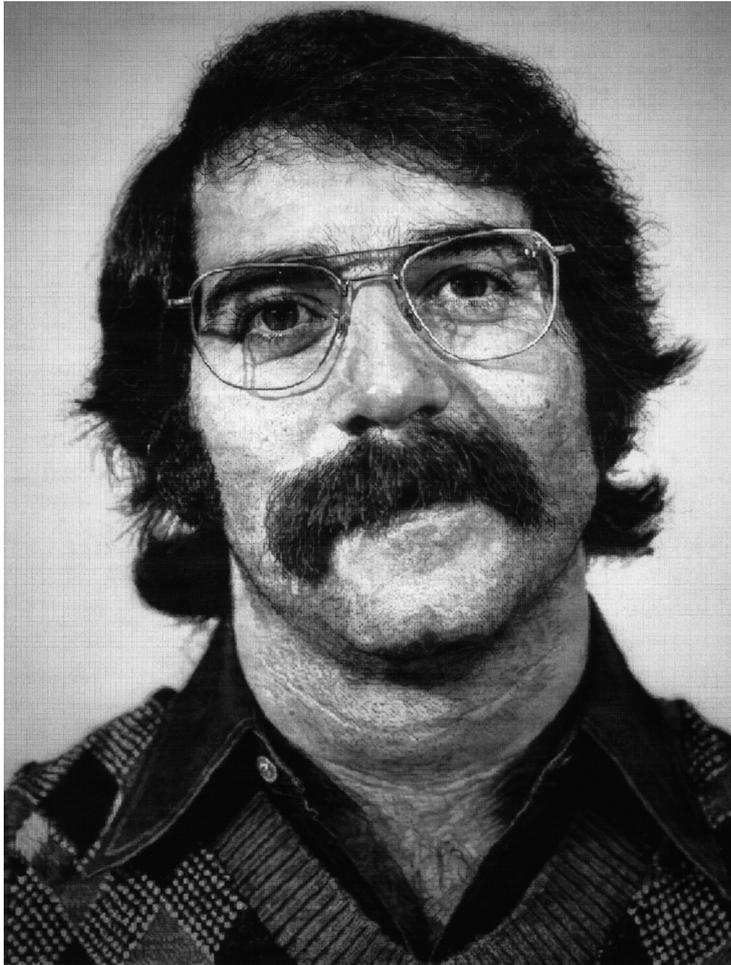


Fig. 95: *Robert / 104,072* (Close 1974).

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<sup>434</sup> “I wanted to make something that was impersonal and personal, arm’s length and intimate, minimal and maximal, using the least amount of paint possible but providing the greatest amount of information possible. Showing no display of the artist’s hand in terms of virtuoso brushmanship but employing unbelievable handwork, you know lots of labor. And I was always interested in the tension that comes from those dichotomies and those extremes. I always thought the best art was extreme whatever it was.” (Close, qtd. in Glimcher and Rose 2005)

The second system listed starts from a “recipe” but allows for a far greater latitude in its implementation. Galanter calls it “rules as recipes for autonomous processes” and exemplifies it with Ruscha’s book *Every Building on the Sunset Strip* (1966). All the photographs in this book are printed on a single sheet, folded as an accordion, with a total length of over eight meters, showing each side of the sunset strip, in Los Angeles. According to Galanter, Ruscha “eschews typical notions of composition and the decisive moment in photography, and instead implements the title of the piece by simply capturing *Every Building on the Sunset Strip* in his camera” (2006) and that even if “the piece was manually implemented, it is generative in principle” because the title rule “could have been handed off to a technician or a robot for execution”.

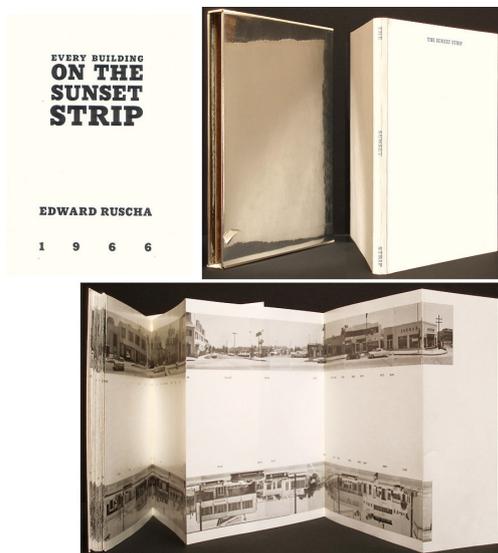


Fig. 96: *Every Building on the Sunset Strip* (Ruscha 1966).

Unlike the algorithm used by Friedman, (described as an “axiomatic system” by Glimcher),<sup>435</sup> the title of *Every Building on the Sunset Strip* can only barely be interpreted as a rule in this case, because if it defines a theme and something that can be generally understood as a goal, it does not constrain in any way the approach that the artist will develop. Stated as it is, the title does not specify how the photos should be made, how they should be composed in the book, or how its physical structure

<sup>435</sup> Axiomatic systems are, according to Glimcher, working under the strictures of rules and use logical systems to control the creation of the work. “These artists (...) identify an axiom or universal law, such as thermodynamics, fractal geometry, or the unidirectionality of time, and set it up as the condition of the artwork’s creation. Unlike some rule-based artists who subject their *vision* to a system as such, artists who pursue axiomatic systems begin with specific propositions, experimenting with their effect in a variety of visual and constructive projects.” (Glimcher and Rose 2005).

should be devised. As relevant as the portrayal of every single building on the Sunset Strip, the accordion folding, the pairing of the opposite sides of the street, the printing and even the “harsh light of high noon, making [the Sunset Strip] appear as dull and tacky-looking as a Midwestern Main Street” (David Bourdon qtd. in Glimcher and Rose 2005, 30), among other factors, all contribute to the significance (and the multiple levels of complexity) of this work. Of all of these, only one is specified by what Galanter identifies as a rule and all of the remaining were left to the artist. If a ‘robot’ or a technician were to be handed with the execution of the photographs (to say nothing about the execution of the entirety of the work), a much more complete and detailed set of rules would have been necessary. It is hard to understand where exactly Galanter is finding the differences between this work and those listed under his “rules dictating thematic manual creation”, so we certainly cannot find a strong enough justification to regard this work as generative. An interesting case can be made when comparing this so-called rule from Ruscha to that of Young on his *Composition 1960 #10* (1960), “Draw a straight line and follow it.” Apparently both are simple instructions, straightforward to follow by any artist, technician or robot, but upon closer inspection it becomes clear that Young’s instruction encompasses (both conceptually as well as formally) all the instructions that are necessary for the realization of the work. It omits supports, formats or any other formal consideration besides that of the line (and its straightness) and (perhaps more importantly) it is presented as a rule without an object (not as a rule attached to an object). As such, each and every time that a process is started from the rule in *Composition 1960 #10*, it will lead to a diverse implementation and a necessarily different result, with its own idiosyncrasies and a characteristic outcome. *Every Building on the Sunset Strip*, on the other hand, is presented as a rule with a single and already existing execution, a rule that seems almost as if it is not intended to be followed again, a process that should not be carried. Lastly, the form of the code should also be taken in consideration. While Young’s rule is formulated in the imperative mood, with clear verbs that describe the actions to be developed, Ruscha’s uses adjectives and nouns, not describing what *should* be done but rather what *has been* done.

“Rules as a well defined widely applicable process” are defined as presentations of processes that “are so widely understood, or so commonly observed, that they begin to become transparent and unnoticed” (Galanter 2006). The example offered is James Siena’s painting *Enter the Faces* (1996). This painting, along with two other works also presented in the *Logical Conclusions* catalogue were, according to Siena,

produced through the “division of rectangle by halves, in succession. Each volume divided by half results in one of the halves being divided again; only up to four times, when another color, or another iteration is introduced within each of the rectangles created by the previous procedure. The process is repeated with changing colors as the picture is filled with rectangles of diminishing size. (A decision is made with respect to the choice of direction for the division of volumes. One could look at it as choosing between ‘right’ or ‘left’ handedness to the iteration. I see it as going ‘towards’ or ‘away from’ the previous cluster of diminishment.)” (qtd. in Glimcher and Rose 2005, 138). About *Global Key, Second Version* (Siena 2000), the artist further states, as an operational program: “Divide upper half of surface with volume density defined by line curved at corners. Divide right side of remaining half of surface the same way. Repeat activity for lower half of left side of the surface, then for left half of remaining surface, then for top half of remaining surface, then for right side of remaining surface, then for bottom half, then left half, then top, then bottom. Line volumes with alternating shades of white and color three times. Choose color with no logical or emotional underpinning, but let each move, or pass, occur in the same color. Repeat division and lining procedure inside all remaining volumes, space permitting, until one quarter of surface has no space remaining.” (qtd. in Glimcher and Rose 2005, 142) These two statements are presented in the catalogue as the rules from which the paintings were executed. A quote from Siena is presented as an artist’s statement, underlining their importance in the artistic process: “I don’t make marks. I make moves. The reality of abstraction is my primary point of engagement. When I make a painting, I respond to a set of parameters, like a visual algorithm. These structuring devices are subject to the fallibility of my hand, and my mind’s ability to complete the work as planned. Using proven mathematical truths (...) I construct pictures that, I hope, are so beyond complex that even a baby can understand them. But like all artworks made by hand, they live or die the essential capabilities of their aesthetic moves.” (qtd. in Glimcher and Rose 2005, 138)

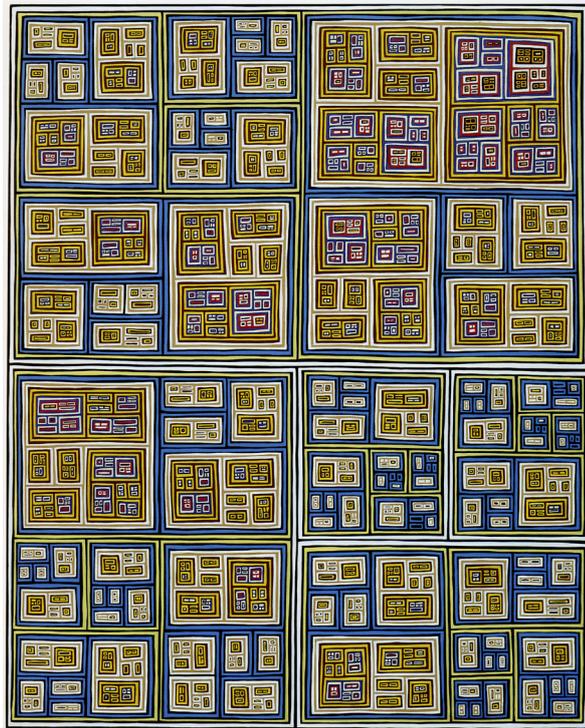


Fig. 97: *Enter the Faces* (Siena 1996).

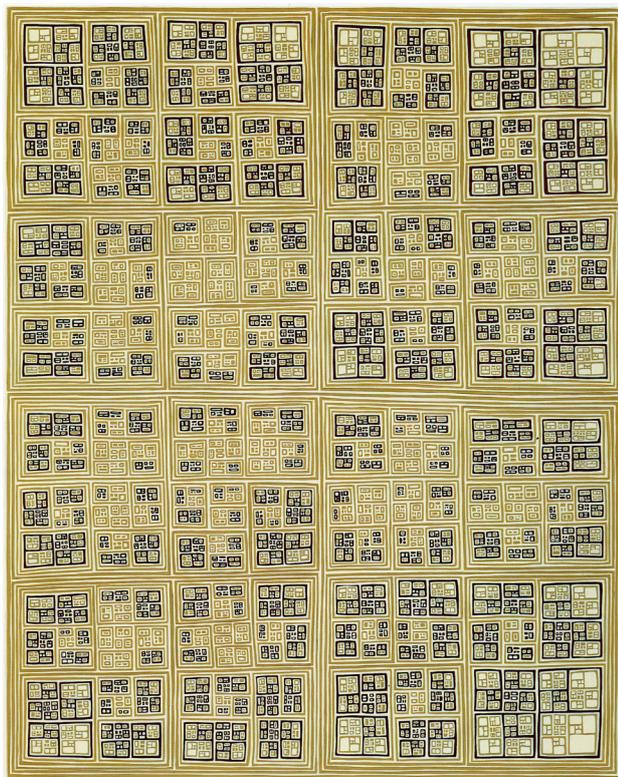


Fig. 98: *Global Key, Second Version* (Siena 2000).

Similar principles can be seen in action in works from other artists, either in manually executed or computer produced artifacts. Eva Schindling works inspired in the Belousov-Zhabotinsky<sup>436</sup> reactions are such an example. The works in this series were programmed with algorithmic descriptions of a BZ reaction and seeded with different initial parameters, from where the process was developed autonomously.<sup>437</sup>

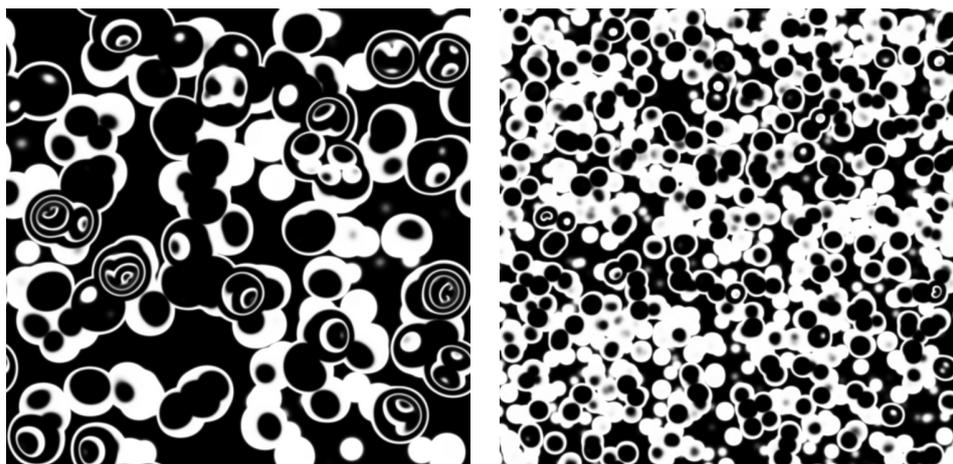


Fig. 99: *Bz\_11295\_Mode1\_A1.2\_B1.0\_C1.0* ( $\text{Alpha}=1.2$   $\text{Beta}=1.0$   $\text{Gamma}=1.0$ ) (Schindling 2009a) and *Bz\_112853\_Mode1\_A1.2\_B1.0\_C1.0* ( $\text{Alpha}=1.2$   $\text{Beta}=1.0$   $\text{Gamma}=1.0$ ) (Schindling 2009b).

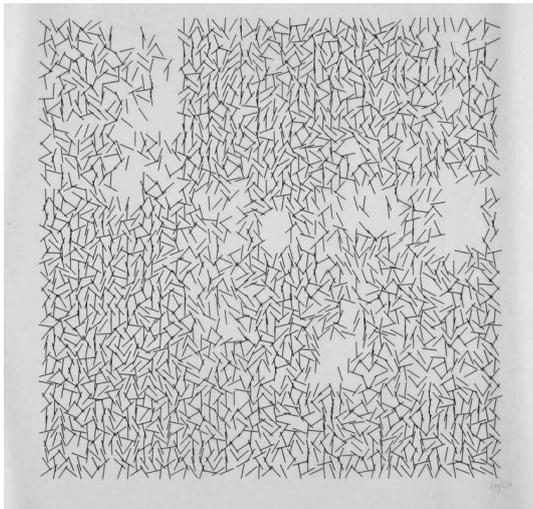
Vera Molnár develops “very simple rules of combinatorial analysis and equally some very plain geometrical forms and step for step” (Molnár 2009), introducing minor changes in proportion or patterning. Molnár develops series of works, each of which she regards as a sample, a stage of a painted research, while trying to capture the

<sup>436</sup> “The Belousov-Zhabotinsky reaction is an example of a temporally oscillating chemical reaction. An unusual and interesting feature of the reaction is that as it progresses on a two-dimensional plate, self-organized spirals are formed.” (Turner 2009) It is a classical example of non-equilibrium thermodynamics, that works as a chemical oscillator as it cycles through its different states in autocatalytic fashion. They are far from equilibrium and remain like that for a very long time.

Boris Belousov (1893-1970) discovered this chemical reaction in the 1950s. In the early 1960s Anatol Zhabotinsky (1938-2008) independently discovered it but neither discovery was widely disseminated until the end of that decade. Besides the importance that the reaction has in the fields of chemistry, physics and mathematics, it has been a source of inspiration for artists and designers — as have also been other reaction-diffusion systems — because they mimic chemical pattern formation in nature, and to biologists, since Turing first suggested that they could hold the source to the understanding of biological morphogenesis.

<sup>437</sup> The images presented by Schindling are captured from ongoing dynamic reactions. Each of these images is developed from several previous stages of the process and were further developed afterwards. The two works shown are (as can be understood by the initial values) two stages of the same process.

phenomenon that she calls “the ‘epiphany’ of art”.<sup>438</sup> As a way to “genuinely systematize” her research, Molnár started to use a technique she called “machine *imaginaire*”, designing programs for an imaginary computer and then realizing them, step by step, creating series “which were completed within, meaning they did not exclude a single possible combination of form” (2009). Molnár eventually replaced the imaginary machine with a real computer,<sup>439</sup> using it for composition, by running her programs and combining forms, in the hope that the tool would enable her to gain some distance from her acquired learning, cultural heritage and surroundings, “in brief, from the influences of civilization that define us” (2009). Either realized by a plotter, by silk-screening processes or manually painted on canvas, Molnár’s works are deeply rooted on and guided by her programs, by the algorithms that dictate her actions while painting. The same happens with Siena, although his rules given him a somewhat larger number of choices to undertake, while in Schindling’s works all the decisions are left to the system with the notable exceptions of the initial parameters and the choice of which steps of the process to crystallize (or document).<sup>440</sup>



**Fig. 100: *Interruptions* (Molnár 1969).**

<sup>438</sup> “The question is whether here and there, by placing them next to one another, one can produce a substantial change, a unique visual situation which could be called art. The underlying problem of my entire work is to capture this phenomenon, the ‘epiphany’ of art. Working with series of pictures is like a visual dialogue between the painter and what has been painted. All stages of such a series naturally form small works of art in the traditional sense.” (Molnár 2009)

<sup>439</sup> “To avoid a false interpretation of my method I wish to emphasize that a large part of my work is designed and frequently carried out with the help of a computer; but whether these works have little value, if at all, is not the computer’s responsibility. This machine, as impressive as it may be, is after all merely a tool in the hand of the painter.” (Molnár 2009)

<sup>440</sup> We may identify here an instance of Aarseth’s coprocessing (1997, 135).



Fig. 101: *Sorties du rang* (Molnár 2003) and *L'ombre prend le dessus* (Molnár 2005).

The fourth place is taken by “combinatorial rules”, described (somewhat simply) as “systems that use a smaller set of elements to create a larger set of combinations”. LeWitt is cited as an example of their usage by systematically applying “a small number of marks to create a large combinatorial exploration” (Galanter 2006). We have previously discussed combinatorial systems, so we will not analyze them again, and agree with the assessment of these as having a great generative potential.

In the fifth place we have “numerical sequences as rules” including “arithmetic or geometric progressions, or the Fibonacci numbers, as a basis for pieces”. As we have seen, when integrated in algorithmic processes, these numerical sequences may appropriate the creation of novelty and turn the system into a data-driven process.

The sixth system in the list, “line composition or drawing rules”, defined as “line-oriented paintings or drawings that are determined by a set of rules or algorithms” comprises manually executed pieces but also “plotter art created by some of the earliest computer artists” but does not define anything more than that in previous rules.

“The rule of serial generation”, however, describes a process that is truly algorithmic and at the core of any computational process and modern programming language and nevertheless “as old as art itself”: the loop, used “to repeat a graphic gesture, or an object” or a complete generative process. Works of Donald Judd<sup>441</sup> and Warhol are presented as examples of this rule.

<sup>441</sup> 1928-1994.



Fig. 102: *Untitled* (Judd 1989).

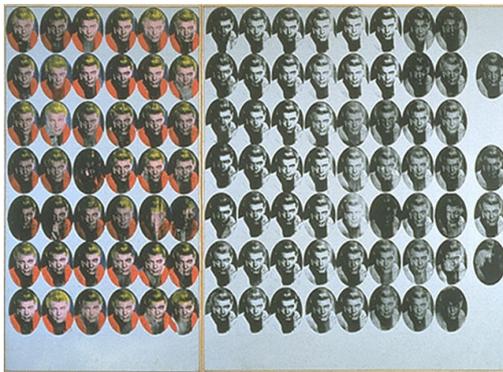


Fig. 103: *Troy Diptych* (Warhol 1962).

Both artists use simple repetition processes, Judd using a module that is translated in the vertical axis, Warhol creating a basic tile system with portraits of American actor Troy Donahue. All computer-based systems described in this work use some sort of looping process in their algorithms and although in many cases the loops may not be directly perceivable in their outputs, it is common to find works where serial generation produces identifiable loops or tiling patterns and may thus be said to be central for the visual composition strategy.

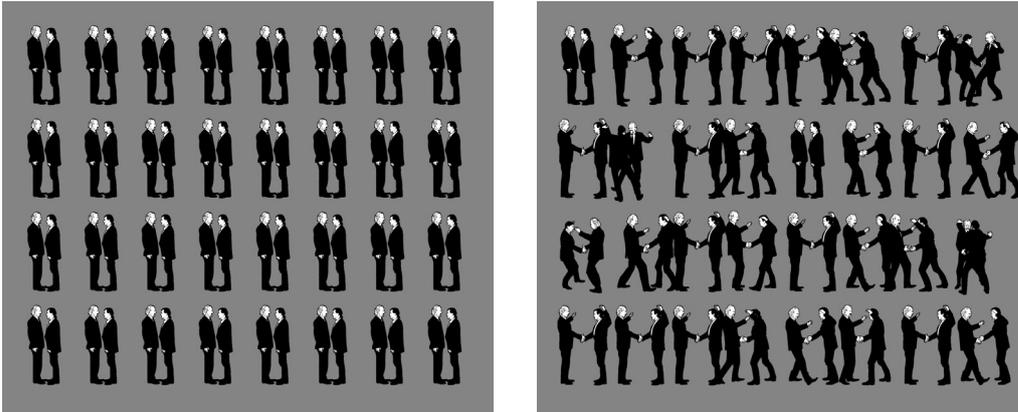


Fig. 104: *The Inability to Solve a War at a Cocktail Party (an Awkward Dance with Mr. Henri Van Zanten)* (Hoogerbrugge 2010).



Fig. 105: *Taken* (Rokeby 2002d).

Serial generation leads us to the eight system in the list, “tiling and other symmetric composition rules”, comprising “abstract patterns that exhibit symmetry and tiling patterns”, something that minimalist artists explored to great effect. Since the late 1950s Carl Andre stopped sculpting using traditional techniques and turned to the use of standard-size modules, either found materials, as in his early works, or industrially produced precut units that were small enough for anyone to be able to lift and move around manually, which he composed by following precise arithmetical relations. With this he sought to explore the relationships between a work of sculpture and the space it occupies, pursuing a sculpture which can stand naturally in space without taking on an architectural function or, on the contrary, being merely decorative. This system can be seen as a direct consequence of the previous, as one of its particular outcomes, when the serial generation is taken to the extent of defining not only the structure of the process but also the form of its output (that can be seen as a multiplication of outputs, of parts that generate a whole). As Andre puts it, his

“constructivism is the generation of overall designs by the multiplication of the qualities of the individual constituent elements.” (qtd. in Glimcher and Rose 2005, 48)



Fig. 106: *Alloy Square* (Andre 1970).

The ninth system takes us from the space of apparent arithmetical precision to what can almost be seen as its opposite, the “chance operation rules”. Systems for injecting randomness and chance in the realization of a work have been popularized throughout the twentieth century but they have been occasionally used in the creation of earlier aesthetic artifacts. The example presented by Galanter, from the *Logical Conclusions* exhibition is Felix Gonzalez-Torres’s<sup>442</sup> piece “*Untitled*” (*Public Opinion*) (1991), created from a pile of more than 300 kg of candies that are spread “on the floor and arranged in a rectangle within an exhibition space” or, alternatively installed “as a corner spill.” (From the loan agreement form reproduced in Glimcher and Rose 2005, 163) Interestingly, Gonzalez-Torres defined any instance of the installed work as a “manifestation of the work”, although he made a point of not presenting it as such, listing it “on all wall texts and related texts as the piece and not as a manifestation of the piece”, and defined the instructions to its set up in a set of guidelines to ensure a consistent installation of the manifestation. In these guidelines he defined an “ideal installation” from where certain deviations were allowed<sup>443</sup> (2005, 162). This clearly configures “*Untitled*” (*Public Opinion*) not as an

<sup>442</sup> 1957-1996.

<sup>443</sup> In the loan agreement form for “*Untitled*” (*Public Opinion*) Gonzalez-Torres explains his definition of ideal: “In all cases, ‘ideal’ refers to the work’s original installation and the ideal manifestation of Felix Gonzalez-Torres’ choosing.

Regarding the type of candy ‘ideal’ means if these exact candies are unavailable, or if (...) [the exhibitor] would like to find another appropriate candy, a similar cellophane wrapped candy may be used.

Regarding the weight of candy, ‘ideal’ means that one may choose to deviate from the exact weight. Although this implies that the exhibitor or owner may choose to install the piece with a weight other than the ideal, it also refers to the fact that the weight of the piece fluctuates as individual candies are taken, and to the fact that the exhibitor or owner has the choice of replenishing the candies back to the piece’s

object but rather as a process that is developed to create a “manifestation” that is temporarily perceived as an object. A dynamic system without clear boundaries and that exists as an ongoing process that is formed by human action, chance and randomness (determining the precise location of each candy and consequently the macroscopic shape of the installation).



Fig. 107: “Untitled” (*Public Opinion*) (Gonzalez-Torres 1991).

ideal weight at any time over the course of the exhibition. (It is recommended that this decision be made in advance of the exhibition in order to order the appropriate amount of candy). If the space chosen for the installation cannot accommodate the ideal weight of the piece, the weight should be altered accordingly so that the floor does not show through the piece and so the thickness of the layer of candies is approximately 1 inch.

Regarding the installation, ‘ideal’ refers to pouring the candies directly on the floor in a rectangle. Should the exhibition space be unable to accommodate such an installation, or the exhibitor feels the piece should be altered from this ideal, the exhibitor may install the piece in the manner of their choice, which may include a corner spill, a square, etc.. Whatever the configuration, the work should reflect or respond to the specifics of the exhibition space. However, the floor may not show through the piece.” (from the loan agreement form reproduced in Glimcher and Rose 2005, 162-63)

Parameters for the manifestation’s maintenance are also provided. “If it is decided to replenish the manifestation of the work back to ideal weight or alternate chosen weight, it may be replenished periodically throughout the exhibition — it is not necessary to wait until all the candies are disseminated (taken). The edges of the installation should be straightened each time it is replenished; however, it is not necessary to straighten the edge otherwise. If the manifestation of the work is allowed to disappear completely over the course of the exhibition, the exhibitor can choose to either straighten the edges of the installation periodically so that it retains its original shape over the course of its existence or simply let it mutate as the candies are taken. Visitors should not be allowed to toss the empty wrappers back into the manifestation of the work. A guard may indicate this restriction to visitors, but there may not be any signage installed in the exhibition space referring to this. If there are empty wrappers mixed in with the wrapped candies they must be picked out immediately as they are noticed.”

Still regarding the visitor’s interaction with the manifestation, it is stated that the exhibitor “agrees to allow visitors to take candies from the manifestation of the work. However, it is imperative that there be no separate referential text indicating this preference, i.e. no signage installed in the exhibition space. However, in order to limit the number of candies each visitor takes, a guard may indicate to visitors that they may take one piece (...)” (2005, 164). The system proposed for the manifestation thus controls not only the assembly of the object itself as well as, at least partially, the behavior of the guards of the exhibition, almost turning them into performers, whose actions are also (to a certain extent) part of the system.

Chance operation rules can be seen, in this context, as parts of the overall process that allow for an indeterminacy of the actual outcomes of the system (in its whole or parts). In Gonzalez-Torres's system much more is left to be molded by chance than in other systems where indeterminacy may be more restricted and the outputs far more controlled, as the previously mentioned *Musikalisches Würfelspiel* (Mozart 1787), where randomness is solely injected in the reordering of the precomposed parts.

The tenth place of the list is taken by a system that seems to stem from combinatorial rules, serial generation and, to a lesser extent, from tiling. Galanter calls it "clustering rules that create composition" and defines it as "layering taxonomic logic upon assemblage, some artists create pieces by ordering collections of found or commercial objects. To the extent that this ordering principle objectively clusters the objects creating unexpected correspondences and relationships, such work can be considered generative" (2006).

The serial element for us resulted from our having collected so much material on certain topics. But our idea of showing material has much more to do with the 19th century, with the encyclopedic approach used in botany or zoology, where plants of the same variety or animals of the same species are compared with one another on the individual pages of the lexicon. It became more and more clear to us that there are definite varieties, species and subspecies of the structures we were photographing. That us, in effect, an old-fashioned approach. Later it was also used in conceptual art, logically enough. (Hilla Becher qtd. in Glimcher and Rose 2005, 68)

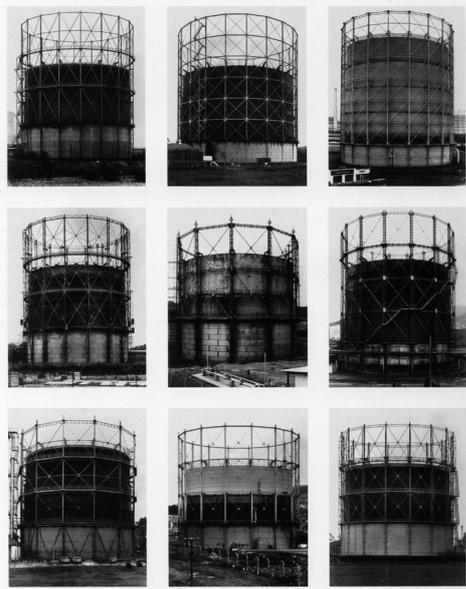


Fig. 108: *Cylindrical Gas Tanks* (Becher and Becher 1984).

The work of Bernd<sup>444</sup> and Hilla Becher is presented as an example, although Galanter states that it is “arguable whether this particular application of clustering is truly generative, turning primarily on the question of whether the clustering method is objective and thus external, or intuitive and subjective” (2006). Clustering as a system, however, can in our opinion be rightfully regarded as a generative system or at least as a relatively common consequence of generative systems that are able to produce multiple variations of the same forms or multiple outputs from the same system. Two examples of works arising from catalogues or typologies of outputs can be found in [UBERMORGEN.COM](#) & Nussbaumer’s *1001 Songs of eBay*<sup>445</sup> (2009) and the cover design for Ozy’s *Tokei* (Carvalhais and Lia 2002) created from serial configurations of a procedural system.

<sup>444</sup> 1931-2007.

<sup>445</sup> A project derived from *The Sound of eBay* (2008), an online project also by [UBERMORGEN.COM](#) and Nussbaumer that, by using eBay user data generates unique songs. The audio release compiles 1,001 of the songs that the system generated.

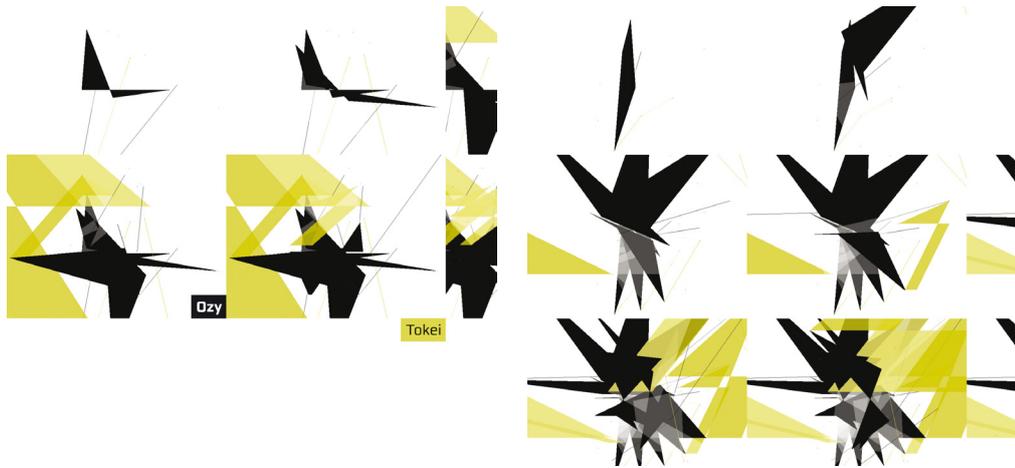


Fig. 109: Cover for *Tokei* (Carvalhais and Lia 2002).

We can also include in this category all those systems that, as *Every Icon* (Simon 1997b), *Incomplete Open Cube* (LeWitt 1974a) or *All Single, Double, Triple, and Quadruple Combinations of Lines in Four Directions One-, Two-, Three- and Four-Part Combinations* (LeWitt 1969a) present more or less long, more or less endless enumerations of systematically produced outputs. We may posit that in *Every Icon* these enumerations are not spatial but rather temporal, as in Kyle McDonald’s “very long sound composition for MP3” *Only Everything Lasts Forever*<sup>446</sup> (2010a).

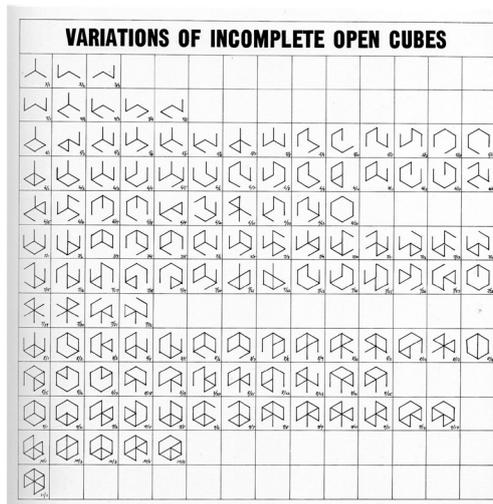
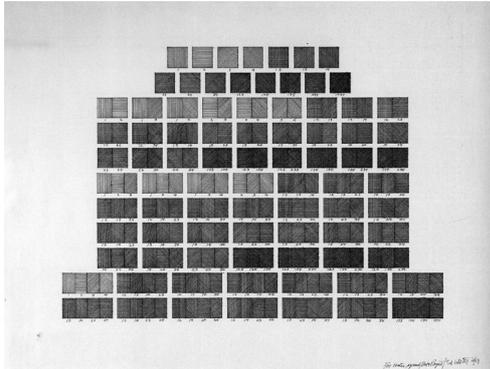


Fig. 110: *Variations of Incomplete Open Cubes* (LeWitt 1974b).

<sup>446</sup> This piece contains every sound we can distinguish as humans, as dictated by the MP3 specification in a composition with a duration of  $10^{450}$  years (McDonald 2010b).



**Fig. 111: All Single, Double, Triple, and Quadruple Combinations of Lines in Four Directions One-, Two-, Three- and Four-Part Combinations (LeWitt 1969a).**

The eleventh system, “mapping from one domain to another” alludes to transformations “from one domain to another, such as temperature into color, or stock market data into sounds” and is, according to Galanter, “a popular technique in contemporary digital generative art (...) also found in generative art from the mainstream.” As we discussed, we do not consider data-driven systems as being generative. Although the parameters (or rules) for the transformation may have a generative potential, if the data-set is static, there is no possibility to bring novelty to the system. Mapping is however a very interesting system, allowing the creation of very curious results and the exploration of digital media and tools. Whitelaw’s *Weather Bracelet* (2009) is created from one year of weather data from Canberra, encoding the dataset (consisting of maximum and minimum temperature plus weekly rainfall) and making it wearable in a circular shape. *Cylinder* by Andy Huntington and Drew Allan (2003) is a series of sculptures based on data acquired by sound analysis,<sup>447</sup> showing a range of different waveforms. The title of each piece implies the sound used in the analysis.

<sup>447</sup> A mapping of the frequency and time domains produces cylindrical forms representing the spatial characteristics of the sound input. Physical versions of the digital 3D models are then 3D printed using stereolithography.

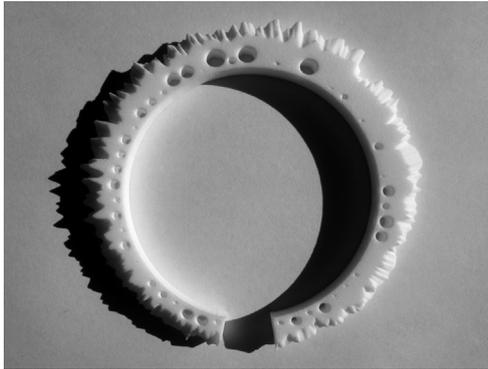


Fig. 112: *Weather Bracelet* (Whitelaw 2009).

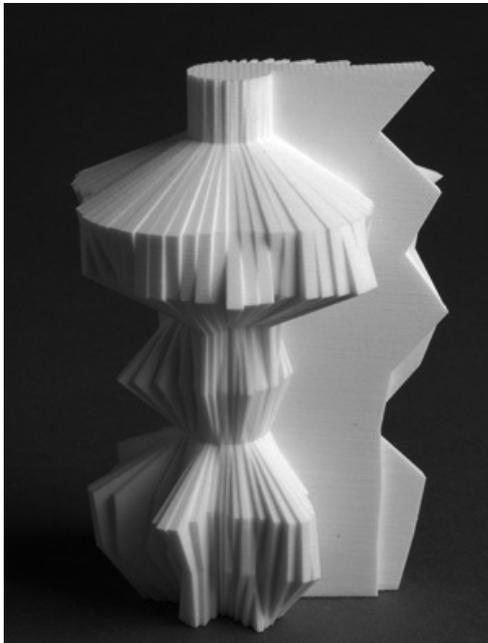


Fig. 113: *Cylinder (Seahorses, left; Breath, right)* (Huntington and Allan 2003).

Finally, Galanter's list closes with "rules which create cycles and phase interactions", classified as "time art" processes that are able to "generate variations by having two or more cyclic behaviors with differing periods. As the cycles go in and out of phase a combinatorial effect is played out, and at any given instant different variations will be apparent." Galanter refers kinetic sculptures as an example, but one can also find plenty other examples in other time-based arts, as music, particularly in twentieth-century American minimalists as Steve Reich or Young.

### 2.3.5 Other Systems

Galanter's list rounds up several of what we could call high-level strategies for procedural artistic practices. Developed as it was from two exhibitions that presented primarily non-computer based works, it is perhaps only normal to find that all of those systems that we could classify as being low-level were not listed.

We can classify as high-level systems all those that organize the macroscopic process, that refer to the creation of the whole system from parts or of some of those parts by other parts. They are often constituents of the main conceptual or operational principles of a system and may also be, to their observers, intrinsic to the aesthetic value of the system. To the execution of manually implemented processes, high-level systems may be all that is required, however, if the system is machine implemented, and especially if the machine is a computer (or a computational device) then a series of lower-level systems will need to be used (or devised) in order to properly implement it.<sup>448</sup>

These systems will allow the implementation of the artifacts' mechanics, of the sub-processes that will build the macroscopic overall process that one identifies as the piece. When programming computational systems, it will not suffice to establish 'randomness' or 'chance' as the conceptual infrastructure of a system but also to precisely define how such randomness will be injected, how indeterminate (or seemingly indeterminate) results will be produced by the algorithm. Any pseudorandom function from a programming language will of course produce apparently indeterminate outputs, but the better the function is, the least structured will these outputs tend to be and more noisy will their outputs be.<sup>449</sup> In the scope of this work it will not be necessary to delve into the details of such algorithms and into the minute differences that make the outputs of different approaches to pseudorandomness be more or less 'random' in a strict sense. It will be enough to state that, generally speaking, any (or most of the) pseudorandomness algorithm will generate noisy and

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<sup>448</sup> Any of these systems can naturally also be used as high-level systems — and have been indeed, as attested by several works cited along this document. Due to some lack of immediacy, however, they may be more difficult to follow by audiences than the more general and concrete high-level systems that were previously enunciated.

<sup>449</sup> Noisy because there will be a statistical homogeneity of the outputs. Any value in the outputs will have the same statistical significance as any other so they will be read as being unstructured, formless.

unstructured output from where it will be too difficult, if possible at all, to extract any meaning or to breed a meaningful structure.<sup>450</sup>

In this work we do not intend to develop a detailed technical analysis of the multiple algorithmic systems<sup>451</sup> that can be used in the implementation of rule-based processes. We are rather more interested in the study of their manifestations — and conscious that if a thorough knowledge of computational mechanics is indeed essential not only to the creation but also to the understanding and critical analysis of the systems (Mateas 2005), the precise details of the algorithms are often of only a relative relevance to the analysis we will develop). A list of such systems would by its very nature always be necessarily incomplete, as new systems are regularly devised. It would include but not be limited to processes as Markov Chains, Riley Waves, Wilson Grids, Mandelbrot and Julia Sets (and other fractals), Convolution, Autonomous Agents, Particle Systems, Network Protocols, Fourier Transformations, Genetic and Evolutionary Algorithms, Neural Nets, Cellular Automata (and its various rules), Swarms, Chaotic Systems, Fuzzy Logic, and a large number of other resources to create novelty (most of which can be articulated in the creation of more complex systems). We will not elaborate on the particulars of these systems here, but we will take a moment to focus on a top-level strategy that has been somewhat common in some procedural creation and that has been left out<sup>452</sup> of Galanter's list.

### 2.3.6 Error / Glitch

The word *glitch* was first recorded in English in 1962, in the writings of astronaut John Glenn, during the American space program, where it was used to describe some of the technical problems that had to be dealt with during training and missions. At a point Glenn describes the technical sense of the word that astronauts adopted: “Literally, a glitch is a spike or change in voltage in an electrical current.”<sup>453</sup>

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<sup>450</sup> In certain cases however, this may be exactly what is necessary. Still, these are cases where pseudo-randomness is used within more complex algorithmic processes that will, in their turn, structure the outputs of the source of randomness into some sort of meaningful and coherent form.

<sup>451</sup> Or from the multiple ways through which each of these systems can be implemented, an exercise that, however interesting, falls outside our scope and has been studied in detail in other publications (Steeb 2001; Reas and Fry 2007; Shiffman 2008; Terzidis 2009).

<sup>452</sup> At least explicitly, as one can always argue that it may be described by, for example, chance operation or rules as recipes for autonomous processes.

<sup>453</sup> The word probably has a German root, according to Random House's American Slang dictionary, from the word *glitschen* (to slip) and the Yiddish word *gletshn* (to slide or skid).

(qtd. in Moradi 2004) A glitch is the result of a malfunction or an error. In a theoretical and objective sense, it is assumed to be the unexpected result of a malfunction, a singular dysfunctional event that progressively became a distinctive part of the grammar of contemporary computational aesthetics, but that has its roots in analogue tools and media.

Strictly speaking, although it results from malfunction or error, and whilst it may be caused by a software bug, a glitch is not a bug, rather it may be described as a special outcome of a bug, as the effect of one or several bugs or of perfectly functioning code that is somehow led astray and that, instead of halting the process of rendering it otherwise inoperative or of producing a predictable error or breakdown, generates a potentially interesting aesthetic output. The glitch is therefore both the cause as the effect, it is the malfunction and the output that it produces, as well as its subsequent creative use. A glitch is an interpretation, not simply a sensorial artifact,<sup>454</sup> it is the aesthetic valorization of the sensorial artifact.

The 'post-digital' aesthetic was developed in part as a result of the immersive experience of working in environments suffused with digital technology: computer fans whirring, laser printers churning out documents, the sonification of user-interfaces, and the muffled noise of hard drives. But more specifically, it is from the 'failure' of digital technology that this new work has emerged: glitches, bugs, application errors, system crashes, clipping, aliasing, distortion, quantization noise, and even the noise floor of computer sound cards are the raw materials composers seek to incorporate into their music. (Cascone 2000, 12-13)

Much in the same way that digital media allow the fixation and reproduction of analog-generated signals, they also allow the accurate reproduction of digitally generated signals, therefore permitting the preservation and reproduction of glitches that could otherwise have merely been ephemeral phenomena. Through processes of trial and error or of reverse engineering, bugs, malfunctions or other sources of glitches can be discovered and the systems can be reprogrammed so that their code (in a broad sense) can generate what originally were glitches but then become intended outputs. An interesting example of this practice in contemporary electronic

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<sup>454</sup> 'Artifact' as both the discrete perceivable object and the object-error in the perception or representation of information.

music can be found in the work of Oval,<sup>455</sup> that in the early 1990s started to produce music with damaged or skipping CDs. The damaged discs used in the first experiences were found pieces or ready-mades, the result of accidents or of careless manipulation. Through these fortunate mishaps and coincidences, the originally undamaged CDs — industrially replicated digital copies — became unique ‘damaged’ pieces, and started to produce sounds that were curiously different from those that were originally encoded. They were quickly followed by other discs, where Oval painted small images on the underside, to provoke the skips and to try to exert some degree of control over the errors these would produce. These images revealed a subtextual layer that was embedded in the compact discs (Cascone 2000, 13), and allowed the sampling and reuse of the glitches, that formed both an abstract layering of skittering rhythms and an interesting commentary to the then-current marketing efforts around the flawless quality of digital audio signals (Thomson 2004, 212).<sup>456</sup>

Turning a read-only medium into a creative and manipulatable tool, Japanese composer Yasunao Tone developed a similar process by painting, scratching or otherwise defacing the readable surface of audio CDs that were then used as the prime matter for the production of new sounds. His ‘wounded CDs’ were furthermore played in CD readers that were violently shaken and distressed on stage during his very physical live performances. Whereas Oval used the discs as sound sources to be further manipulated through software, Tone used them as instruments that were performed live, avoiding overdubs or any further manipulation or processing of the sound output of the player — no mixer, effects or any other resources were used live.<sup>457</sup>

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<sup>455</sup> A project by Markus Popp, Sebastian Oschatz and Frank Metzger.

<sup>456</sup> “I experience this as a zone entirely free of criteria, insofar as the last defining criterium of electronic music is the data format: MP3s or audio files are not defined as text files, but compressed with a particular bit rate and that’s that. For this reason (...) electronic music seems to me more like a general business strategy rather than the beta test of an extremely productive, all-inclusive authoring process” (Popp 2004).

<sup>457</sup> One of Tone’s CD releases is aptly named after this process as *Solo for Wounded CD* (1997).



Fig. 114: Detail of the surface of one of Tone's 'wounded CDs'.

In later works, Oval tried to transfer their entire work process — sound generation, manipulation and composition — to a software platform titled *Oval Process Public Beta* (2000a), distributed as a CD-ROM and presented as the interactive installation *Ovalprocess Terminals* (2000c). The central statement of the *Ovalprocess* series, software platform, installation and CD releases (2000b; 2001) was that electronic music was “irrevocably characterized and limited by the software it uses” (Popp 2004) as it had been in earlier times characterized and limited by the instruments or the compositional canons. Further generalizing, Markus Popp stated that what he found more relevant than “every new form of musical experimentation or hacker ethics” was “a subjective intervening in the standards and specifications behind the workflow” of composition (2004).

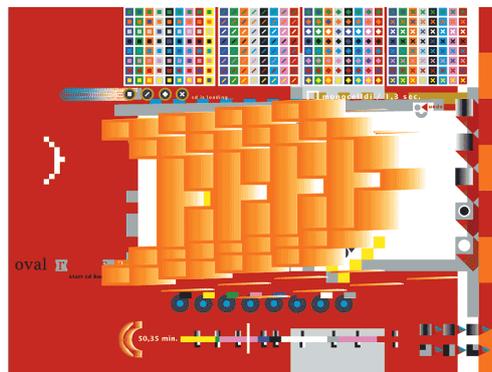
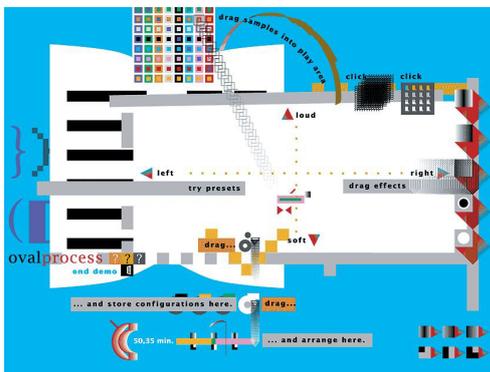


Fig. 115: *Oval Process Public Beta* (Oval 2000a).

Or the standards and specifications behind the medium of the work, an intervention that is not always necessarily motivated by the failures of technology but sometimes starts from them. We can find earlier examples in the works that László Moholy-Nagy<sup>458</sup> or Oskar Fischinger<sup>459</sup> developed by the direct manipulation of the optical tracks of sound films or in Peter Kubelka's short film *Arnulf Rainer* (1960), entirely composed of frames of solid black and solid white, strung together in lengths as long as 24 frames or as short as a single frame.

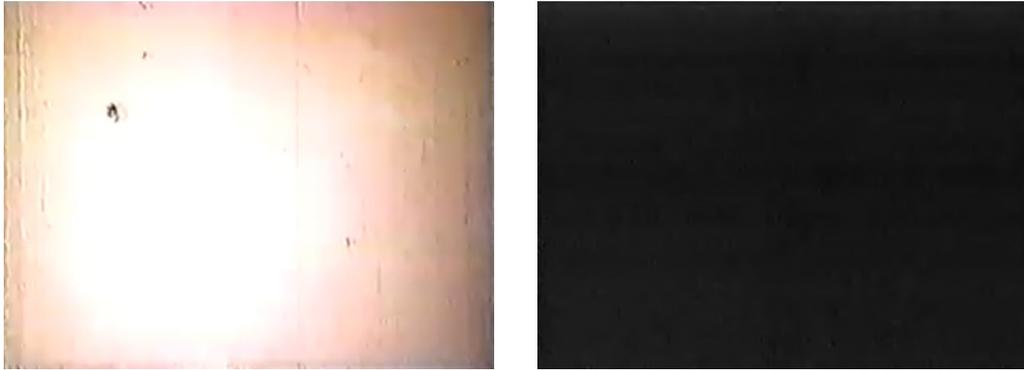


Fig. 116: Two projected frames from *Arnulf Rainer* (Kubelka 1960).

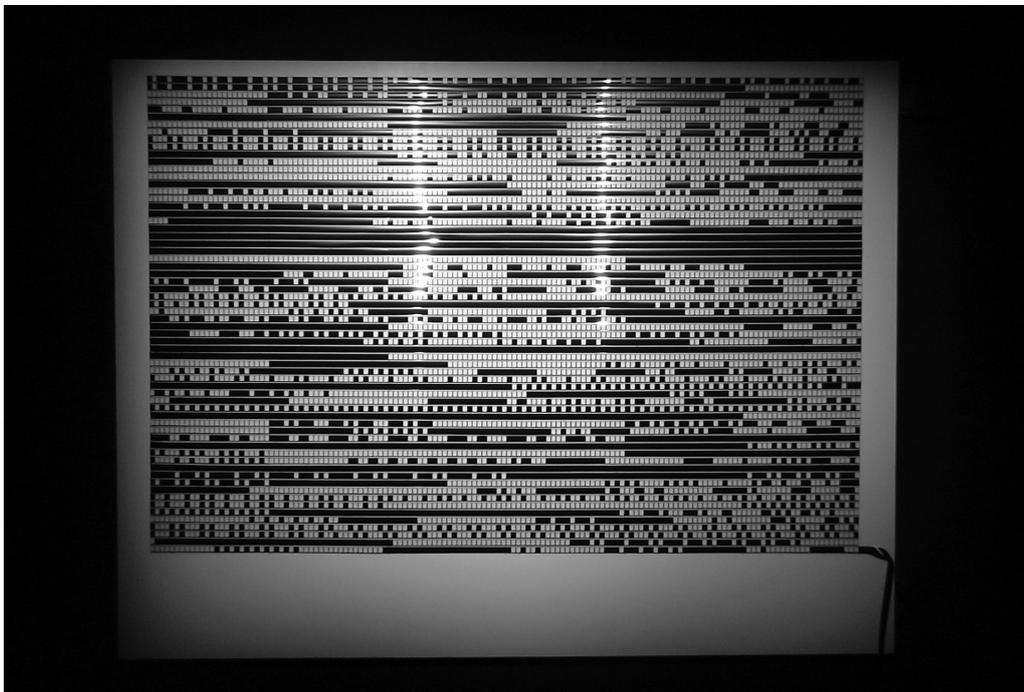


Fig. 117: The 9,216 frames from *Arnulf Rainer* (Kubelka 1960) exhibited at Barcelona's CCCB in 2007.

458 1895-1946.

459 1900-1967.

In a 1988 interview to Christian Lebrat,<sup>460</sup> Kubelka discusses *Arnulf Rainer* as “the film that best approximates to the essence of cinema as it exists because it uses the elements that constitute cinema in its most radical, purest form. There’s light and the absence of light, there’s sound and the absence of sound and their becoming in time. Just that.” There is also the use of what were typically seen as analog cinema glitches: the sharp transitions between underexposed (black) and overexposed (white) frames and the use of the same frames to create the optical soundtrack — white generates (almost white) noise, while black is silent. All the dirt and scratches caused by the handling of the film, by the projector, by dirt in the lenses or on the screen are also turned to part of the film, that thus becomes an accumulation of glitches (both intentional or serendipitous). Another example of this approach can be discovered in Nam June Paik’s<sup>461</sup> *Zen for Film* (1964), a film canister containing a length of approximately 23 minutes of film leader, transparent tape normally used in the start of film reels but not intended to be projected. If *Arnulf Rainer* was a composition that welcomed glitch, *Zen for Film*, once projected was a blank slate that became a composition, as various mechanical and material glitches would set in.<sup>462</sup>

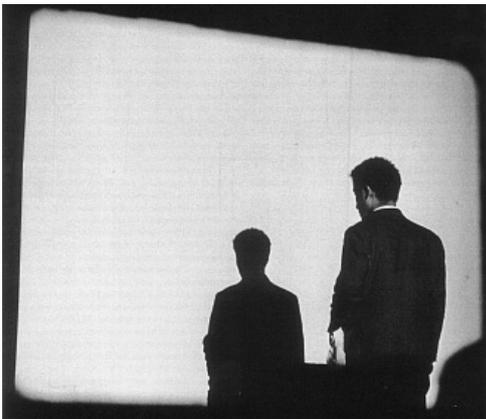


Fig. 118: A projection of *Zen for Film* (Paik 1964).

In visual arts, we can find a similar approach in the execution of Warhol’s *Oxidation Paintings* (1978a; 1978b) where the materials used are prone to oxidize, to literally

<sup>460</sup> Qtd. at the 2007 CCCB exhibition.

<sup>461</sup> 1932-2006.

<sup>462</sup> It is not clear whether Nam June Paik intended this to happen or if the glitches and noises that accumulate in the film were seen as disturbances. We may interpret it as a film which depicts only itself and its own material qualities, among which are the scratches and glitches. We wouldn’t perhaps see it so much as a film about nothingness, or ‘silence’ in the sense proposed by Cage, which would probably be better expressed as a black projection.

rust and decay over time, thus inviting the deterioration and glitch to the artwork and making its surface become ever changing and dynamical.



Fig. 119: *Oxidation Paintings* (Warhol 1978a; 1978b).

If the processes at work in these pieces are not artificially halted by conservation<sup>463</sup> and are allowed to develop to their ultimate consequences, the pieces will eventually destroy themselves, either by accumulation of dirt and noise or by disintegration.

*Zen for Film* is more than the film leader, it is a conceptual piece of film art, an experience of the essence of film, mechanic and philosophical, but it only is all of this when the 23 minutes of film leader are loaded in a projector and shown in a space. Then, *Zen for Film* reclaims the entire space where it is projected, it incorporates the shadows of spectators moving through the projection and makes them part of the film, it absorbs noises from the projector, from the audience and the surroundings as its soundtrack and suddenly, all glitches, interruptions and interferences with the still whiteness of the film are no longer annoyances or perturbations, but rather fuse with the absolute nothingness and become part of the film. In this context it is impossible not to draw a parallelism with Cage's *4'33"* (1952), an even more minimal piece — because it did not require any technological media or even any instruments to be performed.<sup>464</sup> *4'33"* is a piece that builds itself by incorporating the sounds of the audience and the location where it is performed, by incorporating the glitches of the media with which it is recorded or broadcast. First and foremost, the piece

<sup>463</sup> A process that in a certain sense counters the procedural nature of the pieces and, it may be argued, destroys the pieces while preserving an arbitrary configuration of the process.

<sup>464</sup> Although it was commonly performed using a piano, as in the 1952 premiere in August 29, when David Tudor performed it by not playing the piano, starting each of the three movements by closing the piano and ending them by opening it up once again. Over the years *4'33"* has been performed with diverse instruments and even orchestras, as in the September 24, 2008 performance at The Barbican, in London, with the BBC Symphony Orchestra, conducted by Lawrence Foster.

expresses Cage's reflections on silence, on how it does not exist because the contexts for hearing are always permeable to sounds that are external to the music that is the center of our attention, and because, as human beings our sensory perceptions occur against the background noise of our biological systems.

There is always something to see, something to hear. In fact, try as we may to make a silence, we cannot. For certain engineering purposes, it is desirable to have as silent a situation as possible. Such a room is called an anechoic chamber, its six walls made of special material, a room without echoes. I entered one at Harvard University several years ago and heard two sounds, one high and one low. When I described them to the engineer in charge, he informed me that the high one was my nervous system in operation, the low one my blood in circulation. Until I die there will be sounds. And they will continue following my death. One need not fear about the future of music. (Cage 1973, 8)

And the variety of noises, within or outside the human body or the system, whether visual or auidial, seems infinite. Already in 1913 we could find the fascination that these exerted over artists as the Italian Futurists. In the words of Luigi Russolo,<sup>465</sup> if “today, when we have perhaps a thousand different machines, we can distinguish a thousand different noises, tomorrow, as new machines multiply, we will be able to distinguish ten, twenty, or thirty-thousand different noises, not merely in a simply imitative way, but to combine them according to our imagination” (1913). Russolo's manifesto<sup>466</sup> incited artists to shift their focus from the foreground of musical notes to the background of incidental sound (Cascone 2000, 14) and ultimately lead to a questioning of the entire tradition (and culture) of western music. Along with the developing recording techniques, it contributed in the long run to a deep transformation of music, that ceased to be a purely abstract art (that was instantiated in sporadic performances) and on occasion managed to become almost as concrete as plastic arts.

Cage's music was pregnant with glitch and noise, from the total openness of *4'33"*, to the static and hum of *Cartridge Music* (1960), in which phono cartridges were used to amplify sounds that were otherwise nearly audible (but that inevitably amplified

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<sup>465</sup> 1885-1947.

<sup>466</sup> Perhaps one of the most important and influential texts to the musical aesthetics of the twentieth century.

also the unintended movements of the performers or other glitches), or *Imaginary Landscape N° 1* (1939), to the interferences in radio waves of *Imaginary Landscape N° 4* (1951) and their constant detuning, to the preparations in pianos, that enhanced sounds and timbres that were often unwanted in such an instrument. The prepared piano, as popularized by Cage or in the work of other composers, can be thought of as a ‘glitched’ instrument, one where the defects and faults are reinforced and exacerbated, much like with Oval’s or Tone’s CDs.

In spite of the popularization of CD as the delivery technology for recorded music, we could find other media being used for similar purposes, as in Asmus Tietchens’s scratching of magnetic tapes in *Daseinsverfehlung* (1993), or Aki Onda turning a pair of old Sony Walkman portable players and a suitcase filled with cassette tapes into his instruments, or various sound artists manipulating vinyl records.<sup>467</sup> Particularly interesting examples of the exploration (some would say abuse) of vinyl glitch are the works of American composer Christian Marclay and of the Czech artist Milan Knížák, this last one affiliated with the Fluxus group. During the 1960s Knížák used to play vinyl records at variable speeds to explore the changes in the quality of the music that these manipulations provoked — something that Cage had researched earlier, in *Imaginary Landscape N° 1* (1939) for two variable-speed turntables, frequency recordings, muted piano and cymbal — later on, he started to physically damage or destroy the records, by scratching them, by punching holes or otherwise breaking them. Once played,<sup>468</sup> these records created an entirely new music — “unexpected, nerve-racking, and aggressive” (Knížák qtd. in C. Kelly 2009, 142) — and created compositions that “lasted a second or for an infinitely long time (when the needle got stuck in a deep groove and played the same phrase over and over again)” (144). He developed the system further, by sticking tape on the surfaces of the records, by painting them, burning or cutting them up, and gluing fragments of different records back together into a playable form, so as to achieve the widest possible variety of sounds. Unlike Cage’s speed variations, or the hip hop DJ manipulation of the recorded surface through pitching and scratching, Knížák’s actions intended more than ‘remixing’ the recorded sound or to shape it to a different context, they were meant to totally transform the medium, to bring it beyond the

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<sup>467</sup> And entire urban cultures arising from their work, especially Hip Hop, since the 1970s.

<sup>468</sup> Playing these records was a violent act on itself, that according to Knížák not only damaged the needle as, very often, also the record player.

original intentions of the technology and to transform the disc and the information it stored (C. Kelly 2009, 148).

Remixing the medium altogether can produce interesting results, as in the *Vinyl Video* project,<sup>469</sup> introduced in the late 1990s. This project performed a retro-evolution of video media, using vinyl discs to store not only sound but also video content, encoding in the disc's grooves an analog video signal that could be decoded and reproduced on analog television sets with the use of a custom set-top box. Never intended as a mass market project, it nevertheless spawned the production of several specially produced audiovisual projects, by artists such as Olia Lialina, JODI, Nuno Tudela, Vuk Ćosić, among others, that explored the aesthetics of the medium's inherent low bandwidth, low resolution and glitch. Carsten Nicolai's *Telefunken* CD and installation (Nicolai 2000; Noto 2000), encoded on an audio CD several analog video signals, and was composed from these sources.

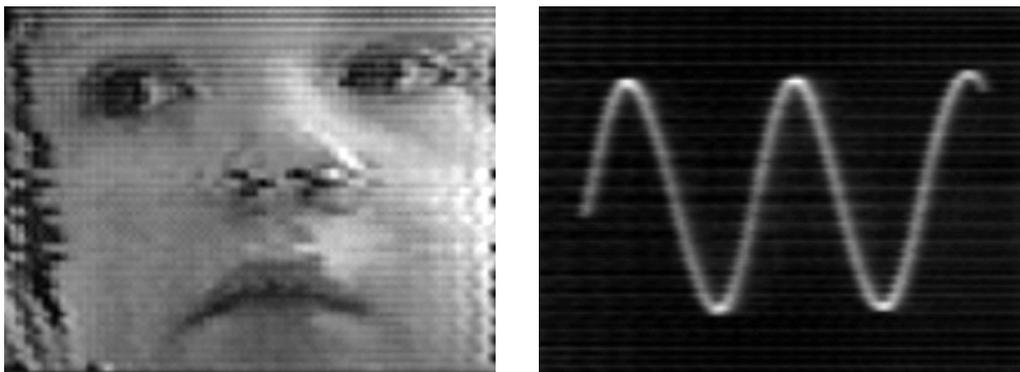


Fig. 120: Frames from *Vinyl Video* projects, as reproduced in an analog television screen.

I destroy, I scratch, I act against the fragility of the record in order to free the music from its captivity. (Christian Marclay qtd. in C. Kelly 2009, 150)

In the 1980s, Marclay's abuse of vinyl records and of their glitches rediscovered many of the techniques deployed by Knížák, adding a sometimes very strong conceptual layer<sup>470</sup> and, perhaps more importantly, exploring the natural glitches of the medium. In two works from the late 1980s, Marclay created records containing music

<sup>469</sup> By Gebhard Sengmüller, Martin Diamant and Günter Erhart.

<sup>470</sup> Marclay's conceptual approach was perhaps taken to the extreme in a work that can be compared to Cage's or Paik's empty pieces, his 12" vinyl *Untitled (Record Without a Groove)* (1987), a black vinyl record with no grooves.

that was intended to be further modified by the medium, by the noise it acquired and by its degradation over time. *Record Without a Cover* (1985) was a one-sided 12” vinyl with a recording of Marclay manipulating records on multiple turntables. As the title implied, the disc was distributed without a cover and all the credits were printed on the (not recorded) back side of the disc, along with an instruction in bold type: “Do not store in a protective package”. So as to pick up dirt and scratches, and to transform the recorded music through that process, one assumes. A later work, *Footsteps* (1989), also a single sided 12” vinyl, bore a composition based on recordings of footsteps, walking, running and tap dancing. All the 1,000 records produced were displayed in the floor of a gallery in Zürich during six weeks, as an installation that invited visitors to walk over the discs<sup>471</sup> thus dirtying and scratching the records. If on *Record Without a Cover* it is the passage of time, the manipulation and use that contribute to the individualization of each disc and to the actual final sound that each of them is permanently in the process of developing, in *Footsteps* the composer’s work was aided by the contributions of several different visitors of the exhibition that, willingly or not, altered the records’ surfaces and made every disc unique.<sup>472</sup> In both cases, heavy glitching of the original sound recordings is added by processes that are conceived so as to be uncontrollable by the composer, so much as to, in certain cases, effectively destroy the record’s surface and render it unplayable.



Fig. 121: *Record Without a Cover* (Marclay 1985).

<sup>471</sup> Or literally forced them, as the room was the only access route to adjacent rooms where other pieces were on display.

<sup>472</sup> Physical evidences of the process, such as actual footprints, were easy to perceive in the records, and sand or dirt were often packaged with the discs that were distributed in standard paper covers.

These works elevate the vinyl disc to something other than a physical distribution medium for the recorded sound. They also make it more than an instrument, in the cagean or the hip hop perspective. They make it become a very concrete (and individual, idiosyncratic) physical object that happens to carry sound but that is far more complex than an otherwise simple and industrially reproduced sound container. In a certain sense these two works by Marclay can almost be regarded as multimodal objects, almost with the character of sculptures, because each of the multiple copies carries a distinct sound with itself. They can be seen as software, because they are pieces that in a way decide their own evolution and the minute details of their outputs. They are objects that display their code, and that are, along with their glitches, living processes. While Knížák's broken records or other damaged discs from Marclay were manipulated as instruments and used to record sounds that were then stored on vinyls, tapes or compact discs that with more or less fidelity reproduced the glitches from the external sources, Marclay's discs are gathering (or even producing) the glitches themselves, a process that ends differentiating every single one of them, turning it into an original.

Still within the music domain, we find the most varied approaches to glitch, from the exploration of obsolete technologies, either digital or analog, for the production of music. A good example can be found in the works of German composer Stephan Mathieu, that crosses digital technologies with early gramophones and phonograph cylinder players, used as instruments in his compositions, exploring all the surface noise, distortion and other malfunctions of the devices as aesthetic resources. Even in his earlier, computer generated works (Mathieu 2001; 2004), we can find a similar attraction for the grittiness of low resolution sound, aliasing and other digital errors. Another source of glitches and richly random sound matter that Mathieu has also used was the radio receiver (2008), thoroughly explored by Tod Dockstader (2005a; 2005b; 2006) and much earlier by Cage on *Imaginary Landscape N° 4* (1951). Radio as a sound source generator offers some degree of control, through tuning, volume or tone control, manipulation of the antenna or of nearby generators of interference but, above anything else, it provides a seemingly unlimited source of variety and novelty through an almost total lack of control over the broadcasts that are tuned and canalized into a particular piece. In the context of a live performance this is far more evident than on a recorded piece, where to some extent happy coincidences

can be created through the compilation of and selection from sometimes very large databases of recordings.<sup>473</sup>

Older or obsolete technologies gain some momentum at a time when current technologies for music production and performance are mostly computer based and, as most computer based technologies, they tend to a certain dematerialization, to become progressively less present on a physical level and therefore, once used in live performances, to become acousmatic. Analog music production technologies almost inevitably imply physical movement: of parts, of the musician, performer or operator. Even if erroneously, they present a causal source for a sound or set of sounds that are produced at a performance and heard by the audience. The computer, and most digital technologies, do not, unless they glitch.

Analog, old or obsolete technologies deploy a visible code, a code that is understood by the audience because it is at least partially shared with it. A large part of the audience of contemporary music has had if not first hand contact, at least some experience of vinyl disc players, analog radios or tape players. They know how to operate them or, in the worst case scenario, know that their operation is accessible to them and know the expected outputs of the technologies. Whenever they see them being performed, they can read the actions of the performer, and understand when these actions produce unexpected results, when for example they transform the sound of a disc by scratching the vinyl or by changing its speed.

Many among those in the current contemporary music audiences have experienced a badly dubbed tape, have had a cassette's tape scrambled by the deck, a vinyl disc that was old, dirty, full of hiss or scratched, or a skipping CD. They are familiar with the panoply of possible malfunctions of the media and respond to those glitches sometimes with surprise, sometimes with affection or a hint of nostalgia. These defects are part of the experience of the media, and once used creatively, their presence is understood as being desired and not as an error or imperfection. As Olga Gorionova and Alexei Shulgin suggest, a glitch reminds us of our cultural experience at the same time as it develops it by suggesting new aesthetic forms (2008, 115). They are produced by error and as such are usually not intended by humans. They are

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<sup>473</sup> This was the process developed by Dockstader in his *Aerial* series of compositions, for which he collected thousands of hours of recordings of shortwave radio noise that were later selected and compiled into a coherent structure published as three CDs.

therefore a not-entirely human-produced reality, “its elements are not one-hundred percent compatible with customary human-logic, visual, sound, or behavioral conventions of organizing and acting in space” (115). An almost radical example of using decay and the (literal) disintegration of the media can be found in William Basinski’s series of works *The Disintegration Loops* (2002; 2003a-c), accidentally created in 2001 while archiving old magnetic reel-to-reel tape loops to digital, a process that ended up destroying the aged tapes and recording that destruction. All six compositions are simply the direct recording of the tapes’ decay as they were played, and the listener is presented with the experience of listening to the slow disintegration of the orchestral tape loops, sometimes for periods as long as forty minutes, much as the composer originally experienced it. As Kim Cascone suggests, in these musics the tools have become the message, and techniques have been developed by artists and composers to expose the minutiae of errors and artifacts for their own aesthetic value, helping to blur the boundaries between what is content and what are the delivery technologies, and forcing us to examine our preconceptions of failure and detritus (2000, 17). Sometimes it is because of glitches that repetitive, monotonous or totally predictable processes come to surprise us. It is not when the system behaves properly but rather when it misbehaves that our attention is refocused in it. Because digital technologies are acousmatic, and because their code is normally not shared with the audience, their operation (on stage or in the studio) tends to become far more opaque. That is, unless they glitch.

Disintegration is not exclusive to physical media such as magnetic tapes, discs, CDs,<sup>474</sup> film, paintings or sculptures. Digital files can also deteriorate and disintegrate, be it through the effect of errors in reading or writing or from deliberate behaviors that are coded by their designers. Unwilling disintegration can sometimes happen due to the enforcement of DRM<sup>475</sup> systems that lock content that is incompatible with current platforms or protocols<sup>476</sup> or that just degrades it, lowering its quality or introducing artificial noise. Successive transcoding, particularly if accompanied by data compression and substandard error checking can also result in the creation of glitches<sup>477</sup> and their long-term preservation in the medium. Finally, the death of

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<sup>474</sup> Physical media themselves, although they carry digital information.

<sup>475</sup> Digital Rights Management.

<sup>476</sup> This is a ‘success’ of the DRM system in the perspective of its designers or of the copyright holders, although it most often is experienced as a failure of the systems from the perspective of its users.

<sup>477</sup> Mostly in the form of compression artifacts or artifacts created by attempts to correct bandwidth problems.

platforms, operating systems, protocols or the lack of support for specific file formats can also destroy or severely damage digital information, when not enough care is put on ensuring its compatibility, redundancy or backup.

But disintegration can become a part of the aesthetic and the conceptual discourses. Artists deal directly with digital errors and deletion by literally coding into the pieces, as Caterina Fake in her online piece *Mount Fuji* (2000) or Zach Gage in *temporary.cc* (2009a), two artworks that literally destroyed themselves. Fake's piece presented a small 300 × 500 pixel image of Mount Fuji in Japan, a reproduction of a classic Japanese painting, accompanied by a haiku stating that should one tap Mount Fuji with a silk scarf every day, in time one would manage to completely erode it. Upon each visit to the project's web page, a single random pixel was deleted from the image, until ultimately nothing at all was left from the image. Fake presented this project as a commentary on the lightning-fast speeds that are expected from online media (or digital media in general) and how these media do not necessarily need to respond to these expectations by accelerating but can, on the contrary, give rise to slowly evolving pieces that are not focused on acceleration but rather on slowness and contemplation.

Gage's website *temporary.cc* is another online study about decay, data corruption and disintegration within a language's standards. Gage intends to question the paradigm of the seemingly "eternal shelf-life" of data on the Internet, caused by the collection and storing of data between "search-engine caching, cloud-hosting, re-blogging, plagiarizing, and the way-back machine" (Gage 2009b). This is done by programming *temporary.cc* to delete part of itself each and every time it is accessed by a visitor. "These deletions change the way browsers understand the website's code and create a unique (de)generative piece after each new user. Because each unique visit produces a new composition through self-destruction, *temporary.cc* can never be truly indexed, as any subsequent act of viewing could irreparably modify it." (2009b) In the end of the process, after falling apart completely due to self-erasure, *temporary.cc* will become a blank website, a 404 or a 410 error page,<sup>478</sup> and all its previous contents and configurations will be "remembered only by those

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<sup>478</sup> The 404 error is the HTTP standard response to indicate that the client was able to communicate with the server but that this could not find the document that was requested. The 410 error indicates that the resource requested is no longer available and will not be available again because it has been intentionally removed.

who saw or heard about it". The sporadic, discrete, single dysfunctional events that were identified as glitches when read in a context of normality, become the rule and take over the space of the artwork, and ultimately consume it, either by overtaking or by erasing it.

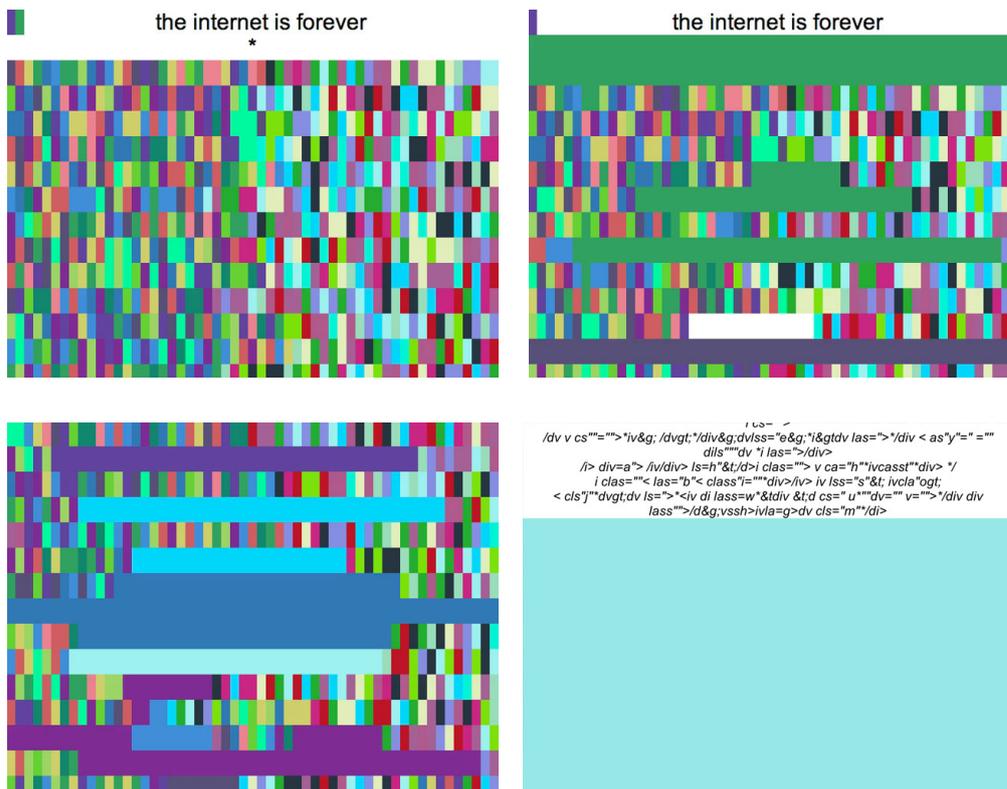


Fig. 122: Different (de)generations of *temporary.cc* (Gage 2009a).

Glitches expose the media behind the delivery technologies. They are always concrete, and make the medium become concrete, because they break the ‘fourth wall’ and lead the audience to experience hypermediacy. All the transcoding processes developed inside the black box, all the mechanical or algorithmic processes that were in principle not intended to be witnessed by a system’s readers or users, can be exposed by an accidental glitch, or the designer can willingly invite its audience to peek the innards of the system by providing glitches as access points. Ewan Meaney is able to find other meanings for the aesthetic use of glitch by returning to the hand-made films of Stan Brakhage<sup>479</sup> and other experimental film makers that work with the direct manipulation of the film or with archive and found materials, like Gustav Deutsch in his *Film ist.* series (1998). In their works Meaney finds an abundance

479 1933-2003.

of scratching and warping, of fading of the stock itself, of technical imperfections affecting focus, color temperature and exposition that are effectively incorporated into the pieces, making very explicit some of the natural processes of decay and erosion of the media, as well as parts of the process of their creation and reminding us that cinema is also a medium and a physical tool, not just a technology of distribution (Meaney 2008). Glitch denotes the wear and aging of the medium, and can naturally also fake it, by adding an artificial patina or simply by accelerating it. Grainy photography, distorted sound recordings, scratched film with burn marks on photograms, or jumps in the film edits are all marks of imperfection, but also recognizable traces of a medium's mechanics, of its chemistry, of its grammar, and of its existence. Much in the same way as digital media transcodes and remediates analog media and previous digital media, it also appropriates their glitches too.

Iman Moradi proposes that we observe an ontological distinction between 'pure glitch' and 'glitch-alike' as two related but fundamentally different approaches to glitch in aesthetic production (2004, 8). While pure glitch defines the outcomes of malfunctions, errors and generally unplanned phenomena, glitch-alike refers to the synthesis of glitches that are alien to the medium being operated, regardless of how well simulated these may be, and to the creation of glitches in the medium that is used, such as the deliberate corruption of files or media (2004, 10). While several characteristics are common to both pure glitch and glitch-alike, namely the fragmentation, linearity, repetition and complexity (37), Moradi identifies a set of five distinguishing and contrasting features (2004, 11):

**Table 1: Five distinguishing features of pure glitch and glitch-alike according to Moradi (2004).**

Pure glitch	Glitch-alike
Accidental	Deliberate
Coincidental	Planned
Appropriated	Created
Found	Designed
Real	Artificial

Following this classification, a pure glitch can never be produced, not even searched, because from the moment that an artist creates the possibility for the occurrence of a glitch, she will be working with glitch-alike phenomena. The only way one can

incorporate glitch in an artwork is to appropriate it, by sampling, by working with what we may perhaps call 'glitch concrète'. One may use the medium to fixate its own glitches, thus incorporating them in the artwork.

We should finally mention that glitches in an aesthetic system, regardless of whether they are pure or alike, can have a fundamental role in the chronological development of the system, by acting as internal generators of information, as sources of randomness and novelty that is incorporated in and developed through the system. Therefore we can regard glitches and 'failures' not as a simple aesthetic resources, but as effectively being (at least in potential) creative inputs in the systems. If we can say, as Cascone did, that "our control of technology is an illusion", and that digital tools are "only as perfect, precise, and efficient as the humans who build them" (2000, 13) we can also see how these apparent shortcomings can in effect be major strengths. Glitches can be signs of failure but they have the potential to be tools of creation.

## AN ANALYTICAL MODEL FOR PROCEDURAL WORKS

### 3.1 Fundamentals

#### 3.1.1 Phenomenological Approach

Procedural aesthetic artifacts are a very diverse set of objects. Their computational nature can in some ways be seen as a unifying characteristic, but it diversifies more than unifies the outcomes of the processes, and these are, in the end, the perceivable phenomena that will communicate. As Dunne puts it, the “electronic object is a confusion of conceptual models, symbolic logic, algorithms, software, electrons, and matter”, where the “gap between the scales of electrons and objects is most difficult to grasp” (2005, 7). These artifacts are “on the threshold of materiality”, not because they don’t have a physical, material existence, but rather because the “CPU of an electronic object is, essentially, physically embodied symbolic logic or mathematics” (11), not form or matter.

Although one could discuss whether or not it is possible to identify true computational art forms, as Steven Holtzman defines them — art forms that one could not even imagine to have been developed without the “calculative capabilities of computers” (1994, 241) and the expressive possibilities that they open — one can also accept that sometimes what we come to identify as being characteristic computer aesthetics do not result from an excess but rather from a certain lack of capabilities.

There are moments in the history of computer technology that are rich in computer functionality producing distinct aesthetics. At such times, computer functionality reveals itself through technological limitations. Bottlenecks, such as processor speed, screen resolution, color depth, or network bandwidth — 4-bit, 8-bit music, 16-color pixelated visuals, slow rendering, compressed image and video with artifacts — create an authentic computer aesthetics, that is, the aesthetics of low-tech today. (Goriunova and Shulgin 2008, 113)

Naturally, all of these constraints or technical limitations can be incorporated in the culture of the media and are consequently recreated and emulated, thus becoming superficial aesthetic layers and not structural outputs.<sup>480</sup> As black and white photography, film, television or video, became a choice and not the only possibilities; as grain, smudges or scratches in film became something other than simply marks of the wear and tear of the medium and turned to stylistic choices rather than the inevitable consequences of the system's use, so did low resolution, low polygon count, limited color depth, compression, aliasing or other marks of the past of digital media.<sup>481</sup> They're not anymore a "manifestation of genuine software aesthetics" (Goriunova and Shulgin 2008, 111), because computational aesthetics are universal, visually able to emulate the aesthetic characteristics of most (if not all) media. While some designers may use computers and digital processes to produce objects of hyperrealistic or classical beauty, the same tools and processes can alternatively be used to produce abstract, dissonant and dysfunctional outputs.<sup>482</sup>

In *Formalized Music* (1992), Xenakis describes his approach to composition as considering "sound and music as a vast potential reservoir in which a knowledge of the laws of thought and the structural creations of thought may find a completely new medium of materialization, i.e. communication", he ensues that for this purpose,

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**480** They can be seen as not being outputs from the generative processes of a system, such as they were when their creation was subject to the technical limitations of a particular system, but rather as being created or affected by the transformational components of the system. In a sense, and adopting Chomsky's terminology, as technology evolves the signs cease to be the effect of the limited competence of the machines and start to become intentional products of the system's performance.

**481** A recent arena for this phenomenon is electronic music, where to each new wave of technological refinements it almost inevitably follows the splash of emulators for the past (and by then most certainly obsolete) machines. Technology inexorably moves on, but some sounds become 'old-school' and are prized for their low resolution, for the digital or electrical noise or other defects turned to patina. Much of the so-called 'clicks and cuts' music, as well as of the IDM (or 'intelligent dance music') exhibits a plethora of recreated glitches and errors, very often simulated at great computational expense.

**482** At least to some members of their audience.

an epithet as “‘beautiful’ or ‘ugly’ makes no sense for sound, nor for the music that derives from it” and that “the quantity of intelligence carried by sounds must be the true criterion of the validity of a particular music”. Some years earlier, when considering the history of computer-aided algorithmic composition systems and replying to a question about the musical quality of those attempts, he bluntly replied that from the point of view of aesthetics the results were meager and that the “hope of an extraordinary aesthetic success based on extraordinary technology is a cruel deceit” (qtd. in Ariza 2009, 66). Xenakis was distinguishing the systems (or the technologies that built the systems) from the aesthetic artifacts they produced, a distinction that suggested that the aesthetic success or failure was dependent on humans and independent of any technologies (Ariza 2009, 66). This is an expectable point of view in a composer, trained to always interface and isolate systems, structures and technologies and their aesthetic outputs — happening as they do at different instances, in different contexts and with different participants — but that one cannot certainly expect from technologically grounded artists like those working with and for media,<sup>483</sup> for whom the aesthetic success (or failure) is directly dependent on the technologies (and not only on the humans operating or collaborating with them). Still, even for creators that depend on the technological realization of the outputs, the conceptual aspects of a given system can weight more than the aesthetic evaluation of the outputs per se. One wouldn’t certainly experience Cohen’s AARON’s (1973a) drawings or Musgrave’s landscapes<sup>484</sup> in the same way knowing they were produced by a human rather than by a computer program. One wouldn’t even be able to listen to Cage’s 4’33” (1952) without some previous knowledge of its conceptual foundation.<sup>485</sup>

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**483** Where one can certainly classify Xenakis’s electronic pieces (or tape music) as *Persepolis* (1971), in contrast to his other pieces scored for orchestra or instruments. If the later are computer-assisted compositions, the former can be seen as being integrally computer-realized compositions, composed and performed through computers. Such was also the case with the pieces developed with and for the UPIC (Unité Polyagogique Informatique du CEMAMU) system, as e.g. *Mycenae Alpha* (1978).

**484** Musgrave uses computer graphics to create the “most ancient of artistic genres, the landscape” (Blais and Ippolito 2006, 20), developing algorithms that have since been used in software packages dedicated to animation and film. “Although landscapes have hitherto been the province of painters trained in two-point perspective, Musgrave has cited Mandelbrot to underscore the inadequacy of Euclidean geometry for describing nature: ‘Clouds are not spheres, mountains are not cones, coastlines are not circles...’ What shapes can accommodate Nature’s wispy, rugged, meandering profile? Fractals, of course, because they marry repetition and randomness. Musgrave writes recursive algorithms that perform the mathematical equivalent of Genesis, building mountains crag by crag and trees limb by limb, tracing the paths of virtual light rays to cast shadows of virtual peaks and to paint reflected sky in virtual water.” (20)

**485** One could argue that without the conceptual framing, 4’33” wouldn’t even exist and that therefore it simply wouldn’t be possible to hear. Defined singularly by conceptual aspects, 4’33” is formed before the listening act, not during it, as it would normally be expected. The focus of the listener has to be attuned

Built from systems and computational procedures, all digitally produced aesthetic artifacts can be seen as being conceptual in essence. In computational art as in conceptual art, much of the artist's attention is focused on exploring different systems for their own intrinsic value, exploring ideas that become machines that "make the art" (LeWitt 1969b). After these processes are defined, after the ideas or concepts are in place, the actual construction of the work is, according to LeWitt, a "perfunctory affair" (qtd. in Galanter 2003, 18), something that although necessary, is nevertheless secondary to the conceptual part of the artistic process.<sup>486</sup> In the domain of digitally generated artifacts, the actual construction of the work is also, at many levels, a matter of processes and ideas, a matter of algorithms and code. Musgrave, for example, describes his aesthetics by invoking a notion of proceduralism, to explain the algorithmic nature of the work.

If I dislike the resulting hue in a particular highlight (a local effect) I may change the color of the light source accordingly, but this changes tones everywhere that light falls in the scene. Similarly, if I dislike the shape or location of a given wave in the water or mountain peak in the terrain, I may change it, but this change will also affect all other waves or peaks and valleys. The randomness at the heart of the fractal models I use grants both enormous flexibility and expressive power, but it also entails complete abdication of control over specific details in relation to their global context. (Musgrave qtd. in Blais and Ippolito 2006, 20)

As with conceptual art, a considerable part of the aesthetic value of the artifacts is to be found at the level of the ideas and not at the level of the actual construction of the perceived outputs.

A piece of software is a set of formal instructions, or, algorithms; it is a logical score put down in a code. It doesn't matter at all which particular sign system

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to the typology of sounds that form the piece and not those that would normally constitute a musical composition (particularly one performed, as 4'33" originally was, on a piano).

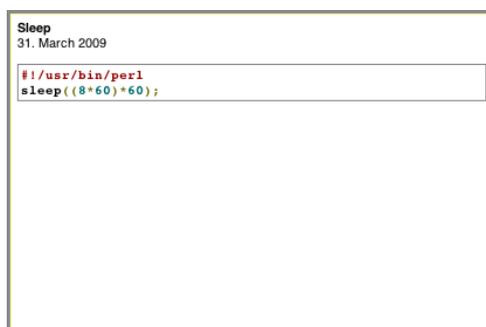
**486** "LeWitt regarded the execution of the conceptual plan as a tactic for avoiding the 'expressive', or self-consciously authored, art object, and the conceptualists developed the form of 'instructions for the making of art'. This represented a shift in authorial hegemony, from a centralised model (centred on the body of the artist) to a distributed one. However, although by following the instructions anyone could make the artwork, the instructions themselves retained the authorial privilege. The 'original' idea remained sacrosanct. This highlights a contradiction in the stated intention — to de-subjectify the artwork — and the final result, in which the user/viewer is still subjected to the didactic stance of the artist." (Albert 2009, 89)

is used as long as it is a code, whether digital zeros and ones, the Latin alphabet, Morse code or, like in a processor chip, an exactly defined set of registers controlling discrete currents of electricity. (Cramer 2002)

Therefore, as in conceptual art, we run into the problem that these ideas must either be carried explicitly, communicated *by* or *with* the artifact. When this doesn't happen the experience of the artifact will necessarily be lacking because it will be misinformed (or under-informed) and it will be up to the reader to find clues of the process in the outputs that the system produces.

Art is the external representation of things that happen in the head of the artist. Art forms differ in terms of the materials they employ, the way the representations are created, what they purport to represent, and how they are manifest in the world. (Laurel 1993, 30)

Art is the external representation of the computational processes that the artist creates, and these can be seen (at least partially, one might say) as already being representations of what happens in the head of the artist. Either way, the final representation will always be dependent of the representation that exists at the level of the code and it will not necessarily represent it, in the sense that it may not allow<sup>487</sup> the reader or user to fully understand the structure and the processes being developed at that level. Viewers are placed in art contexts but may have no interaction whatever with the machines, other than by seeking their rationale through their outputs. They are, as Saul Albert puts it, invited to examine how the artist's relationship with the machine affects her status as the artist, and theirs as viewers (2009, 91).



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Sleep
31. March 2009

#!/usr/bin/perl
sleep((8*60)*60);
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Fig. 123: *Sleep* (Thayer 2009b), from the *Microcodes* series (2009a).

<sup>487</sup> Or more often than not, will most certainly *not* accurately represent the level of the code.

But unless the source code of a system is available and readable — something that may happen in some cases but that is far from being the norm<sup>488</sup> — and unless the reader is capable of reading and understanding the code (in whatever programming language it may have been written) subsequently understanding the processes that the creator developed, her role as a user in the system, which other external influences will have any effect in the system's outputs and how these effects can affect it, she will not truly be in the possession of enough information about which things happen in the machine, much less about which things may or may not have happened in the artist's head, to return to Laurel's quip, and a multitude of questions related to the openness of the artwork, of its possible links, metaphors and analogies. This is the space of critic, a space that quickly spreads beyond the artist, the artwork and their multiple motivations, a layer of interpretation that according to Mansoux and de Valk is often forgotten but that is very present as a direct consequence of the openness of an artwork impacting not only its relation to its audience but also greatly influencing the process that underlies it — that is why it is “important to understand that software is not just a technical component of digital art, it *is* the artwork and its code provides another reading of it” (2008b, 10).

One must raise questions concerning the extent to which the artist developed the code, not only which parts of the code were of her own creation — a minor question, in the days of sampling, collage, GNU, copyleft and shared or open source code libraries — but to what extent is the artist or designer a skilled programmer, to which extent she understands the tools and the code and is ‘procedurally literate’, to follow the definition proposed by Michael Mateas (2005).<sup>489</sup> This is a challenge to the practitioners as well as to the readers and critics.

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**488** Thayer's *Microcodes* (2009) are very small code-based artworks, presented as code and as fully contained works of art, where the conceptual meaning of each piece is revealed through a combination of the title, the code and the results of running them on a computer.

**489** It is not so much a matter of historically framing a work, thus trying to understand what was feasible by a certain author at a certain time, but also to try to understand what was easier to produce by a given author at a certain time, with the set of tools that were available to her — tools that are not always immediately visible in the finished artifact. As Mateas puts it: “Procedurally illiterate new media practitioners are confined to producing those interactive systems that happen to be easy to produce within existing authoring tools.” (Mateas 2005). Although craft and technical expertise can always be difficult to discuss, particularly in the artistic context, it is clear that one must regard Musgrave's coded landscapes, created from algorithms that he devised and developed in an altogether different way from the countless similar images one comes across more recently, generated by plug-ins of 3D modeling software (that may happen to be developed from Musgrave's algorithms) that demand very little (both in creativity or craft) to be deployed. This shifts the role of the creator (temporarily in some cases) to the role of a user, much in the

This metainformation problem was present throughout the twentieth century. The more the conceptual aspects of the artwork or the artistic process were fundamental to the reading of the pieces, the more the lack of information on how to read and comprehend the artwork was felt. As a consequence, several of the fundamental artists of the twentieth century are unknown to audiences at large and to most besides a somewhat small group of literati that is able to understand the context of creation and the framing of the pieces. This phenomenon happened with many artistic fields and the problem is inherited by digital arts, operating as they are in similar grounds.<sup>490</sup> Stephen Wilson (2002) argues that the terms ‘digital’ or ‘computer-based’ may no longer be enough to describe a coherent aesthetic category, es-

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same sense as someone using Mozart’s *Würfelspiel* would not really be composing — as Mozart was when creating the game — but rather deploying the system and exploring the results of the possible combinations. The user was supplying the chance element and therefore she was indispensable to a particular instantiation of the game and to the particular output being produced, and so one may regard her as coauthoring the output, but never as its creator or composer.

**490** Fuller and Morrison discussed the tensions in this relation in two articles in the Mute Magazine, in the end of the 1990s: *Ten Reasons Why the Art World Loves Digital Art* (Fuller 2009) and *Ten Reasons Why the Art World Hates Digital Art* (Morrison 2009). In our view, both arguments fail to address the fundamental point of the question as their authors try to make of digital art something other than the traditional, or non-digital art — “Digital Art’ does not exist. In proclaiming itself as a new medium, digital art has failed to recognise that art is no longer medium-specific. Artists now operate across disciplines — text, image, moving image, event — and use whatever tools are at their disposal.” (Morrison 2009, 82) — “Both fields, art and digital art, attempt to control what art and artists should do and what they should be called.” (Fuller 2009, 88) — identifying several aspects where both differ but failing to identify the most important of these. That is the fact that what turns digital arts into something fundamentally different are not the techniques or the technologies with which the artifacts are created — those, as Morrison points can very well almost be anything that is at the artist’s disposal at a particular time — but the concepts behind the artifacts and the artist’s work. It is not the medium but the procedural layer of the medium. It is not the surface layer but what lies at the core of the work, the seed at the core of the apple — to use Scott McCloud’s analogy (1999) — from where rest of the fruit grows. It is not what one sees, smells or tastes, although all these layers are naturally important, but rather what is enveloped by the fruit and is its *raison d’être*. “Digital technology exists. Art exists. Art which uses technology exists. Digital art does not exist ‘in its own right’.” (Morrison 2009, 82) We believe one can use the term digital art, provided it is used not to refer to art that is developed with digital technology but to art that makes use of generative processes, or procedural principles in its development. Art that uses code, art that is programmed. In this sense, this art is not about visual (or sensorial) pleasure, it is rather an art about intellectual pleasure, because it is intelligence that builds procedural, generative, truly digital artifacts. As Holtzman notes, from a creative perspective, “what is interesting is not how well computers can emulate traditional human models for performing their tasks and solving problems, but, rather, the new territory that computers will reveal. What are the new possibilities opened by computers? What ideas and means of expression will we discover that are only conceivable with computers? What new models will we develop for viewing the world in light of computers? What means of expression are idiomatic to computers?” (Holtzman 1994, 240) Although some genuinely new visual or audial forms will undoubtedly arise from computational creation, like fractals or granular synthesis, for example, it is perhaps not at this sensorial level that we will find the idiomatic means of expression.

pecially now that the power of digital systems to create or emulate practically any output one can think of. He therefore suggests a broader approach, and the use of the term ‘information arts’, a proposal that has the merit of shifting the focus from the medium or the tools into the process.<sup>491</sup> The question is not *what* one can do with digital tools, but rather *how* one can work with digital tools, which processes give rise to the work that is, itself, also defined as a process.<sup>492</sup> Not what is ultimately output at the system’s surface — although that is certainly important — but much more which structures are developed in the system, creating the outputs.<sup>493</sup>

In order to perform an analysis of diverse computational aesthetic artifacts, one must therefore not rely exclusively on the physical characteristics of the aesthetic outputs of the systems. As Blais and Ippolito note, artists working with procedural systems not only tolerate, as they even celebrate, outputs that are unruly or downright ugly, provided they allow them to “focus on the code itself as the object of interest” (2006, 21). If we follow the definition proposed by Galanter, that sees generative art as “any art practice where the artist uses a system, such as a set of natural language rules, a computer program, a machine, or other procedural invention, which is set into motion with some degree of autonomy contributing to or resulting in a completed work of art” (2003, 4), it becomes clear that we will face a dilemma previously identified by Cramer:<sup>494</sup> should these works be “evaluated according to code (form) or result (function)?” (Blais and Ippolito 2006, 24)

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**491** Conversely, Dominic McIver Lopes proposes a distinction between digital art forms and ‘computer art forms’ based in the definition of a computer art form as an item that “1) it’s art, 2) it’s run on a computer, 3) it’s interactive, and 4) it’s interactive because it’s run on a computer.” (2010). We will not debate this definition here, it may suffice to say that in the context of this work we generally disagree with it.

**492** “Taking a cue from A. Michael Noll, graphic design maven John Maeda of the MIT Media Lab encourages designers to think of computers as impertinent collaborators rather than slavish layout tools.” (Blais and Ippolito 2006, 47)

**493** “The computer is essentially a structure manipulator. The workings of a computer program involve defining relationships between different objects — assigned parts of memory, bytes and words, variables or absolute values, operands — and object manipulators or operators — machine instructions that can relate and transform different objects, adding them together, shifting them left or right, comparing them for differences, moving them from one place in memory to another.” (Holtzman 1994, 139)

**494** “If software art could be generally defined as an art: 1) of which the material is formal instruction code, and/or 2) which addresses cultural concepts of software, then each of their positions sides with exactly one of the two aspects. If Software Art would be reduced to only the first, one would risk ending up with a neoclassicist understanding of software art as beautiful and elegant code along the lines of Knuth and Levy. Reduced on the other hand to only the cultural aspect, Software Art could end up being a critical footnote to Microsoft desktop computing, potentially overlooking its speculative potential at formal experimentation. Formal reflections of software are, like in this text, inevitable if one considers common-sense notions of software a problem rather than a point of departure; histories of instruction

The correct answer lies within and across both views. Audience, critics and creators,<sup>495</sup> must be procedurally literate. They need to be able to read and analyze computational artifacts, valuing them either by their final aesthetic outputs or by the processes that produce the aesthetic outputs and that may very well be, by themselves, part of the aesthetic experience. “Without an understanding of how code operates as an expressive medium, new media scholars are forced to treat the operation of the media artifacts they study as a black box, losing the crucial relationship between authorship, code, and audience reception.” (Mateas 2005)

Although one usually has no access to the code in order to read or criticize the artwork, one may try to infer from the experience of the artifacts enough information to understand the processes that are being developed within it. In cases where information about the process is communicated with or in the artifact, like e.g. Simon’s *Every Icon*<sup>496</sup> (1997b) it is easy for any viewer to incorporate the knowledge about the core process (even if the precise technical details of the implementation may be unknown) into the analysis of the artifact and into its aesthetic fruition. The presentation of the core process<sup>497</sup> becomes an integral part of the artifact, once that simply the visual representations that emerge from the process may not be able to communicate it as swiftly as the author would like.<sup>498</sup>

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codes in art and investigations into the relationship of software, text and language still remain to be written.” (Cramer 2002)

**495** Or the metacreators, should we adhere to Whitelaw’s view (2004).

**496** Simon composes a simple statement in the piece, adjacent to the grid where the process is set in motion: “*Given*: An icon described by a  $32 \times 32$  grid. *Allowed*: Any element of the grid to be colored black or white. *Shown*: Every icon.” In an artist statement published in the *Parachute* magazine, Simon develops the concept: “Can a machine produce every possible image? What are the limits of this kind of automation? Is it possible to practice image making by exploring all of image-space using a computer rather than by recording from the world around us? What does it mean that one may discover visual imagery so detached from ‘nature’? *Every Icon* progresses by counting. Starting with an image where every grid element is white, the software displays combinations of black and white elements, proceeding toward an image where every element is black. In contrast to presenting a single image as an intentional sign, *Every Icon* enumerates all possibilities. The grid contains all possible images. Any change in the starting conditions, such as the size of the grid or the color of the element, determines an entirely different set of possible images.” (1997a)

**497** Albeit in a very simplified manner, once that it is simply the idea of the process that is presented, not the actual code that algorithmically describes the process.

**498** One can argue that with a process as simple as that behind *Every Icon*, and with the speed at which it is developed (100 frames/icons per second in Simon’s original 1997 version) would eventually be understandable by most of its audience, but it is nevertheless easy to understand Simon’s will to introduce the algorithm, in a way that would clear any doubts about the process or the intent driving the piece and as to whether any viewer should expect to see a particular image or would indeed just be invited to witness a part of the development of the process: “When *Every Icon* begins, the image changes rapidly. Yet the

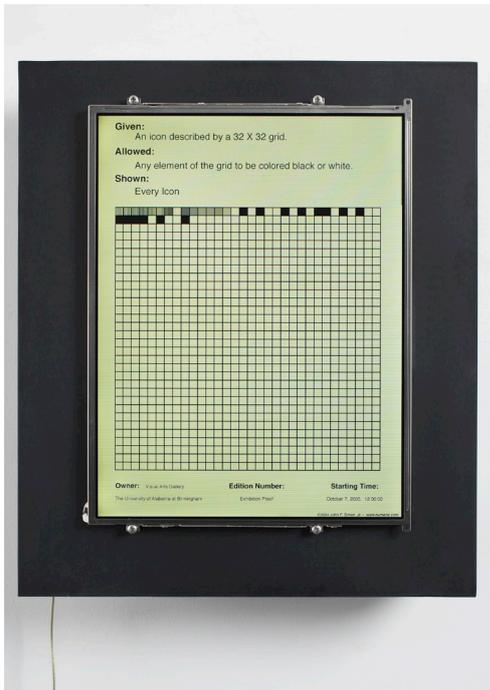


Fig. 124: *Every Icon* (Simon 1997b).

This is somewhat similar to the experience of seeing one of LeWitt's *Incomplete Open Cube* (1974a) sculptures (or 'structures', as he preferred to call them) or an exhibition of several of these pieces titled *Variations of Incomplete Open Cubes* (Baume 2001), in the sense that the title contextualizes the conceptual process that is developed in all the pieces of the exhibition and thus prepares and frames the aesthetic experience. In LeWitt's case it also deliberately places each sculpture inside a broader corpus of work, raising the viewer's awareness to its existence as part of a methodic process of formal research, of an enumerative presentation of the work.

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progression of the elements across the grid seems to take longer and longer. How long until recognizable images appear? Try several hundred trillion years. The total number of black and white icons in a  $32 \times 32$  grid is:  $1.8 \times 10^{308}$  (a billion is  $10^9$ ). Though, for example, at a rate of 100 icons per second (on a typical desktop computer), it will take only 1.36 years to display all variations of the first line of the grid, the second line takes an exponentially longer 5.85 billion years to complete." (Simon 1997a) The image the viewer is presented with is that of the process, not of any particular frame, of any particular icon but, as the title states, of *every icon*. This is a piece of and about potential, a piece where the recombinations are not a means to a final configuration but where the multiple configurations achieved through recombination are the aesthetic object. This is also a piece about time and its passing, as many pieces that deal with systematic iteration and recombination of parts inevitably tend to... This is a piece of machinic aesthetic, of logic and method and process turned into sensorial outputs.



Fig. 125: *Incomplete Open Cube* (LeWitt 1974a).

Through the repeated experience of the artifact and of its multiple outputs one may in some cases be able to grasp part of the underlying process, even if this is not represented directly by, with, or in the artifact. This will be particularly feasible in those cases where the systems visualize processes, but more difficult if there is a high degree of randomness coded into the process or if this is using real-world data as a source for control.<sup>499</sup> *Every Icon* is a good example of the first, as is *phiLia 01* (Lia 2009), a visually complex but structurally simple application that allows the user to manipulate the motion of several particles towards the creation of dynamic visual compositions, or *Text Rain* (Utterback and Achituv 1999). In *Text Rain*, the user sees herself in a mirror projection where text permanently falls, respecting the boundaries of the body or of any objects one may be holding, and piling over it unless one shakes it off. *Text Rain* deals with the principles of gravity and motion that are familiar to everyone, and uses the user's body as the control device, thus needing no introduction or explanation before its use.

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<sup>499</sup> Of course that the work may also deliberately hide any clues to the system, instructions of operation or mentions of the code or process — this happens for example in some of Lia's online pieces (both in the *turux* (Lia and Dextro 1997-2001) website as in the later *re-move* project (Lia 1999-2003), where she created control menus that have cryptic iconic marks or descriptions and that sometimes don't even produce an immediate and clear feedback from the piece. The creators of these pieces may intend to develop a game of discovery with the user or player, to turn the experience of learning how to control (or not) the system inside the black box into a part of the narrative that is created by the piece and its users.

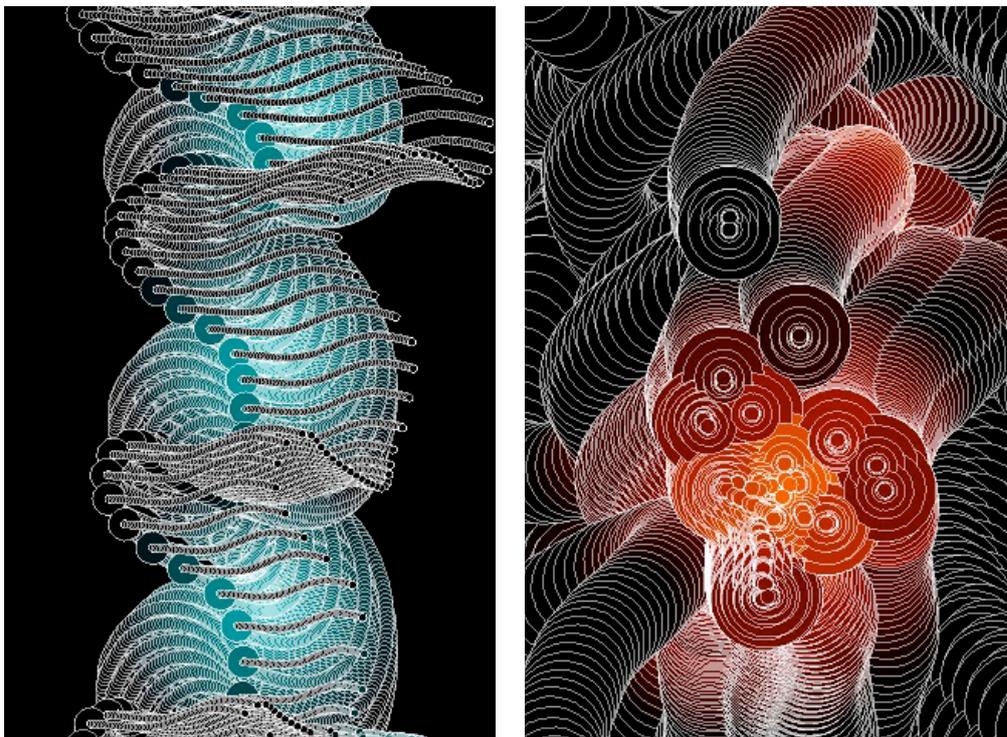


Fig. 126: *phiLia 01* (Lia 2009).



Fig. 127: *Text Rain* (Utterback and Achituv 1999).

*Merce's Isosurface* (Levin 2009) is a good example of the later, a video created from data captured from a performance by Merce Cunningham<sup>500</sup> and later interpreted by Golan Levin. The elegant motion of the rendered form is reminiscent of Cunningham's hand dance but, unless one is explicitly informed of the provenience of the data, it will be very unlikely to infer it from the piece alone. In Verostko's series of plotted paintings *Seven Sisters: the Pleiades* (1998b) (as in many other of his works) no information is given to the viewer about the algorithms of the production pro-

<sup>500</sup> 1919-2009.

cesses used in the work. Although occasionally the pieces can be presented in the context of computer art exhibitions, due to the nature of the production process — the use of paint and brushes attached to a multi-pen plotter driven by the artist’s software — there aren’t many clear signs that suggest the computational origin of the structure, besides the total horizontal symmetry, so uncanny in such a complex form. There is an air of familiarity between all the seven pieces in this series because all of the pieces “were rendered algorithmically within a specified set of parameters”, something that generated a set of “forms with a strong familial resemblance. The *Sisters* resemble each other as they were created with the same form generator sharing a common set of parameters.” Verostoko further explains that this work “demonstrates the similarities between the artist’s software and epigenesis” and that “somewhat as in a garden, the family of Pleiades were ‘grown’ with the artist’s software.” (1998c) But, in the absence of such an explanation, one wouldn’t expect the viewer to deduce any of this.



Fig. 128: *Merce's Isosurface* (Levin 2009).

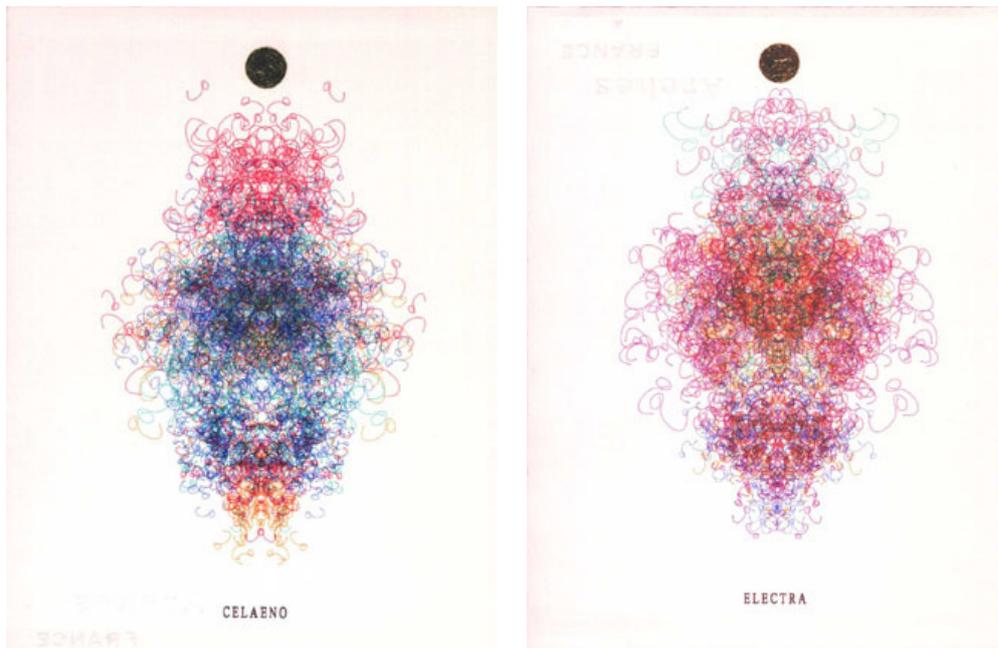


Fig. 129: *Celaeno* and *Electra* from *Seven Sisters: The Pleiades* (Verostko 1998b).

Naturally, what one may or may not grasp in the systems is not the actual code but rather an understanding of the principles of operation, of the ground rules of the piece that are enunciated by the code. What one will then need to understand in order to analyze the pieces are not the programming languages per se, but the general programming principles and the behaviors coded through these. We can argue that what seduces the viewer in the works of these artists is not necessarily the finished physical objects by themselves (however aesthetically pleasing or simply beautiful these may be in many cases) but much more the way in which each of them carries with it a process, a logic, a grammar and a set of concepts that are inseparable (and in some cases indistinguishable) from the artifact itself. Besides all other concerns central to the creation, interpretation and critical analysis of any aesthetic (or artistic) artifact, computational art uses code to speculative or critical ends (Blais and Ippolito 2006, 25), it perverts it, by turning the cold logic of algorithms into an expressive tool, a “playful perversity” that distinguishes the artistic use of code from “the merely technical one” (25), and that turns computational art into something that is much more than art made for or with machines, into something that is “highly concerned with artistic subjectivity and its reflection and extension into generative systems.” (Cramer and Gabriel 2001) It follows that beyond and besides the senso-

rial aesthetic experience of the artifact, the narratives it may develop,<sup>501</sup> and the mechanical aspects of the system's operation,<sup>502</sup> one permanently needs to consider the code layer of the system because it is ultimately this that generates and develops all the other layers. It is a fundamental part of both the aesthetic and the narrative experiences and it is at the core of the mechanical implementation of the system. It also is, however, mostly invisible to the users of the system, so in most cases it will be impossible to evaluate it directly and one will have to rely on indirect information or on clues presented by the system to hypothesize on it. One will have to develop an analysis that is not based on the code but that is phenomenologically based, that uses the outputs of the code to try to discern the processes and what is happening inside the black box of the system.

One thing that really makes this complicated is that, as an artist who writes code, I don't think that 'my medium' is the same as the 'viewer's medium'. My medium is the code. That's what I shape and manipulate to convey my 'message'. The viewer's medium can be something else. It could be the Internet or the computer or the screen, depending on how they regard the work. It could even be the code as long as I reveal it. But I'm not really in a position to dictate to the viewer what they may or may not refer to as 'the medium'. That's dependent on their own experience. Regardless, whatever I consider as 'my medium' has a big impact on the nature of the work itself. In many ways it defines and guides the creative process. (Thayer 2008)

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**501** One can argue that time-based experiential pieces always develop a narrative, although they may not *tell* a narrative, in the traditional sense one associates with narrative media. If, as Laurel proposes, we define experiential activities as those that, "such as computer games" are "undertaken purely for the experience afforded by the activity as you engage in it, while productive activities such as word processing have outcomes in the real world that are somehow beyond the experience of the activity itself (...) 'productivity' as a class of applications is better characterized not by the concreteness of outcomes but by their seriousness vis-a-vis the real world" (1993, 22-23), we should regard experiential pieces as always containing or being able to generate a narrative during their experimentation.

**502** The mechanical aspects of a system mostly refer to whether the computational processes that are developed in the system are digital, analog or hybrid, whether the system is self-running or if it depends on user input, etc.

### 3.1.2 On the Importance of an Analytical Model

Several new media, digital media, computer arts or digital aesthetics critics and scholars recognize that the lack of an established and rigorous terminology is one of the major problems found in their study. On one hand, as practitioners originate from a variety of backgrounds, they bring with them terminologies inherited from aesthetics, computer sciences, mathematics or life sciences<sup>503</sup> that aren't always compatible. On the other hand, several of the phenomena that are discovered are genuinely new and unprecedented, without clear references in other arts or fields of knowledge,<sup>504</sup> thus lacking study and a clear nomenclature.

This nomenclature must necessarily deal with questions of authorship, with technical issues, with narrative and dramatic issues and finally, with the cognitive aspects of aesthetics,<sup>505</sup> with interaction and agency. It must recognize computational aesthetic artifacts as a diverse group of objects and systems, with links not only to art and design theory and history but also to computer sciences, and many of its practitioners as often operating in both fields. It must also bear in mind that even if one could argue that to a certain extent everyone is minimally conversant with digital technologies, we can safely assume that most are knowledgeable in what is usually referred to as an 'end-user' perspective, that is, in the usage of computer programs and platforms following models of operation that are largely dictated by the applications and their designers, and not in the production of code, of new applications

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**503** "Digital artists need no longer emulate traditional media only! The computer allows us to create new media, with new rules, more naturally suited to the new tool. But such rules are best when they too follow physical phenomena, instead of arbitrary mathematical constructs. I have learned to paint with electrons moving over a potential landscape, quantum waves trapped between walls, chaotic dynamics, and with colliding molecules... You could say that I'm using physics as my brush." (Eric Heller qtd. in Blais and Ippolito 2006, 40)

**504** With perhaps the exception of computer sciences, to which, according to Bolz, media theory will resort for its foundations: "The task that media theory is confronted with is the transformation into computer theory, because that will certainly become the metatheory in this area. Within it, the connection will have to be made between the electronic media and the metamedium computer." (2004, 25)

**505** Media theory is necessarily based on a new aesthetics, "if you define aesthetics as the 'theory of perception.' The eye absorbs five gigabytes per second. This is such an enormous amount that the biggest mainframes can only barely equal it. With the eye, one can absorb much more information than with any other sense or intellectual capacity. This means that information processing must be visual in the future, because the eye possesses the potential for processing large quantities of information in a meaningful way." (Bolz 2004, 25)

or programs. People are well-versed in the usage of existing software, not in the creation of new software or on what Mateas would call procedural literacy (2005).<sup>506</sup>

As digital technologies become ubiquitous, as they are embedded in multiple devices and almost all of the media, they are increasingly produced by a combination of human and mechanical activities, all arts tend to become cyborg arts and all communication becomes cyborg communication. These are in dire need of a “criticism and terminology with less clear-cut boundaries between human and machine, creative and automatic, interested and disinterested” (Aarseth 1997, 134), a terminology that has a “distinctive power as well as unproblematic connotations” (59), that is “not grounded in computer industrial rhetoric (cf. *hypertext*, *interactive*, *virtual*, etc.) but purely on observable differences in the behavior” between the artifacts and their users. Aarseth defends that the recent visibility of the so-called ‘new media’ has inspired everyone to look at the old media in a new light. What results from these observations is the conclusion that the ‘stability’ of the traditional media (and in the case of his study particularly of the printed book and other supports for texts) is “just as metaphysical and illusory as the (...) claims of a new electronic writing that alters the functions of (...) communication in singular and revolutionary ways”. All media share properties and *modus operandi*, regardless of their digital or analog foundations, therefore, for “reasons of formality”, the physical differences of the media<sup>507</sup> should not be given substantial status in a terminology for the study of the artifacts. As is “evidenced by the history of the media, the physical stratum of the medium does not necessarily influence the user-text relationship. An illustration of this is the transition from long-playing records to compact discs in the music industry, where the analog-to-digital shift of the artifact did not change any substantial aspects of the cultural production or consumption of music”. As such, Aarseth defends an approach that configures the terminology functionally, that makes it less dependent of ad hoc perspectives and particular contexts of implementation — there are analog artifacts that function more like digital artifacts than other arti-

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<sup>506</sup> “By procedural literacy I mean the ability to read and write processes, to engage procedural representation and aesthetics, to understand the interplay between the culturally-embedded practices of human meaning-making and technically-mediated processes. With appropriate programming, a computer can embody any conceivable process; code is the most versatile, general process language ever created. Hence, the craft skill of programming is a fundamental component of procedural literacy, though it is not the details of any particular programming language that matters, but rather the more general tropes and structures that cut across all languages.” (Mateas 2005)

<sup>507</sup> Such paper vs. screen, paint vs. light, etc.

facts in the same physical medium, therefore, the analog-digital dichotomy “cannot be given analytical power as such, but it must be further examined if we wish to determine the exact significance of the materiality of the medium. The false simplicity of these terms must be abandoned, just as the poststructuralists deconstructed the simple dichotomies of the structuralists. In their place, a more discerning model based on empirical observations, able to accommodate future media patterns, must be constructed.” (59)

Introducing his own effort to build a terminology, grounded in an analytical model that provides a typology of textual communication, Aarseth describes some previous efforts to create typologies that reflect media diversity. He mentions Jan Bordewijk and Ben van Kaam, that proposed a typology of four modes of information ‘traffic patterns’:<sup>508</sup> *allocution*, *consultation*, *registration*, and *conversation*, ordered by two questions: “Who owns the information?” and “Who controls the program for information access?” Questions that are answered by individual consumers or a ‘central provider’. Secondly, Richard Ziegfeld’s *Interactive Fiction: A New Literary Genre?* (1989) compares the elements of interactive fiction with those of other media, introducing a variety of what he terms ‘software options’, such as movement, simulation or interaction, which are related to the various literary elements. However promising the premises of the essay may seem, they are however “marred by [Ziegfeld’s] lack of conceptual rigor and focus of interest” (Aarseth 1997, 60). Finally, Aarseth notes the distinction that is proposed by Joyce in *Siren Shapes* (2003) between explorative hypertexts “versus texts that can be changed, added to, and reorganized by the user” (1997, 60), that Joyce terms constructive hypertexts<sup>509</sup> a classification that proved particularly useful to the user functions section of his model, that we will analyze soon, and that will also be rather important in this work.

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**508** In their 1986 article *Towards a New Classification of Tele-Information Services* (Bordewijk and van Kaam 2003).

**509** “Constructive hypertext quits the text and enters the laboratory. Constructive hypertext requires a capability to create, change, and recover particular encounters within a developing body of knowledge or writing process. Like the conference or the classroom or any other form of the electronic book, constructive hypertexts are versions of what they are becoming, a structure for what does not yet exist. For silence.” (Joyce 1995, 101)

### 3.1.3 Aarseth's Model

Grounded on these three previous models and on his own investigation, Aarseth proposes a new 'textonomy', a typology of textual communication. He tries to establish a basis for a common terminology and the basic concepts that apply to all the objects under consideration, those that he defines either as texts or as cybertexts.<sup>510</sup> The first step to do so is then naturally to define what is the focus of the analysis — textuality — therefore defining what is a text, or “what circumstances allow us to describe a certain object as a text?” (62) ‘Text’ itself is something without a universal definition, to which disciplines “both within and outside of literary theory attach different meanings”, but that as Aarseth recognizes, needs a definition that is very pragmatic and broad, “one that will reveal, rather than obscure, any inherent flaw.” (62)

A text, then, is any object with the primary function to relay verbal information. Two observations follow from this definition: 1) a text cannot operate independently of some material medium, and this influences its behavior, and 2) a text is not equal to the information it transmits. Information is here understood as a string of signs, which may (but does not have to) make sense to a given observer. (62)

Aarseth finds it useful to distinguish between the strings as they appear to the readers and the strings as they exist in the text, once that these may not always be the same. “For want of better terms, I call the former *scriptons* and the latter *textons*. Their names are not important, but the difference between them is. In a book such as Raymond Queneau's sonnet machine *Cent mille milliards de poèmes*, where the user folds lines in the book to 'compose' sonnets, there are only 140 textons, but these combine into 100,000,000,000,000 possible scriptons.” (62) He recognizes that, in addition to the textons and the scriptons, a text consists of something other that he calls the 'traversal function', “the mechanism by which scriptons are revealed or generated from textons and presented to the user of the text”. It is particularly important to note that a text's scriptons “are not necessarily identical to what readers actually read, which is another entity (...) and one not determined by the text”, scriptons are what an 'ideal reader' would read if she would strictly follow the linear structure of the textual output.

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<sup>510</sup> Texts are analyzed in the typology almost as control artifacts, that need to be present to ensure that the typology accurately distinguishes them from the newer forms that are the object of the analysis.

In order to describe a text according to its mode of traversal, Aarseth proposes a set of seven variables: *dynamics*, *determinability*, *transiency*, *perspective*, *access*, *linking* and *user functions*, each with a range of two to four possible values. These variables and values taken together create a “multidimensional space of 576 unique media positions ( $576 = 3 \times 2 \times 2 \times 2 \times 2 \times 3 \times 4$ )” (64) and any text classified by this typological model will have a profile “which identifies it as belonging to a specific class of the 576 genre positions” (65).

Employing correspondence analysis, a branch of exploratory data analysis, Aarseth analyzes categories and variables as well as objects, trying to link categories and objects, singling out variables that “can describe substantial differences between the textual modes” (61). Correspondence analysis (CA) is a well-established method in other scientific areas, but one that Aarseth nevertheless argues should only be regarded as tentative in this context.<sup>511</sup> CA is a multivariate statistical technique that was developed by the French data analysis school of Jean-Paul Benzécri (60), and that is conceptually similar to the method of principal component analysis (PCA) but that scales the data (which must be non-negative) so that rows and columns are treated equivalently. In essence, both methods try to transform a number of possibly correlated variables into a smaller number of uncorrelated variables.<sup>512</sup> In each case the first principal component accounts for as much of the variability in the data as possible, and each succeeding component accounts for as much of the remaining variability as possible. Therefore, these methods generally allow to reveal the internal structure of the data in a way which best explains the variance in the data, largely simplifying (or even making possible) its analysis and mapping. In the case of Aarseth’s typology, CA is used to reduce the “multidimensional space to two synthetic axes, with a two-dimensional position for each of the texts and categories.”<sup>513</sup> (65) The set of seven original variables is condensed to fewer dimensions and the CA per-

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<sup>511</sup> “Although correspondence analysis has been applied to a wide variety of disciplines and problems, ranging from textual criticism to economics and archaeology, I am not aware of any previous applications in the field of literary genre or textual media typologies. I have previously used the method to describe media variety in computer games, but it seems that very few literary applications exist. The technique was not developed with this kind of application in mind, and my approach seems fairly unrepresentative of mainstream applications of this method. So although the method itself is well established, in this context it should be considered tentative.” (Aarseth 1997, 61)

<sup>512</sup> Called principal components in PCA.

<sup>513</sup> Aarseth also notes that if the model “should be shown to contain errors (such as misreadings, inconsistencies, or idiosyncrasies) that render it unacceptable, a better model can be constructed and displayed following the same principles.” (1997, 65)

formed on the data allowed to understand that one synthetic variable would manage to account for 31.13% of the variation, while two would account for 49.38% and three for 63.95% (70), while further variables would add relatively little to the accuracy, and would make the data become much less readable. “The third axis, as it turns out, is not very interesting: it shows mainly that the text *Agrippa* is very different from all the others; that is, it has an unusual combination of attributes that positions it far away from the other texts in the three-dimensional space of the three main axes. With this in mind, we can concentrate our interpretation on axes one and two.” (67) Describing the data by only the first two of these synthetic dimensions provided by the CA, Aarseth gives up “51 percent of the completeness, but that is the price we pay for readability.” (67) He defends the usefulness of the technique by pointing that the gain in interpretability of the data far exceeds the loss in information.

Mapping the data gathered from the CA, Aarseth concludes that there aren't clear signs of the classical dichotomy between printed and electronic texts, as proposed by Bolter (2001) and other authors. From the 23 texts analyzed, 10 are printed texts (as diverse as Herman Melville's *Moby Dick*, the *I Ching* or the *Cent mille milliards de poèmes*), and when one looks at their distribution along the two axes of the synthetic variables, one finds that the group of printed texts largely overlap with the group of electronic texts, “instead of clustering together and away from each other” (Aarseth 1997, 70).<sup>514</sup> In the light of the typology “there is no evidence that the electronic and printed texts have clearly divergent attributes”, and it is in fact clear that the variation within each group is much larger than the variation between the groups, although it is also clear that two of the corners of the triangle formed by the distribution of all the texts are clearly dominated by each of the groups.

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<sup>514</sup> There are some distributions that can be mapped to conventional genre partitions. If one compares each quadrant of the plot with those genres one sees that “the northwest quadrant is dominated by typical adventure games (...) and that the northeast quadrant is similarly (but not so strongly) occupied by forking texts and hypertexts. The southeast quadrant is less homogeneous, and in the southwest we find the most unpredictable and user-oriented group of samples” (Aarseth 1997, 70).

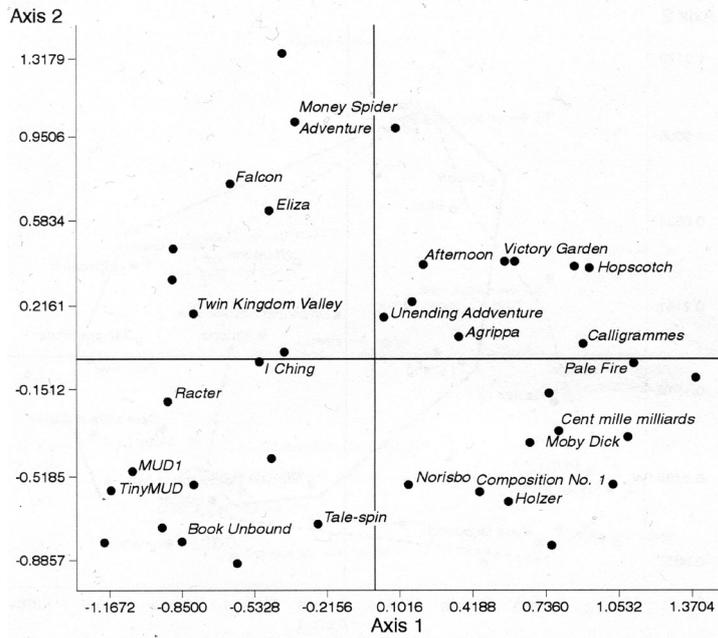


Fig. 130: Plotting of the analyzed texts over the two axes of the CA, the unmarked dots are the categories (Aarseth 1997, 71).

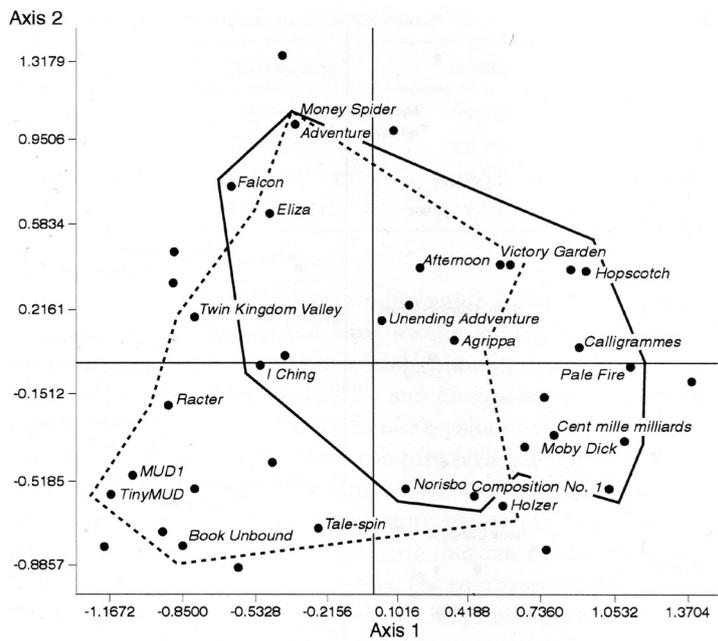


Fig. 131: Plotting of the overlap between the group of 13 electronic texts (dotted line) and the group of 10 paper texts (solid line) (Aarseth 1997, 72).

There seems to be at least three different ways to partition the material. The first and simplest is to follow the primary axis and divide the plot into two areas,

west and east. In the west we find most of the ludic texts, those that invite the user to role-play and to creatively participate. In the east we find calmer, more contemplative texts, with fewer features but also freer access. If we divide the plot according to the second axis, we find a clear group in the north, identical to the adventure game corner of the triangle and dominated by intratextonic dynamics and the exploring user function; in the south there is a clear split between east and west. This brings us back to the triangle model, which provides three poles: static texts (southeast), adventure games (north), and unpredictable texts (MUDs and text generators, southwest). North is further divided between adventure games (northwest) and hypertexts (northeast). The southeast is best described by interpretative user function and no linking. Further subdivisions may be useful, such as between the MUDs and text generators in the southwest, but I leave this to the reader's imagination. (72-3)

Concluding his analysis, Aarseth questions whether we could be witnessing yet another reconfiguration of the always contested and problematized concept of text. He questions if one should use the same term for "phenomena as diverse as *Moby Dick* and MUDs? Or for that matter the *I Ching* and *Moby Dick*? If the answer is yes, we face some hard rethinking about the subject of media analysis." (74) Searching for common features to all the samples, Aarseth concludes that the main question is related with the user activity, as any text directs its user, by convention, mechanism or social interaction.

The reader is (and has always been) a necessary part of the text, but one that we now realize can (or must) perform more than one function. If these are all texts, perhaps the word reader no longer has any clear meaning. However, if the answer is no, we still have to construct a viable terminology to describe the literary games and rhetorical rituals we can observe both in the new media and in the old papery ones. There is still much to be said for the concept of text, and the various samples examined here in no way invalidate the category. The important lesson to be learned from discontinuous and forking texts is that when two readers approach a text they do not have to encounter the same words and sentences in order to agree that it probably was the same text. And this is not new: it is a classical feature of reading, as Roland Barthes points out in his comment on tmesis. (74)

Based on this analysis Aarseth discusses the question of what to call these texts, dismissing the hypothesis of following the tendency to call all electronic texts of hypertexts (and to call paper based texts with paths or similar forking devices of protohypertexts), classifying it as imperialist and deeming it not useful, “considering the wide variety of textual types (many of which are already known by other names, such as MUDs and adventure games)” (75). Hypertext may be a useful term when applied to the structures of links and nodes that support forking texts (whether electronic or paper-based), but it is far less useful if includes all digital texts, regardless of their structures (one may consider *Agrippa* as being a truly digital text, but one that bears no resemblance whatsoever with any hypertextual structure), therefore Aarseth suggests that the term cybertext should be used for those texts “that involve ‘calculation’ in their production of scriptons.” (Aarseth 1997, 75) This is a criteria that nicely fits the results of the analysis and almost perfectly follows the division established by the main axis, while to “distinguish further between the southwest and northwest quadrants, we might borrow Joyce’s terms and describe the southwest texts as constructive cybertexts and the northwest group as exploratory”. Furthermore, Aarseth states that this designation was a consequence of the model, not something planned, and that it resulted as something of a surprise to him, as ‘calculation’ was not one of his formal categories.

### 3.1.4 On a Model for Procedural Media

‘Calculation’, algorithms, or effective procedures, must be at the basis for the definition of a typology for procedural aesthetic artifacts. We will leave the discussions around terms such as ‘media’ or ‘artifacts’ for other grounds — in this context, most times both of the terms can be in effect be used interchangeably, although we generally prefer to use ‘media’ when referring to the communication technologies and ‘artifacts’ when referring to the contents of communication or to the actual pieces, to what one may call the work of art or the communicational object, regardless of the particular media through which it is conveyed (when that distinction is possible).<sup>515</sup> The simplest example to give is perhaps that of cinema, where a particular work can usually be conveyed through a variety of alternative media: film or digital projection in theaters, digital video, television, computers, portable devices, etc. Naturally each medium will constrain the work to a particular format or choice of formats

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<sup>515</sup> And we have to grant that the distinction between media and artifacts, media and systems or between media and works is very often confusing, especially in those cases where the work *is* the medium.

and to specific limitations in its final sensorial output, but one can argue that the piece that is conveyed by all is fundamentally the same, in disregard of the medium-specific metamorphosis it may be subjected to. In this sense, many of the artworks and aesthetic artifacts that we discuss in this work are ‘notational’, as proposed by Goodman.<sup>516</sup> They are not unique artifacts as paintings are, “bound up with the question of who produced [them]” (Lee 2006, 33) and naturally forgeable, as “a faithful reproduction can be illicitly presented as the original”. Texts are not forgeable in this sense because any textual sequence that corresponds with the original text is a genuine instance of the artifact. “According to Goodman, when Pierre Menard happens to write a novel identical to Cervantes’s *Don Quixote*, in Borges’s story, Menard’s novel just is the *Quixote* — who wrote it, and where or when it was written, are irrelevant to its identity as a work.” It is important to notice Goodman’s distinction between ‘autographic’ works, such as paintings and other unique objects — not only bound by the authority of their producers but also by the specific medium in which they are produced and through which they are communicated<sup>517</sup> — and notational or literary works, that he calls ‘allographic’.<sup>518</sup>

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**516** “Goodman claims, pictures are a language no less than is English, and the nature of their capacity to refer to or represent things in the world is essentially the same. They are used, according to systems of rules, by people who agree that certain symbols will stand for certain things.

Nonetheless, pictures are clearly a different kind of symbol system from some others, and Goodman approaches this subject by distinguishing notational symbol systems from those that are not, in somewhat technical terms. According to Goodman, five basic conditions are required for a symbol system to be notational, the first two syntactic, and the rest semantic:

1. The system must consist of symbols (utterances, inscriptions, marks) that form equivalence classes (characters), which can be exchanged without syntactical effect. Alphabets are a prototypical example — any ‘a’ is as good as any other; they are ‘character-indifferent.’ The characters have to be disjoint, so that one mark qualifies as an instance of more than one character. In general, Goodman takes compound inscriptions (e.g., sentences) to be characters as well.

2. Characters have to be ‘finitely differentiable’ (or ‘articulate’) in the sense that their disjointness is feasibly testable; this rules out, in particular, ‘dense’ systems in which any two (ordered) characters have another between them.

3. Notational systems must be unambiguous, so that the extension (i.e., what is referred to, which Goodman calls the ‘compliance-class’) of an inscription is invariant with respect to time, context, and so on.

4. The compliance-classes of all characters must be disjoint. (Also, the system will ideally be nonredundant.)

5. Compliance-classes must also be finitely differentiable. Thus, for example, any system that is ‘semantically dense,’ in that its compliants form an ordering such that any two have another between them, is excluded.” (Lee 2006, 30-31).

**517** Not a broadly defined medium like oil painting, marble or other stone but the specific molecules of the medium in which they are produced, a specific stone, not a type of stone, specific paints or canvas...

**518** We may make a note for implementations of allographic works that become autographic works, such as first editions prints of books or original manuscripts that were later reproduced. Of course that in this sense, the manuscript or a first edition of *Don Quixote* are not equivalent to the latest paperback

Music, of the typical Western kind, is notated, and the creation of the notation Goodman calls the ‘execution’ of the work, but it still needs to be ‘implemented’ through performance to properly exist. This idea of implementation is given considerable prominence. A novel is implemented by being printed, published, promoted, circulated, and ultimately read. A play is implemented through performance before an audience in a theater, an etching by the taking of impressions, a painting perhaps by being framed and hung. A work is somehow incomplete until it has fulfilled its communicational destiny: execution is the making of a work, but implementation is what makes it work. (33)

Of course that one wouldn’t go as far as to state that allographic works completely remove the authorial authority from the equation, as McKenzie Wark suggests in *Gamer Theory* (2007, 219),<sup>519</sup> but one would rather say that traditional authorship is increasingly turning into what Murray calls ‘procedural authority’, something that, according to Bogost “not only expresses systems of interrelated actions, but also teaches us to read both technology-based works and non-technology-based works from the single perspective of their shared procedurality” (2006, 46). Our definition cannot be grounded on the set of signs used in the communicative act, nor on the particular kind of information that one exchanges with the system, therefore the simple definition of an “object with the primary function to relay verbal information” (Aarseth 1997, 62) will be as useful (or useless) as any definition mentioning visual, aural or any other specific kind of information.

What we can retain from his definition are the two observations, that we can rephrase as: 1) an aesthetic artifact cannot operate independently of some material medium, and this influences its behavior, and 2) an aesthetic artifact is not equal to the information it transmits. We should however bear in mind that this rewording is (perhaps too simply) just replacing the somewhat undefined object of Aarseth’s study, *text*, with the apparently even less defined object of this study, *aesthetic artifacts*. But, one can question, is ‘aesthetic artifact’ a sufficient definition for our object of study? What is an aesthetic artifact then? It is something concerned with beauty

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edition, but it is the medium and the tangible (and historical, in this example) artifact that creates the difference, not the *Quixote*, the literary work.

519 “Writing sends the word — logos — out into the world estranged from the authority of its author, erasing the line of its paternity, making of it an orphan.” (Wark 2007, 219)

or its appreciation<sup>520</sup> and something that is man-made (directly or otherwise) but that is not naturally occurring in the world. It is then necessarily a communicational artifact, in the sense that it either deploys information to convey the aesthetic effect or that it uses the aesthetic effect as a resource for an effective communication of its information. As we previously noted, which information and class of signs are used by the artifact are certainly relevant to its analysis under an aesthetic perspective, but this analysis would have to focus on and to depend upon the particular classes of signs being used and in the meaning of the information that is transmitted.<sup>521</sup> Therefore, the analysis of a sound-based artifact would necessarily differ from the analysis of a text-based artifact, despite many hypothetical similarities at the level of the processes developed in the pieces. What we propose in this work is that the analysis can perhaps be developed at the level of the processes and that, despite obvious disparities at the sensorial level, similarities can be found between pieces that are driven by similar processes.

Obviously we are not defending that an analysis based on the procedural aspects of these artifacts should replace one that is focused in the aesthetic features, as one wouldn't defend that an aesthetic analysis should replace a broader cultural or contextual analysis. What seems clear as more and more procedural aesthetic artifacts are produced, as they reach broader audiences and as they become part of the mainstream of communication design and of the arts, is that the analysis of the procedural aspects of these artifacts should also become part of their study.<sup>522</sup>

The typological approach is one way to question conceptions about texts, readers, and the limits of such concepts. Its reductionist perspective makes it easy to check, criticize, modify, or even reject if necessary. The larger categories attained by this method explain themselves through their construction, and the problem of industrial-rhetorical terminology that haunts so much of the current theoretical discussions of the new media can thereby, we hope, be avoided. The same approach could probably be used in other typological studies of cultural phenomena, such as the study of literary genres. The open categories approach also allows for a prediction of hypothetical textual modes, by

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<sup>520</sup> From the Greek root of the word, *aisthetikos*, from *aistheta* 'perceptible things', from *aisthesthai* or to 'perceive'.

<sup>521</sup> Which naturally also opens the way to a multitude of cultural, political and sociological analysis.

<sup>522</sup> And by extension of the study of arts, music, communication design, etc...

combining functions that are not found together in any existing texts. Thus the model works both on an abstract, synthesizing level and on a particularizing, predictive one. (Aarseth 1997, 74)

Taking a cue from Aarseth's proposal, we will attempt to develop a typology for procedural aesthetic artifacts, striving to find common characteristics among the immense diversity of these systems. We will take Aarseth's textonomy as a starting point, already focused as it is in the 'calculations' happening beyond the artifacts, in the systems' 'black boxes' more than in their sensorial outputs.

### 3.2 Aarseth's Variables

#### 3.2.1 Dynamics

The first variable in Aarseth's typology is *dynamics*, describing the contrast between the behavior of scriptons in a static text, where they are constant, from that observed in dynamic texts, where "the contents of scriptons may change while the number of textons remains fixed (...) or the number (and content) of textons may vary as well" (63). A hypertext as *Afternoon* (Joyce 1990) will present a fixed number of scriptons (and textons), while a game like *Colossal Cave Adventure* (Crowther 1976) will present a fixed set of textons but a variable number of scriptons, that are of course the result of different texton combinations and are determined by the progress of each individual play. "In a MUD, where other concurrent users can type in anything, the number of textons is not known." (Aarseth 1997, 63) Aarseth therefore classifies *Afternoon* as a static text,<sup>523</sup> the *Colossal Cave Adventure* as displaying 'intratextonic dynamics' or IDT and a MUD as displaying 'textonic dynamics' or TDT.

When used to describe text-based pieces this variable is easily understandable, but it can be somewhat harder to apply to other classes of signs,<sup>524</sup> particularly if one considers temporal media, but the experience should nevertheless be undertaken. Whenever a system presents a fixed number of signs and of their combinations<sup>525</sup>

<sup>523</sup> Although it is a hypertext where one can develop a nonlinear reading experience.

<sup>524</sup> 'Signs' as something that stands for something, as discrete units of meaning, a definition that not only includes words (textons and scriptons) as well as images, gestures, scents, tastes, textures, sounds or any other way through which information can be communicated as a message.

<sup>525</sup> However freely the reader or user can roam between these, and regardless of whether the signs are dynamic in time, or 'transient', as we shall see.

we will be able to classify it as *static*. This will be the case in printed works such as Nake's *Hommage à Paul Klee 13/9/65 Nr.2*<sup>526</sup> (1965) or Watz's *Conical* (2009), but also in time-based works such as linear videos, where in spite of temporal dynamism, very often one does not witness the introduction of new elements or articulations.

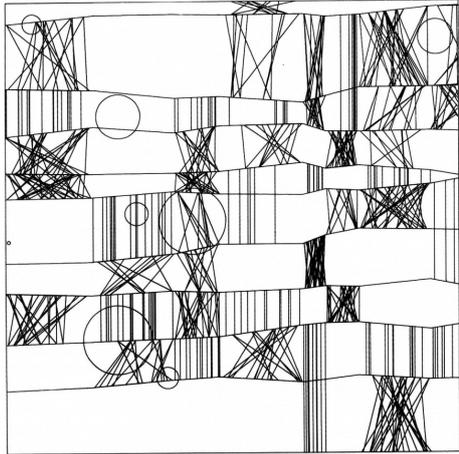


Fig. 132: *Hommage à Paul Klee 13/9/65 Nr.2* (Nake 1965).

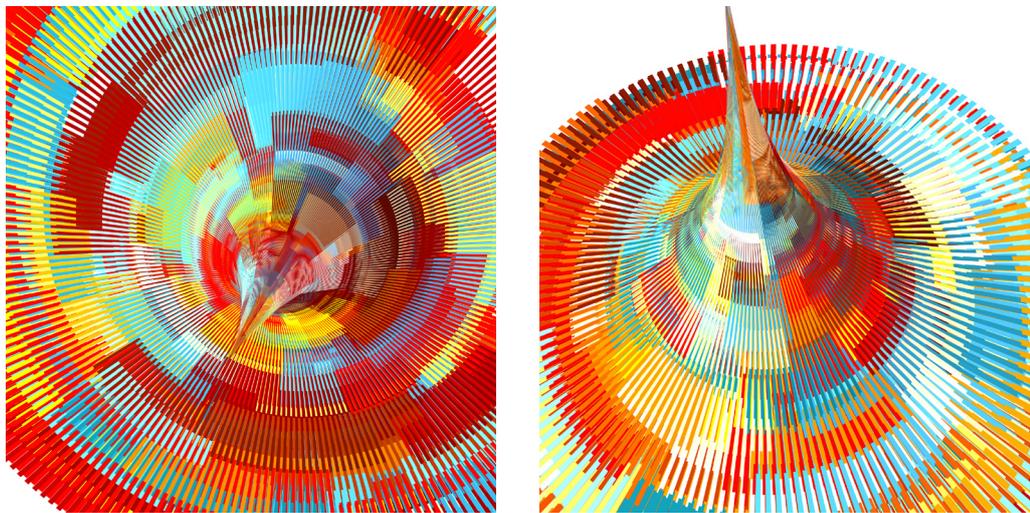


Fig. 133: Two prints from the *Conical* series (Watz 2009).

<sup>526</sup> Klee's drawings led Nake to think about programming visual art as a tension between macro and microaesthetics. They were based on linear structural elements that stretched out across the plane of the drawing but that also allowed for smaller groups and for clustering in intricate local sets. Nake developed the language COMPARTER ER 56 referring to the Standard Elektrik ER 56 computer, for which it was written. ER 56 contained three sub-packages, a space organizer, a set of different random number generators, and selectors for the repertoire of graphic elements. The program chose a stochastic matrix, raised the quantities to powers, and then visualized the numerical results by allocating characters or colors according to their amount.

Beyond static dynamics, where Aarseth analyses the difference between textons and scriptons, we will need to focus on a similar but broader distinction that is possible to analyze in other media besides text. Signs may exist at various levels in an aesthetic artifact: the entire artifact may in many cases be interpreted as being a single sign and it may be interpreted as being composed of several signs, much like a text, as described by Aarseth, is composed of scriptons that are themselves composed by textons.

If texts are to be described in topological terms, they must be shown to consist of a set of smaller units and the connections between them. Further, the function of these units must be relevant to our notion of nonlinearity. It is not difficult to partition any text into graphemes (letters), lexemes (words), or syntagms (phrases or sentences), but none of these elements indicates nonlinearity by its presence. (...) Therefore, the unit for which we are looking is clearly not defined by linguistic form. This unit, which is best conceived as an arbitrarily long string of graphemes, is identified by its relation to the other units as constrained and separated by the conventions or mechanisms of their mother text. As a suitable name for such a unit I suggest *texton*, which denotes a basic element of textuality. In accordance with the concept of textuality developed in the previous section, a more logical name might seem to be *scripton*, but this term posits that the textual unit belongs to the reading process rather than that it inheres in the textual structure as a strategic potential. A *scripton*, then, is an unbroken sequence of one or more *textons* as they are projected by the text.<sup>527</sup> (1994, 60-61)

When looking at the signs in a non-textual artifact,<sup>528</sup> we will need to distinguish two broad classes<sup>529</sup> that are also not clearly defined: those we could perhaps name ‘macro-signs’, or simply ‘signs’ and those that can be seen as the micro components

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**527** Aarseth also discusses alternative nomenclatures: an “alternative to *texton* might be *lexie*, after Roland Barthes’s ‘*unités de lecture*’ (‘units of reading’) in *s/z*. This candidate, adopted by George P. Landow (1992) from an English translation as ‘*lexia*,’ I want to avoid because of Barthes’s emphasis on seriality (‘*fragments contigu*’) and the destructive process of its separation (‘*découpé*’) from the text.” (Aarseth 1994, 61)

**528** Or for that matter in a multimodal artifact that includes text but *is not* exclusively composed of text.

**529** This is not a semiotic analysis, distinguishing between iconic, plastic (colors, shapes, textures) and linguistic signs, but rather one that tries to understand how, in the heterogenous artifacts one is studying, all these are articulated and where they stand in the hierarchy of the system’s structure.

from which the signs are built.<sup>530</sup> The first can be roughly compared to Aarseth's scriptons<sup>531</sup> and can be understood as those forms that are directly perceived in the system's output, while the later are the parts from which these are built.<sup>532</sup> These are not necessarily indexes, icons or symbols<sup>533</sup> (Callahan 1994), although they may be (and usually are) on the way to become either of them, or they may forever stand in the delicate balance between realism and abstraction, as expressed by Wassily Kandinsky<sup>534</sup> (2008). They will generally not be the technological structural components, like pixels, or voxels,<sup>535</sup> but will be built from these, and will stand in the middle-ground between these and the signs. We can understand this in *phiLia 01*, where the forms that are perceived at the surface of the system are constructed from several circles (of regular diameters, in this case, but of varying colors and moving around more or less freely in the plane of the composition) or, one could also put it, emerge from the behaviors of these.<sup>536</sup> It is tempting to (however simplistically) compare the two roles of forms and components to Chomsky's deep and surface structures when referring to the structure of sentences or messages. Although we are reluctant to appropriate terms from linguistics, as we would be to use a nomenclature from any particular area of artistic or aesthetic field because the phenomena that we are trying to identify are transversal to all of these, and can be identified across visual, aural or verbal systems, these designations are very attuned to what we are trying to describe.

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**530** This bears some resemblance to Nake's tension between macro- and micro-aesthetics, macro- and micro-elements, or signs.

**531** Although they can very often be seen as being the entire sensorial output of the system — which in Aarseth's model would correspond to the whole text — but this is not something that contradicts the model.

**532** In a sense the first can be seen as the gestalt components of the artifact and the later can be seen as structural components.

**533** 'Icons' are a class of signs whose signifier keeps a direct analogy with what is represented, 'indexes' keep a causal relation of physical contiguity with what is represented, and lastly, symbols are related with what they represent merely by a convention (Joly 2008, 38-39). This classification, first proposed by Charles Sanders Peirce (1839-1914) remains somewhat controversial and is often criticized, it is nevertheless useful for the study of images and of the different kinds of images so, according to Martine Joly it is still commonly used (2008, 39).

**534** 1866-1944.

**535** A volumetric pixel, or Volumetric Picture Element.

**536** There are a dozen or so components in the system, all of them moving across the plane and reacting to the user's inputs and to each other. These leave traces that ultimately compose the perceivable form.

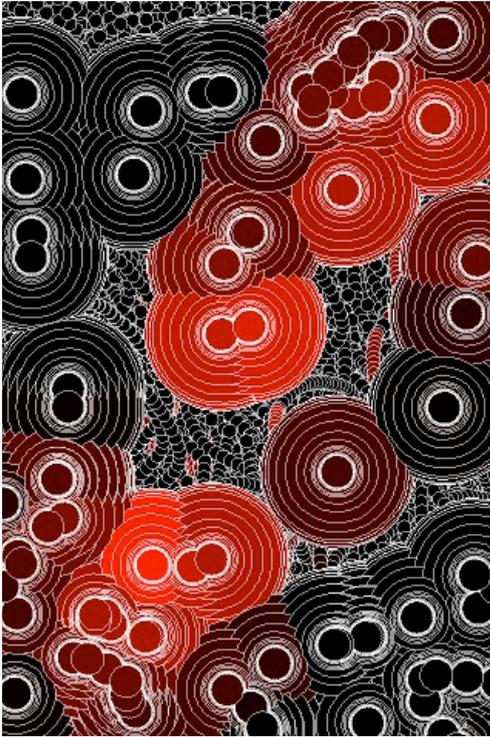


Fig. 134: *phiLia 01* (Lia 2009).

We can then maybe talk about ‘surface forms’ and ‘deep structural forms’ or, picking up after Alexander’s definition (2002a), we could also (and probably more accurately) describe these elements as ‘centers’ or, if choosing to follow Krome Barrat’s (1980) nomenclature, we could finally propose to call them ‘surface units’ and ‘deep units’. What is important in this context, however, is to name the phenomena and not the actors that create it. Consequently, to the dynamics value that Aarseth calls IDT or intratextonic dynamics, when scriptons change but the textons do not, we can tentatively call ‘surface unit dynamics’ (SUD) or simplifying, ‘surface dynamics’. This will describe all systems where a fixed number of deep units are articulated in the production of several (or varying) surface units (or forms). *phiLia 01* is such an example, as is *Every Icon* or *Page 0* (Paterson 2004) an online system that creates illustrations from recomposing a limited (albeit large) set of deep units every time the user clicks the window.

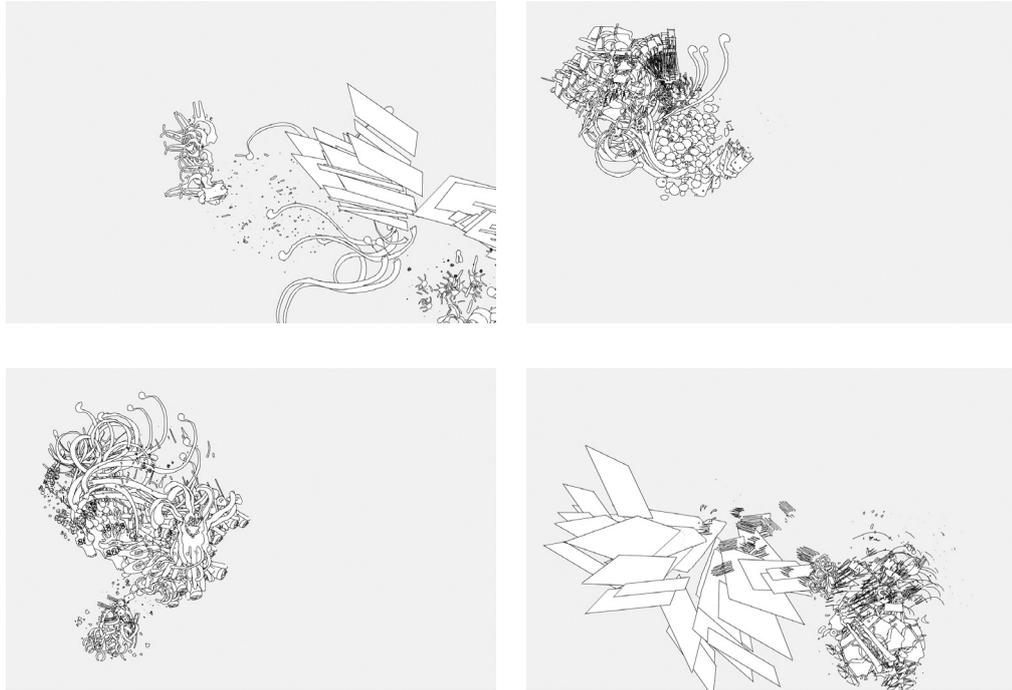


Fig. 135: *Page 0* (Paterson 2004).

If we look at design systems like the identity for the 2007 Lovebytes festival in Sheffield<sup>537</sup> (Universal Everything 2007), and particularly if we study the entire system and not any single piece produced within it, we will also find an example of surface dynamics. The system was designed to create twenty-thousand different ‘creatures’, a population that appeared throughout the festival’s literature, very often in unique digital prints (such as posters and postcards). These forms were produced from variable parameters for hair color and length, head shape, and eye shape and number, using a somewhat limited array of deep structural units,<sup>538</sup> from which a remarkable diversity of surface units resulted. Likewise, in the design program for the *Faber Finds* collection of print on demand books<sup>539</sup> (Wall and Schmidt 2008), we find that a repertory of “micro templates” that “form a shape vocabulary” for the borders of the covers (Schmidt 2008c) from which the print-ready files are created.<sup>540</sup>

<sup>537</sup> Concept and art direction by Matt Pike, programming by Karsten Schmidt.

<sup>538</sup> Something that obviously had the benefit of making all the different forms that were produced (or ‘spawned’, in the words of the art director) bear a strong look of familiarity between each other.

<sup>539</sup> Art direction by Darren Wall, design and programming by Karsten Schmidt.

<sup>540</sup> “The custom software written in Processing, straight Java and PHP works as an internal webservice at Faber which receives new batch orders and then generates complete, print ready PDF files with all copy, branding, spine, ISBN, barcode and optional high-res JPG preview using the book details supplied. Generating a single cover only takes about 1 second, but due to its iterative and semi-random nature can

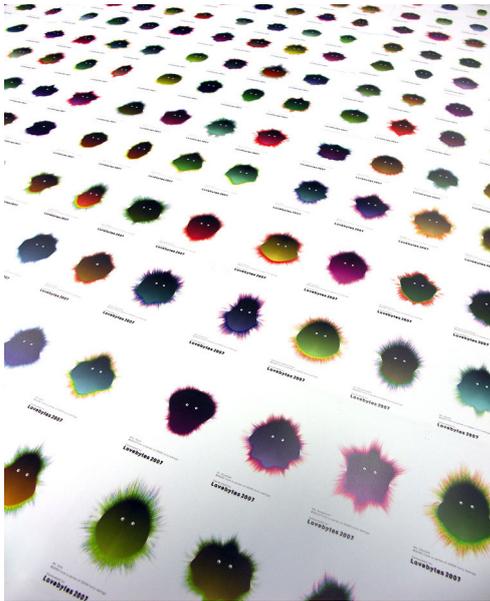


Fig. 136: Postcards for the Lovebytes Festival (Universal Everything 2007).



Fig. 137: Faber Finds collection (Wall and Schmidt 2008).

Finally, in a phenomenon equivalent to what Aarseth calls  $\tau\delta\tau$  or textonic dynamics — when textons change (and consequently also do scriptons) — we will find that in some systems the deep units change automatically or can be changed by the user, invariably leading to consequences in the surface units. To this we can call ‘deep units dynamics’ (DUD).

An example of a system that displays deep unit dynamics is found on the *Perpetual Storytelling Apparatus* (von Bismarck and Maus 2009b), “a drawing machine

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sometime require hundreds of attempts until a ‘valid’ design is created which is judged to be ‘on brand’ by software itself.” (Schmidt 2008c)

illustrating a never-ending story by the use of patent drawings"<sup>541</sup> (2009a) directly fetched from online databases. The basic procedure starts from the parsing of a text,<sup>542</sup> eliminating all the words that are meaningless in the context of the process, namely pronouns, articles, prepositions and conjunctions, mostly keeping nouns and verbs, and using these as keywords for a search for patents in public-access online databases. Relating patents found through the keyword search and the references that these patents contain to prior patents, the system is able to semantically connect the patent drawings, using these in the creation of large-format compositions.

Although the *Perpetual Storytelling Apparatus* outputs by plotting on paper, one should perhaps regard it as being closer in essence to a screen-based system rather than focusing on the more obvious physical similarities with for example Verostko's paintings. The *Apparatus* emphasizes the performative aspect of the system<sup>543</sup> over its outputs as artistic objects per se,<sup>544</sup> while Verostko's paintings, or the images produced by *AARON* (Cohen 1973a) are aesthetic artifacts per se, they are, in a sense, finished works. We can argue that much like the *Apparatus*, systems like Jean Tinguely's<sup>545</sup> *Méta-Matics* or Leonel Moura's *Robotic Action Painter* (2006), although producing outputs that are physically independent from the system are not created as artistic devices intended to produce artworks but rather as artworks that produce aesthetic outputs. Therefore, if with Verostko or Cohen the final outputs are the works of art and the systems that produce them are in a sense metacreators,<sup>546</sup> with Tinguely, Moura or von Bismarck and Maus, the systems are the works of art and it is the operation of the system that is focused by the authors when communicating their work, while the outputs that are created can sometimes almost be seen as mere byproducts of the systems.<sup>547</sup>

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**541** "The machine translates words of a text into patent drawings. Seven million patents — linked by over 22 million references — form the vocabulary. By using references to earlier patents, it is possible to find paths between arbitrary patents. They form a kind of subtext. New visual connections and narrative layers emerge through the interweaving of the story with the depiction of technical developments." (von Bismarck and Maus 2009a)

**542** The texts used are taken from recent best seller books, found online.

**543** Comprised by the software, the data, the plotter and the paper where the output is drawn.

**544** Although of course one may justly consider that the outputs are interesting aesthetic objects in their own right.

**545** 1925-1991.

**546** Systems that are produced to produce art.

**547** We could, as many do, call them 'drawing machines', but we believe that such a designation somehow misses the point, as in these cases what is valued as an artistic creation are not the drawings them-

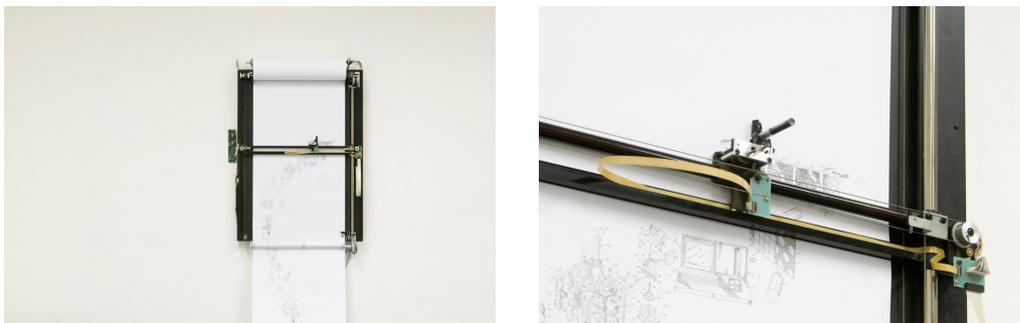


Fig. 138: *Perpetual Storytelling Apparatus* (von Bismarck and Maus 2009b).

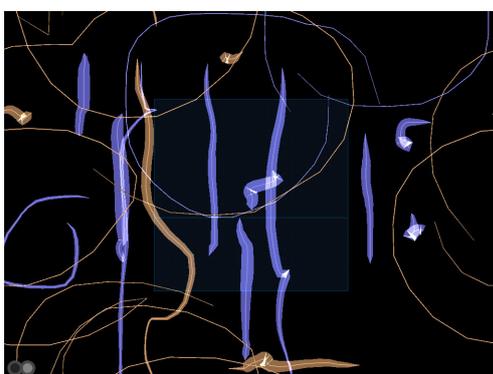


Fig. 139: *Yellowtail* (Levin 2000).

Concluding the analysis to the dynamics variable as proposed by Aarseth and repurposed here, we arrive to the apparent contradiction of classifying temporal media such as film or audio as static,<sup>548</sup> but if we regard the global structure of the artifacts and particularly the fact that the immutability of that structure creates a canon whose invariability defines the identity of the piece, we see how adequate such a description can be.<sup>549</sup>

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selves but rather the systems that create the drawings (that are in many cases secondary to the machines, and not the primary focus, as in Verostko's case).

**548** Something that Aarseth himself already did, classifying some digital texts, such as Jenny Holzer's *I Am Awake at the Place Where Women Die* (1993) as static, although their experience is necessarily temporal, in the sense that the contents of the projection are altered during the reading. The overall number of textons, and the articulation of these into scriptons is however fixed.

**549** It is not that the artifact does not change — what we perceive of it permanently changes, repeated viewings of the artifact may lead to different experiences (as in *Afternoon* or other hypertexts) — but the structure over which the experiences are developed is unchanged.

### 3.2.2 Determinability

The *determinability* variable concerns the stability of an artifact's traversal function. In Aarseth's typology a text is determinable if the scriptons adjacent to every scripton are always the same, otherwise it will be indeterminable. As an example he describes how in "some adventure games, the same response to a given situation will always produce the same result" while in "other games, random functions (such as the use of dice) make the result unpredictable" (1997, 63). Applied to a broader universe of aesthetic artifacts, determinability may describe whether multiple readings of (or interactions with) the same artifact will result in exact repetitions of the same experience or if, on the contrary, they will evolve differently.<sup>550</sup> 'Determinable' systems will repeatedly behave similarly and will allow the reenactment of previous experiences, while 'indeterminable' systems will sometimes lead the traversal function as much as the user herself, pulling the experience into unknown territories and forcing the user to adapt or react to new usage scenarios.<sup>551</sup>

We can find examples of determinable systems in *Every Icon*, *Agrippa*, *Moving Pixel Portraits*<sup>552</sup> (Laric 2006) or *Three Buttons* (Leegte 2005). The first two present the user with a sequence of events that regardless of their intervention or of any other factors (given that the systems are not susceptible to external influences and do not include inner sources of randomness or variation) is repeatable.<sup>553</sup> Laric's and Leegte's works are systems that although allowing for a multiplicity of configurations to be developed from their initial states respond uniquely to the user's interaction and do so linearly, without any noise or randomness, allowing the user to perfectly reproduce any sequence of interactions, thus reproducing the configurations they develop.

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<sup>550</sup> Let us presume that the hypothetical user's behavior is repeated without changes or variations, either at the level of which actions are developed as at the level of their sequence and relative timings.

<sup>551</sup> Classic computer games come to mind, where after repeatedly clearing a level, a player could almost replay it without looking at the screen, much as one solves a Rubik's cube blindfolded. The memorization of full levels or games of 'shoot-em-ups' wasn't an uncommon practice among frequent gamers of what we can maybe call the 'pre-AI' era of computer games.

<sup>552</sup> A work where a single row of scaled-up pixels is wrapped in variable configurations depending on the user-defined window size.

<sup>553</sup> Even, at least theoretically, in *Agrippa*, provided one can break the encryption or have access to multiple copies of the work.



Fig. 140: *Moving Pixel Portrait of Aleksandra Domanovic* (Laric 2006).

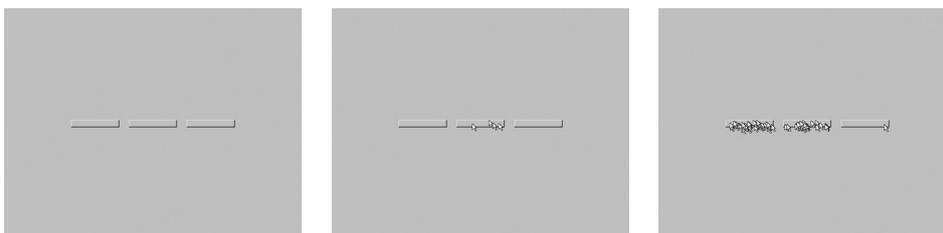


Fig. 141: *Three Buttons* (Leegte 2005).

Contrasting with these, systems like *Page 0*, *phiLia 01*, *Yellowtail* or *Robotic Action Painter* can be classified as indeterminable, in some cases due to random functions that create varying and unpredictable behaviors, in other cases due to the fine degree of control that the systems allow, repeating the exact same outputs may become an impossibility.<sup>554</sup> Finally, if the system relies on information that is fetched from other sources besides the user — from the real world, from online databases, from other users (in synchronous or asynchronous time) — the determinability of the system may be directly connected to the determinability or lack of it in that information.

One should also question whether there is a relation between dynamics and determinability. One could expect static systems to always be determinable — which of course happens to be true in linear videos, printed pieces or some hypermedia systems like *My Boyfriend Came Back from the War* (Lialina 1996) or *Afternoon* (Joyce 1990) — but that is not universal, both in Aarseth's analysis and in our own. Two of the texts that Aarseth classifies as being both static and indeterminable are the *I Ching* and Saporta's *Composition N° 1* (1961),<sup>555</sup> texts that rely on randomization procedures. It should be pointed that although *Composition N° 1* is indeterminable, the

<sup>554</sup> If the actions are timed to the millisecond, or tracked to a tenth of a millimeter it may be impossible for all users to repeat exact sequences of actions because the motor control necessary to do it will be outside of human reach.

<sup>555</sup> *Composition N° 1* consists of loose sheets, shuffled and read in a random sequence.

structurally similar novel *Hopscotch*<sup>556</sup> (1966) by Julio Cortázar<sup>557</sup> is determinable. Although both texts can be read freely by connecting different pages or chapters, only Saporta's clearly states that the individual pages should be shuffled randomly, while Cortázar provides predetermined paths as reading suggestions and then leaves the reader to determine her own paths across the novel, but without ever explicitly suggesting that chance and randomization should play a role in the process.

Systems displaying surface unit dynamics can be found to be determinable — *Agripa* or *Every Icon* — or indeterminable — *30x1*, *Page 0*, *Vanitas* (Harvey and Samyn 2010) — mostly depending on whether they make use of randomization procedures to organize the deep units.

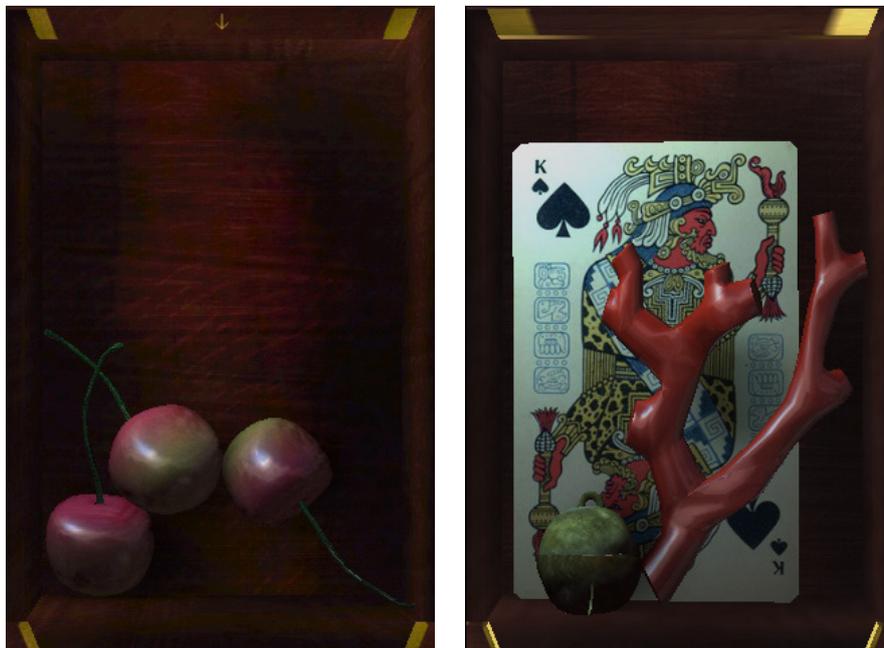


Fig. 142: *Vanitas* (Harvey and Samyn 2010).

Artifacts displaying deep units dynamics are typically indeterminable, both in Aarseth's analysis as in ours.

<sup>556</sup> *Rayuela* in the original Spanish version.

<sup>557</sup> 1914-1984.

### 3.2.3 Transiency

*Transiency*, as defined by Aarseth, is related to the temporal existence of the artifact. “If the mere passing of the user’s time causes scriptons to appear, the text is transient; if not, it is intransient. Some texts (...) scroll (...) at their own pace, while others do nothing unless activated by the user.” (Aarseth 1997, 63) *Agrippa* is a perfect example of the former, relentlessly scrolling by the user regardless of her actions, while many hypertexts passively wait for interaction. Jenny Holzer’s *I Am Awake at the Place Where Women Die* (1993) and two MUD systems are also identified by Aarseth as being transient, while the majority of the texts that were analyzed were classified as intransient.<sup>558</sup> In our analysis we have found that most time-based outputs<sup>559</sup> are transient, while those outputs that are not time-based are in general intransient, as exemplified by *My Boyfriend Came Back from the War* or *Page o. ‘Drawing machine’* systems like the *Perpetual Storytelling Apparatus* are transient, although the artifacts they produce are intransient and a system as *temporary.cc*, although not producing time-based outputs, can be classified as transient because each output is ephemeral within the system, that continues to evolve as other visitors access it through the World Wide Web.

### 3.2.4 Perspective

Aarseth’s *perspective* focuses on the text requiring the user to play a strategic role as a character in the world described by the text, in which case the text’s perspective is ‘personal’, otherwise being ‘impersonal’. “A text such as Italo Calvino’s *If on a Winter’s Night a Traveler...* pretends to involve the reader as a participant, but there is nothing for the real reader to do but read. In a MUD, on the other hand, the reader is (in part) personally responsible for what happens to his or her character.” (Aarseth 1997, 63) This is not simply a question regarding the narrative and the place that the reader as narrator or character takes in it, it is a variable that looks at how the reader or user actually becomes a character in the narrative and is allowed to shape it directly, influencing the evolution of whatever events may or may not take place.

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<sup>558</sup> In an earlier version of the typology Aarseth proposed a distinction between two modes of transiency, related to the diegesis of the texts, a distinction that is not mentioned in the final version: “If the transiency has the nature of ‘real time’ it is *synchronous*; if the relationship between the user’s time and the passing of fictional time is arbitrary, we call it *asynchronous*.” (Aarseth 1994, 61)

<sup>559</sup> All the processes whose output is developed in time. The expression ‘time-based processes’ seems almost oxymoronic.

In this sense, this variable is intrinsically linked to the diegesis of the narrative that is created by the system and the user's actions with it.

It is difficult to repurpose this variable to systems where a narrative is not explicitly created,<sup>560</sup> even though we can certainly identify narratives in contexts that are not traditionally regarded as being narrative, such as for example in simulations,<sup>561</sup> one should perhaps only consider a system to offer a personal perspective if it creates a narrative where the user is allowed to step in, becoming a fundamental part of it, either as a character or as some sort of a diegetic operator.<sup>562</sup> This is largely the domain of games or game-like systems, and even in these it is not always clear in which cases the player becomes a character in the narrative and therefore when the perspective becomes personal. Manipulating the events through interaction is hardly the same thing as embodying or becoming a character in the narrative — in hypertextual narratives such as *Victory Garden* (Moulthrop 1992) or *Afternoon*, the reader has a substantial power to control the narrative, through the choices that are made and the unique traversal of the text that she will define. Despite this, the reader never becomes a character in the narrative. Much in the same sense that a checkers or chess player has the fundamental power to shape the development of the game without ever becoming a piece of the game, without becoming a character in the particular narrative of the game.<sup>563</sup>

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**560** Be it as a purposeful creation from the author, as in clearly narrative works such as literature or film, be it as a side effect, as Sean Cubbit defends may have happened in the early days of cinema: "Narrative, then, is not an essential quality of film, but only a potential and secondary quality arising from the production of time in the differentiation within and between frames." (2004, 38)

**561** "Frasca (...) clarifies that simulations are indeed narrative, in that 'for an external observer, the outcome of a simulation is narration.' Frasca privileges simulation over narrative, the former providing an interactive experience for representations, the latter providing, at best, a more distant and less 'first-hand' experience of the representation in question. Murray calls this phenomenon of first-handedness immersion, or the ability to construct new beliefs through interaction with computational media." (Bogost 2006, 98)

**562** In games as *The Sims* (Wright 2000) or *Civilization* (Meier 1991), the player does not play a character or a group of characters but rather controls the diegetic world, thus influencing the behavior of all the characters in the game world and the unfolding of the narrative. In these games we could conceive of the player's role as (and it is often described as such) god-like, because of the relative omnipotence towards the characters of the game and the distance that is simultaneously kept from these.

**563** The player is a character in another narrative, one that exists at a level above from that of the game: the narrative of the board configurations and of the movements of the pieces, from the start of the game until its conclusion, does not include the players although it is caused by them. One can describe a complete chess game without ever mentioning the players, or even acknowledging their existence, taking the board and the 32 pieces as the diegetic world. One can conceive of a higher-level narrative that includes the players, but this will not be the narrative of the game, although it will contain it.

We can find that in very specific cases where a literary narrative is not created the user interacts with the system not only with her body but by placing it (or its image) in the outputs of the system. Such is the case of *Text Rain* (Utterback and Achituv 1999), where one not only interacts but also acts within the system, thus becoming a surface unit in it. What is relevant in this example is not the use of the body for the interaction but the fact that the body is also represented in the system's outputs, it is in a sense appropriated by the system and then returned to the user and other spectators. A similar phenomenon happens in *Reface [Portrait Sequencer]* (Levin and Lieberman 2007), where the user's face is captured by the system and used as a deep unit in the production of new outputs or in *Inner Forests* (Kontopoulos 2007), where the viewer's shadow is appropriated by the system and used as a seed surface where to grow trees and shrubs. The longer the user stands still, the more growth occurs, but if the user moves, the growths quickly disappear. In other cases where full body interaction may be used, but where the user's bodies are not appropriated by the system and are strictly used in the interaction,<sup>564</sup> the system could be classified as impersonal.

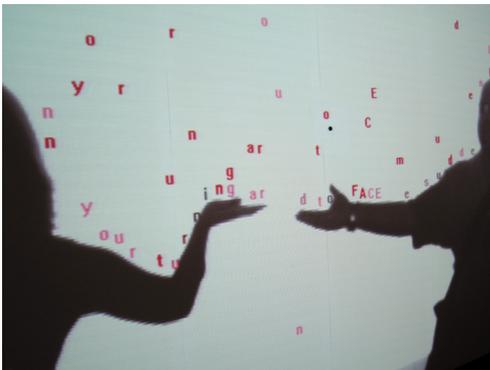


Fig. 143: *Text Rain* (Utterback and Achituv 1999).



Fig. 144: *Reface [Portrait Sequencer]* (Levin and Lieberman 2007).

<sup>564</sup> That is, in a layer that is external to the system and the outputs it produces.



Fig. 145: *Inner Forests* (Kontopoulos 2007).

These three systems are examples of what Bolter and Gromala describe as incorporation of the users in the displays of the pieces (2003, 12). Here the “visitor immediately discovers [that] she herself becomes the show”, that is “as much an expression of its viewers as of its creators (...) [and] is about the process of its own making.” (13) Still, if one wishes to comply with the spirit of Aarseth’s model, one will have to classify these three pieces as being impersonal, because neither of them develops something that can be remotely described as a conventional narrative or a diegesis. Even if the user participates and leaves a trace of her participation (and image) in the system, this trace is not incorporated in a manner that is remotely similar to that what happens in a narrative where the user becomes an acting character.

### 3.2.5 Access

The *access* variable in Aarseth’s typology describes if “all the scriptons of the text are readily available to the user at all time” (Aarseth 1997, 63) in which case the text is random access or if, alternatively, the access is controlled. “In a codex novel, you may turn to any passage at any time, directly from any other point. In a hypertext such as *Victory Garden*, to get to a specific passage you must typically follow an arbitrary path involving other specific passages before you get what you want. In other words, hypertexts without free text search capabilities are more, not less, linear than the codex.” (63)

This is a topological variable that at first look may be related to the transiency of the systems because it will seem natural to consider that transient systems should have controlled access. One may consider that transient and linear systems such as videos may be deemed to be random access, provided the user is not kept from scrubbing

the playback or, to put it another way, provided that the user has control over the temporal flow of the system and is not forced to always follow a predefined pace. We are aware that this may be a controversial option but in this context we may regard what can be seen as fundamentally the same work as having different access modes depending on how it is presented to the user. In an exhibition or projection, a transient linear work such as *Merce's Isosurface* can certainly be classified as having controlled access,<sup>565</sup> while if the same piece is viewed in a DVD or in a personal computer, the user can have random access to its contents.<sup>566</sup> We have however classified all linear video pieces, regardless of the contexts of exhibition or distribution as having controlled access. We considered that independently of what certain devices or formats may allow users to explore in linear videos, the pieces were nevertheless created with the intention of controlling access, not of allowing random access to its parts.<sup>567</sup> Systems that output static images can be classified as random access when the images themselves are the final works,<sup>568</sup> as in Verosko's case, or as having controlled access in other cases, such as the *Perpetual Storytelling Apparatus* or Tinguely's machines, when the sum of all the images that are produced can (at least ideally) be considered as part of the work.

### 3.2.6 Linking

*Linking* classifies the organization of a text "by explicit links for the user to follow, conditional links that can only be followed if certain conditions are met, or by none of these" (Aarseth 1997, 64) when no links exist. In Aarseth's model it describes the existence of a hypertextual topological structure and of its working process. Texts

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<sup>565</sup> The arrow of time points in only one direction, and the pace of the piece is fully determined by the system or the author.

<sup>566</sup> The arrow of time can be made to point backwards, and the pace can be controlled or even halted by the user.

<sup>567</sup> One can disassemble or deconstruct many other systems, altering not only their access as well as other characteristics. This will however, most likely result in new systems. We can therefore posit that the systems are transformed (just slightly in some cases, profoundly in some other) when their platform, context or media is shifted. When one removes a linear video from an installation or projection context and 'brings it home', whether in a DVD disc or through a download, one does not only lose scale (visual and audial), darkened surroundings and the communal watching experience. One also gains the power to randomly access it, and this, like all the other changes fundamentally alters the perception we have from the piece, as well as our capability to read it (if on one hand that capability is increased by random access, we can also propose that it may also be diminished by it, decreasing the potential concentration of the viewer, turning every cinema-like experience into a television experience).

<sup>568</sup> And the scope of the random access is within each image, not across all the outputs of the system.

such as the *Cent mille milliards de poèmes*, *Composition N° 1* or traditional paper-based literary works<sup>569</sup> present no linking, hypertexts such as *Victory Garden* or *Hopscotch* present explicit links because they direct the user in the traversal of the text,<sup>570</sup> while other hypertexts such as *Afternoon*, the *Colossal Cave Adventure* and several MUDs are classified as presenting conditional links.<sup>571</sup>

We like to think about linking as describing the topology of the system and not the specific tools or resources that are available to the reader or user in the traversal. In this sense, conditional or explicit linking will be related to the existence of devices and/or rules that lead the user through the traversal. Random access systems can present explicit links (as is the case of *Hopscotch*) but they cannot, however, present conditional links, as these contradict the possibility for random access. Controlled access systems may present any of the three linking values.<sup>572</sup>

In non-literary systems linking can also be identified whenever the user is able to navigate through different possibility spaces within a system, as in *Page o*, where the linking is explicit or in *temporary.cc* where the linking is conditional.<sup>573</sup> Systems like *Yellowtail*, *phiLia 01* or *Inner Forests* all present explicit links, because they place the users in possibility spaces that they are allowed to leave and to where they are not able to return (the access is controlled).<sup>574</sup>

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569 Such as *Moby Dick*, *Don Quixote* or Apollinaire's *Calligrammes*.

570 Regardless of the medium — print in Cortázar or screen in Moulthrop — as linking describes the structures that guide the traversal function of the text. Gibson's *Agrippa* is also, according to Aarseth, explicitly linked. One could interpret it as being linked so explicitly that in fact it forces the user to follow the links by following them itself, while it inexorably scrolls forward during reading. We could argue that maybe Aarseth was simply focusing on the links that the user needs to follow from the opening screens to the main body of the text, but we think that would maybe be oversimplifying.

571 The links are presented depending on the paths that are followed by the user or the context where the user is led to. The user may or may not be forced to follow the links, and they are not followed automatically by the system.

572 The same holds true in our preliminary analysis, as we will later see.

573 This is a debatable classification, to say the least, and as we will again see in the next variable, one that is related to the nature of the process that is developed by each of the pieces. *Page o's* linking is explicit because linking to a new state is all that the piece allows the user to do and because those new states are virtually infinite and potentially repeatable. In *temporary.cc*, the configuration reached after each link is not repeatable and dependent on a series of actions from all the users of the system.

574 Navigation through these possibility space is commanded by the users, not by the system, through clearly labelled buttons or other interface controls in the system or through gestures and/or activities acted by the user (as in *Inner Forests*).

### 3.2.7 User Functions

Finally, Aarseth's typology describes the user functions that are present in each text besides an omnipresent interpretative function.

The use of some texts may be described in terms of additional functions: the explorative function, in which the user must decide which path to take, and the configurative function, in which scriptons are in part chosen or created by the user. If textons or traversal functions can be (permanently) added to the text, the user function is textonic. If all the decisions a reader makes about a text concern its meaning, then there is only one user function involved, here called interpretation. In a forking text (...) the reader must also explore, by making strategic choices about alternative paths and, in the case of adventure games, alternative actions. Some texts allow the user to configure their scriptons by rearranging textons or changing variables. And finally, in some cases the users can extend or change the text by adding their own writing or programming.<sup>575</sup> (Aarseth 1997, 64)

The explorative user function is exemplified by texts such as *Afternoon*, *Victory Garden* or *Hopscotch*, texts that are assemblies of discrete parts intended to be navigated non linearly by the reader. The configurative user function is found in works as the *Cent mille milliards de poèmes*, the *I Ching* or a system like *ELIZA*, all of them texts where the reader is able to arrange the order of the parts and to create (or shape, or influence) the navigable structure, more than just to move across it as in the explor-

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<sup>575</sup> Aarseth had earlier proposed to look at these functions as active feedback functions, suggesting the existence of four rather than three functions: "Besides the *interpretative function* of the user, which of course is present in the use of both linear and nonlinear textuality, the use of nonlinear texts may be described in terms of four active feedback functions: the *explorative function*, in which the user decides which 'path' to take; the *role-playing function*, in which the user assumes strategic responsibility for a 'character' in a 'world' described by the text; the *configurative function*, in which textons and/or traversal functions are in part chosen and/or designed by the user; and the *poetic function*, in which the user's actions, dialogue, or design are aesthetically motivated." (1994, 62) Comparing both versions we find that Aarseth kept only those user functions that made sense topologically, splitting the configurative function into a clearer textonic function and dismissing those that were only aesthetically motivated or that extended to the diegesis of the work (the role-playing function seems to be found in the perspective variable that was later included in the *Cybertext* model, while the poetic user function was altogether abandoned). The split of the previous version of the configurative function is maybe inspired by the two dynamic modes, intratextonic dynamics, related to a configurative user function, and textonic dynamics, related to a textonic user function. They are however only conceptually related, as no correlation is found in the analysis between the two pairs of user functions and dynamics.

ative texts. The textonic user function is exemplified by MUD systems or by a work as *Book Unbound* (Cayley 1995), a “literary work not easily classified by traditional aesthetics”, “a computer program (...), [that] takes over the screen and spits forth short suggestive sentences one word at a time” (Aarseth 1997, 56). *Book Unbound* assembles lines from its ‘hidden texts’ according to the programmed algorithms but, as “the process goes on, the hidden text is changed by what is displayed, and the user can select passages for inclusion in the regenerative process”, influencing the text output that becomes different for each copy of the text<sup>576</sup> (57). For Aarseth this work becomes an “impurity, a site of struggle between medium, sign and operator”, constructed of fragments that are “clearly not authored by anyone, (...) pulverized and reconnected echoes of meaning, and the meaning that can be made from them is not the meaning that once existed. (...) The pleasure of this text is far from accidental; it belongs not to the illusion of control, but to the suggestive reality of unique and unrepeatability signification (...) it shows how meaning struggles to produce itself, through the cyborg activity of writing.” (57)

Aarseth's four user functions are very useful in specifying the nature of the user's interactions with the texts or other systems. Although he emphasizes the interpretative function (not making it primary to all the other but by asserting its omnipresence and concurrence with the remaining) we should note that user functions are not always dominated by interpretative interests and goals, as in gaming in general and in computer games in particular, where one interprets in order to “be able to configure and move from the beginning to the winning or some other situation, whereas in ergodic literature we may have to configure in order to be able to interpret.” (Eskelinen 2001)

We can consider that the user of a computational aesthetic system always performs an interpretative function, in the sense that she needs to decipher the surface units created by the system. If Aarseth defined ergodic texts as those “in which at least one of the four user functions, in addition to the obligatory interpretative function, is present”, something that may also be seen as “a depiction of a cybernetic feedback loop between the text and the user, with information flowing from text to user (through the interpretative function) and back again (through one or more of the other functions)” (1997, 65), we find that the objects of this study are very often de-

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<sup>576</sup> “Cayley calls the produced output ‘holograms,’ fragments that contain holographic versions of the initial material...” (Aarseth 1997, 57).

defined as requiring nothing more than the interpretative function, in all cases where no interaction is required from the user or reader or when this interaction does not affect the outputs that are produced.<sup>577</sup> *Agrippa* or *Merce's Isosurface* are very similar at this level, characterized by the exclusivity of the interpretative function.

*Page o* requires the user to act on the system through a simple action that can almost be likened to the page turn in a book: the reading process advances, but the page turn is not shaping the narrative.<sup>578</sup> Unlike the printed book, however, in these controlled access systems the user's simple action becomes explorative because she's accessing spaces and structures to which she previously had no access. This is similar to the user function present in *My Boyfriend Came Back from the War*, regardless of the possibility the user may have in this narrative to return to previous spaces, something very unlikely to happen in *Page o*. If however the user's input is used constructively<sup>579</sup> one may identify a configurative user function. As a rule we then find that when the user's actions are navigational, accessing spaces of configurations that are not created with her intervention, we have an explorative user function. When the user's actions are creating new spaces of configurations, we have a configurative user action.

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577 We can however speculate if the interpretative function developed in these systems differs qualitatively from that of linear texts. What a reader interprets here is not narrative or description but rather (and also) the procedural nature of the systems, the rules upon which they are based and their creative capabilities. Perceiving them is a big, one would even dare say fundamental, part of the interpretation of these systems. "Perhaps a game (...) is not just an allegory but also an 'allegorithm.' Being a gamer is a different persona to being a reader or a viewer. (...) Alex Galloway: 'To play the game means to play the code of the game. To win means to know the system. And thus to interpret a game means to interpret its algorithm (to discover its parallel allegorithm).' What is distinctive about games is that they produce for the gamer an intuitive relation to the algorithm. The intuitive experience and the organizing algorithm together are an allegorithm for a future that in gamespace is forever promised but never comes to pass. The allegorithm by which the gamer relates to the algorithm produces a quite particular allegory by which gamer and algorithm together relate to gamespace. In a game, any character, any object, any relationship can be given a value, and that value can be discovered. With this possibility, a challenging but fair verdict can be passed on the profane world: it is characterized as a world in which any value is arbitrary, yet its value and its relation to other values can be discovered through trial and error." (Wark 2007, 030)

578 One will actually never know for certain whether the user's actions are influencing the system without a further investigation of the workings of the system or without a longer experimentation period. In *Page o* one is led to believe that all compositions are created randomly and independently of the time between actions, of the place or location of the clicks, and that the user's actions are simply triggering the refresh, not parametrizing it.

579 Regardless, one might add, of the user's awareness regarding that constructive contribution.

In pieces like *Mount Fuji* or *temporary.cc*, we find a user function that may seem similar to that in *Page 0* but that upon closer inspection is found to differ in one fundamental way: in *Mount Fuji* and *temporary.cc*, each action has an inexorable and indelible effect on the system, causing it to progress towards a point of no return, to generate outputs that will never again be experienced.<sup>580</sup> The operational knowledge that is communicated about these two pieces could therefore lead us to classify them as *textonic*, in Aarseth's sense. In the context of this work we could perhaps rename this user function as *structural*, because the user will be able to manipulate the deep units or the traversal functions, permanently adding either of them to the artifact.

### 3.2.8 Summing Up Aarseth (and Going Beyond)

In Aarseth's typology we find the following variables and values:

**Table 2: Variables and their possible values in Aarseth's typology.**

Variable	Possible Value
Dynamics	Static, IDT, TDT
Determinability	Determinable, indeterminable
Transiency	Transient, intransient
Perspective	Personal, impersonal
Access	Random, controlled
Linking	Explicit, conditional, none
User function	Explorative, configurative, interpretative, textonic

<sup>580</sup> In *Page 0*, although the chances for repetition are astronomically small they are nevertheless higher than zero. In *Mount Fuji* and *temporary.cc* the hypothesis of a repetition is actually zero.

In the context of this work this typology can be repurposed as (new values in *italics*):

**Table 3: Repurposed variables and their possible values.**

Variable	Possible Value
Dynamics	Static, <i>SUD</i> , <i>DUD</i>
Determinability	Determinable, indeterminable
Transiency	Transient, intransient
Perspective	Personal, impersonal
Access	Random, controlled
Linking	Explicit, conditional, none
User function	Explorative, configurative, interpretative, <i>structural</i>

Although this set of variables allows the analysis of systems whose outputs are not strictly textual, one wonders whether new variables should be added to the set in order to achieve a more complete typology. Before turning our attention to this problem we should consider if all seven variables are necessary in the context of this study or if some may be somewhat redundant or provide us with a negligible amount of information. We will therefore need to apply the model adapted from Aarseth (bearing all the seven variables) to a first series of systems and to analyze the results obtained with these variables. These systems will be selected from the works mentioned in previous chapters but, bearing in mind that this selection can be somewhat biased by the author, we solicited external help with further selections that could also be analyzed. We approached Austrian artist Lia,<sup>581</sup> Norwegian artist and curator Marius Watz<sup>582</sup> and Golan Levin<sup>583</sup> from the USA, who were kind enough to provide us with selections of pieces — personal favorites or works otherwise deemed relevant in this context. We did not provide them with extensive in-

<sup>581</sup> Lia — liaworks.com — is one of the early pioneers of software- and net-art, known for her live visual performances and from online projects such as *turux* (with Dextro) and *re-move*. She currently lectures at the Fachhochschule Joanneum in Graz and lives in Vienna.

<sup>582</sup> Watz — mariuswatz.com — is an autodidact artist working with visual abstraction through generative systems. In 2005 he founded the *generator.x* platform that has resulted in a series of events related to generative art and design. He is also a lecturer at the Oslo School of Architecture and at the Oslo National Academy of the Arts, Department of Design.

<sup>583</sup> Levin — flong.com — received undergraduate and graduate degrees from the MIT Media Laboratory, where he studied in the Aesthetics and Computation Group. He is an Associate Professor of Electronic Time-Based Art at the Carnegie Mellon University, where he also holds courtesy appointments in the School of Computer Science and the School of Design and directs the Studio for Creative Inquiry.

formation about the project's aim or scope, hoping with this to exert the minimum possible influence in their selections. The project was only briefly described and the request was made for a small selection of works that they would classify as 'generative', not necessarily computer-based but computational in nature.

At a second stage we repeated the exercise while selectively removing those variables that we suspected might have a marginal value in the model, so that we were able to understand what was their relative weight in the model's effectiveness.

After this analysis we considered the expansion of the model through a series of other possible variables that might describe characteristics of the systems that were not accounted for by those in Aarseth's model. We then classified all the pieces, trying to assess whether the new variables were applicable to all the systems<sup>584</sup> and if their inclusion in the typology resulted in a qualitative increase (for which we developed tentative multiple correspondence analysis).

### 3.3 Works Analyzed

#### 3.3.1 Golan Levin's Selection

Many of the works referenced by Golan Levin are included in the notes of his lectures in *Special Topics in Interactive Art & Computational Design* (2010) at Carnegie Mellon. They include, in chronological order, the following 10 artifacts:

- Karl Sims, *Evolved Virtual Creatures* (1994a);
- Christa Sommerer & Laurent Mignonneau, *A-Volve* (1994);
- Camille Utterback & Romy Achituv, *Text Rain* (1999);
- Andreas Müller, *For All Seasons* (2004);
- David Lu, *Droom Zaacht* (2004);
- Mario Klingemann, *Ornamism* (2005);
- Jonathan Harris & Sep Kamvar, *We Feel Fine* (2006a);
- Michael Kontopoulos, *Inner Forests* (2007);
- Karsten Schmidt, *Print magazine August 2008 cover design* (2008e);
- Universal Everything & Karsten Schmidt, *Nokia Friends* (2008b).

<sup>584</sup> And not to just a subset of those systems. We will focus on variables that can describe the procedural aspects of the systems and not their other aspects that are often successfully described by other theories.

Sims's *Evolved Virtual Creatures* (1994a) is a research project involving simulated Darwinian evolutions of virtual creatures. Sims created a population of several hundred creatures that moved and behaved in a simulated three-dimensional physical world (Sims 1994b). A 'genetic language' using nodes and connections as its primitive elements directed graphs that described both the morphology and the neural circuitry of the creatures (1). The phenotype of each creature was composed by a "hierarchy of articulated three-dimensional rigid parts" while the genetic representation was a graph of nodes and connections containing "developmental instructions for growing a creature" and ways of "reusing instructions to make similar or recursive components within the creature" (2). Each creature was tested for its ability to perform a given task, such as the ability to swim in a simulated water environment. Those that were successful, survived and were copied by combining and mutating their virtual genes into a new population that was, in their turn, subjected to the same fitness evaluation. As this cycle of variation and selection continued, creatures with more and more successful behaviors could emerge.

The video selected by Levin shows some of the results from the project, final products from many independent simulations in which the creatures were selected for swimming, walking, jumping, following, and competing for control of objects. Sims's system combined the development of morphology and systems of control in the creatures, so in a sense every creature documented in the video emerged from the system, from the challenges that every lineage of creatures had to face, from the fitness functions defined and of course, from evolution. As Sims's states, all creatures were autonomously generated from a language that "defines a hyperspace containing an indefinite number of possible creatures" and that when searched "using optimization techniques, a variety of successful and interesting locomotion strategies emerge, some of which would be difficult to invent or build by design" (1), in a process that does not require "cumbersome user specifications, design efforts, or knowledge of algorithmic details." (8)

In *Evolved Virtual Creatures*, Sims has abandoned the goal of emulating the look of nature in favor of emulating its behavior. (...) The result is an astounding wealth of evolutionary strategies for aquatic and terrestrial locomotion. (Blais and Ippolito 2006, 224-25)



Fig. 146: A school of swimming 'water snakes' in *Evolved Virtual Creatures* (Sims 1994a).

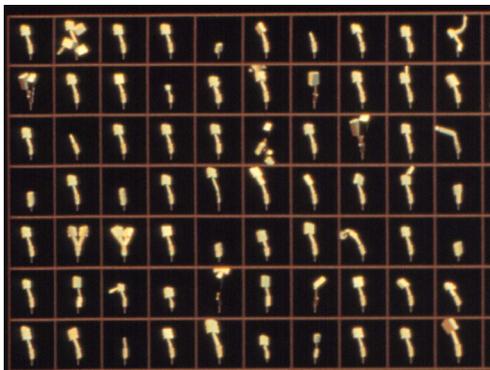


Fig. 147: A slightly evolved population of block creatures, which are being selected for swimming velocity in *Evolved Virtual Creatures* (Sims 1994a).

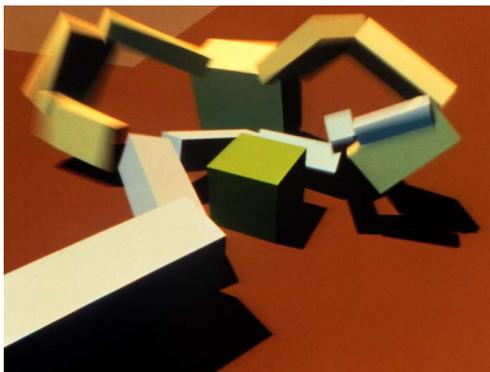


Fig. 148: Two creatures struggling for possession of a block in *Evolved Virtual Creatures* (Sims 1994a).

Christa Sommerer & Laurent Mignonneau's *A-Volve* (1994) is an interactive environment where visitors interact with virtual organisms in the real space of a water filled glass pool. Visitors can create three-dimensional organisms by drawing the profile and shape of any possible form on a screen. These organisms are then trans-

ferred to the water of the pool, displayed as three-dimensional creatures that are immediately animated, as if brought to life, moving and swimming in the water. The virtual creatures are sensitive to the user's hand movements in the water, reacting to them in ways that are determined by the creature's form. The viewer can also modify their forms and, as various visitors are able to interact with different organisms at the same time, they necessarily interact with each other. Like Sim's system, *A-Volve* includes evolutionary aspects, selecting the fittest creatures to survive longer and to be able to mate and reproduce, mutating into new forms.

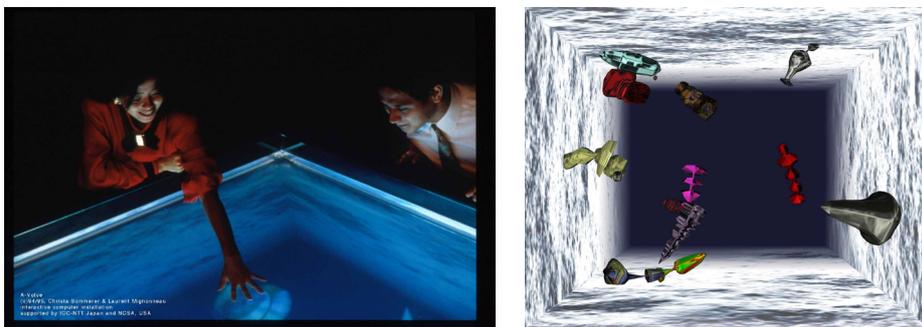


Fig. 149: *A-Volve* (Sommerer and Mignonneau 1994), overview and detail of the projection.

*Text Rain* (1999) was previously discussed, so we will not further elaborate on it here.

Andreas Müller's *For All Seasons* (2004) is an interactive typographic illustration originally developed as a desktop application and now also available for mobile platforms. It is a "piece about memories, seasons and using the elements of the textual representation of the memory to create an interactive one" (2004) and it is scripted, in the sense that the actions are laid out in advance.<sup>585</sup> However, as the user has a considerable degree of freedom (or number of freedoms) to affect the development of the actions, and the actions themselves are algorithmically described in ways that incorporate randomness and chance, the overall experience of the piece will greatly vary.

<sup>585</sup> As suggested by the storyboard.



Fig. 150: *For All Seasons* (Müller 2004), iPhone version.

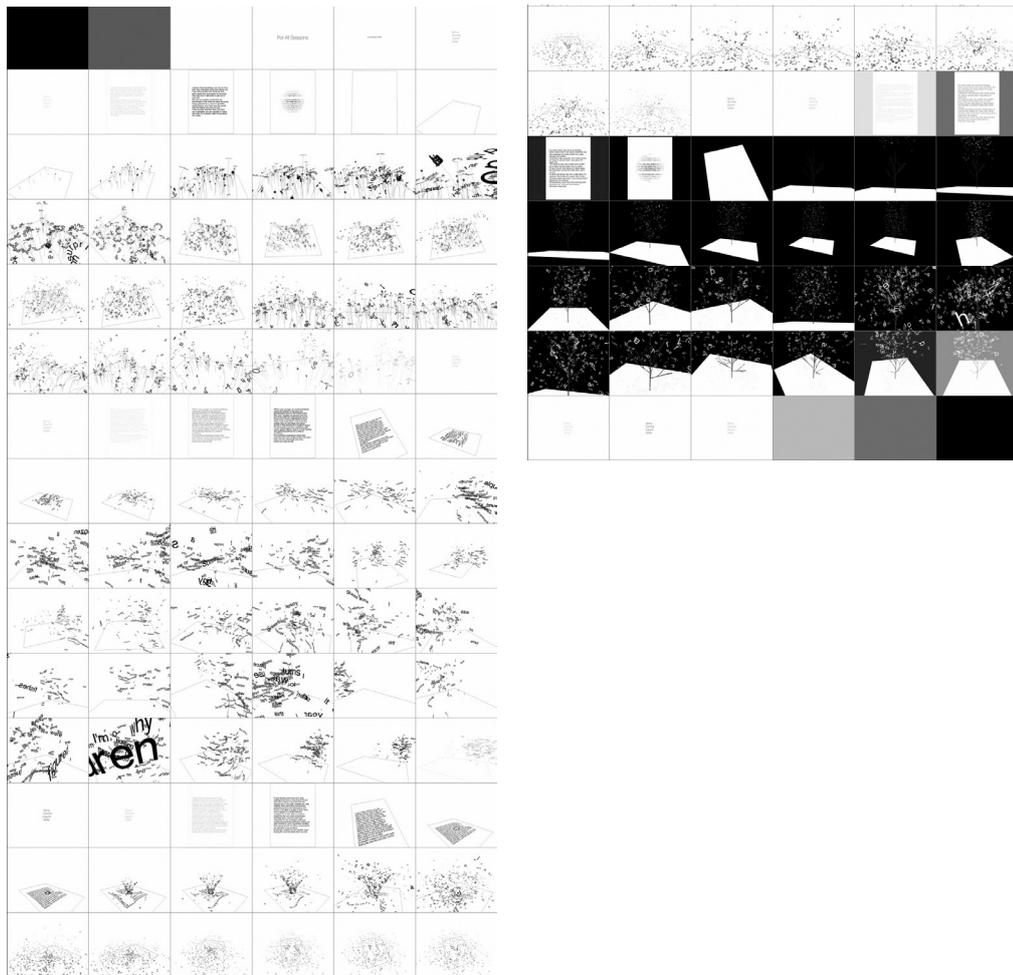


Fig. 151: *For All Seasons* (Müller 2004), storyboard.

David Lu's *Droom Zaacht*<sup>586</sup> (2004) is presented as “drawing tools for sleepy people” and it is a set of five “unconventional drawing tools (...) intended as an example of calm technology — that is, software that brings about a sense of calm and reflection” (2004). All tools are mouse-driven and semi-configurable through two sliders.<sup>587</sup> One interesting aspect of this system is how while the user draws a longer line the shape of the line is affected by its position, the speed of the drawing and the curves that may be drawn, taking over some of the control that is usually handed to the user in such tools (particularly those that are more classic and utilitarian). In the fourth machine (pictured below) the lines are dynamic, permanently jiggling and moving, even after the user moves on to creating other lines.



Fig. 152: *Droom Zaacht* (Lu 2004), machines four and five.

Mario Klingemann's *Ornamism*<sup>588</sup> (2005) is a non-interactive pattern generator inspired in the biological forms documented by Ernst Haeckel<sup>589</sup> in his book *Art Forms in Nature* (1904). *Ornamism* constantly mutates and moves, breeding forms of a very high complexity, rich in symmetries and reminiscent of organic and mineral forms.

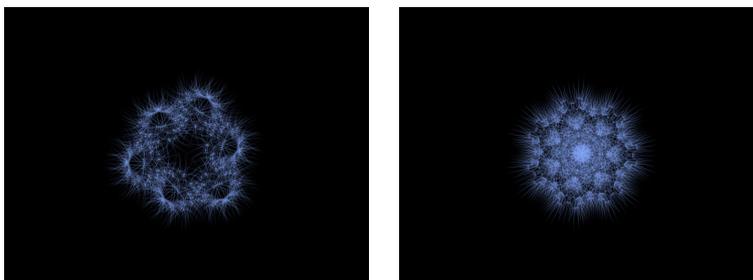


Fig. 153: *Ornamism* (Klingemann 2005).

<sup>586</sup> Flemish for ‘Sweet Dreams’.

<sup>587</sup> That are not labelled and do not have the same effect in all the machines.

<sup>588</sup> This title is a portmanteau word blending ornament and organism.

<sup>589</sup> 1834-1919.

Jonathan Harris & Sep Kamvar’s *We Feel Fine* (2006a) depends on a “a data collection engine that automatically scours the Internet every ten minutes, harvesting human feelings from a large number of blogs” (2006b). The sources are scanned for occurrences of the phrases ‘I feel’ and ‘I am feeling’ and, once such a sentence is found, “the system looks backward to the beginning of the sentence, and forward to the end of the sentence, and then saves the full sentence in a database”. The sentence is then scanned for one of about 5,000 pre-identified ‘feelings’.<sup>590</sup> Whenever a valid sentence is found, the system interprets it as representing one person that feels accordingly, and compiles as much data as possible regarding the author of the sentence.<sup>591</sup> The process is then repeated, identifying an average of 15 to 20,000 feelings per day. The data collected is then presented in an interface created from “a self-organizing particle system, where each particle represents a single feeling posted by a single individual. The particles’ properties — color, size, shape, opacity — indicate the nature of the feeling inside, and any particle can be clicked to reveal the full sentence or photograph it contains. (...) At its core, *We Feel Fine* is an artwork authored by everyone. It will grow and change as we grow and change, reflecting what’s on our blogs, what’s in our hearts, what’s in our minds.” (2006b) *We Feel Fine* is simultaneously a visualization system — a tool to access the data — and a large hypertextual narrative, as well as an aesthetic experience built from interpretations of that data.



Fig. 154: *We Feel Fine* (Harris and Kamvar 2006a).

<sup>590</sup> A list of valid feelings was “constructed by hand”, and “basically consists of adjectives and some adverbs” (Harris and Kamvar 2006b) from abandoned, abashed, abating, abdominal, abducted, abhorrent, abiding, abject and able all the way to zealous, zero, zillion, zippy, zoning and zonked.

<sup>591</sup> “Because a high percentage of all blogs are hosted by one of several large blogging companies (...), the URL format of many blog posts can be used to extract the username of the post’s author. Given the author’s username, we can automatically traverse the given blogging site to find that user’s profile page. From the profile page, we can often extract the age, gender, country, state, and city of the blog’s owner. Given the country, state, and city, we can then retrieve the local weather conditions for that city at the time the post was written. We extract and save as much of this information as we can (...)” (Harris and Kamvar 2006b)

Michael Kontopoulos's, *Inner Forests* (2007) installation intends to reward slow interactions, valuing a visitor's investment of time to interact with the system, instead of handing a quick and immediate reward.



Fig. 155: *Inner Forests* (Kontopoulos 2007).

The last two pieces in Levin's list share a common author, German born and London based Karsten Schmidt. His cover for *Print magazine August 2008* (2008e) is a typographic illustration work created for a print medium<sup>592</sup> through the usage of algorithmic code),<sup>593</sup> 3D printing and finally photography.

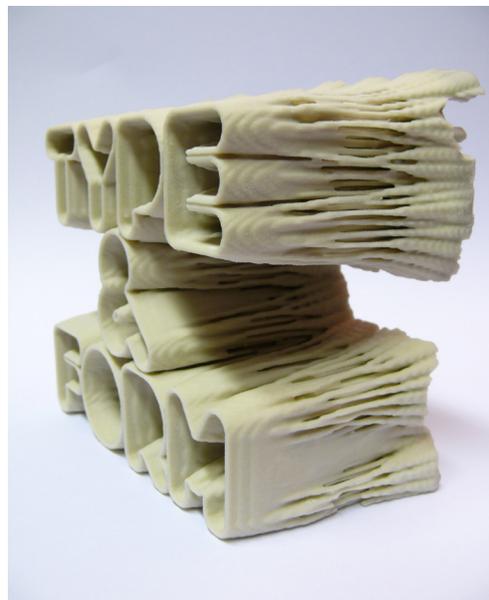


Fig. 156: *Print magazine August 2008 cover* (Schmidt 2008e) and a view of the fabricated object.

<sup>592</sup> It was awarded at the 2009 Type Directors Club competition.

<sup>593</sup> A process called Gray-Scott reaction diffusion, a model used in chemistry and biology and related to Cellular Automaton, although is not rule-based and cannot be used for computation.

*Nokia Friends* (2008b), created by Schmidt and Matt Pyke’s studio Universal Everything, was an advertisement installation presented on five 14.8 × 3.36 meter LED screens at the terminal 5 of London’s Heathrow airport. The concept behind the system was “simple enough (...) A procession of diverse characters glide by on a travelator — friends, families, kids, lovers, rugby teams, fat couples, thin models — celebrating the diversity of people seen at Heathrow T5. Every character riding the travelator is unique, using generative software to create an ever-growing population.” (Schmidt 2008d) The system created behaviors that “were not only suitable to support the formation and appearance of characters” (including body shape, color, hair styles, etc.) but could “also be ‘shaped’ and controlled fairly easily to create a variety of behaviours” (2008d) (including body and eye movement, collisions, etc.).

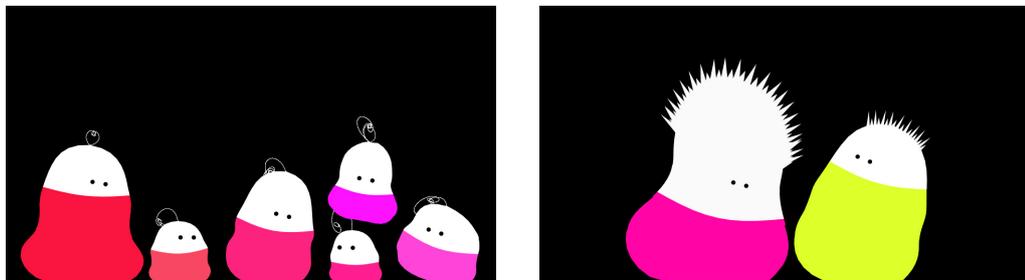


Fig. 157: *Nokia Friends* (Universal Everything and Schmidt 2008b).

### 3.3.2 Marius Watz’s selection

Marius Watz selected a group of fifteen works, listed chronologically:

- Matthew Lewis, *Sketch* (1998);
- Andy Huntington and Drew Allan, *Cylinder* (2003);
- Mark Napier, *Black & White* (2003);
- Jared Tarbell, *Happy Place* (2004);
- Leonardo Solaas, *Dreamlines* (2005b);
- Alex Dragulescu, *Extrusions in C Major* (2006);
- C.E.B. Reas, *Process series* (2007; 2006a-f);
- Boris Müller, *Poetry on the Road* (2006a);
- Lab[au],<sup>594</sup> *Pixflow #2* (2007a);
- Eno Henze, *Der Wirklichkeitsschaum* (2007);
- Brandon Morse, *A Confidence of Vertices* (2008);

<sup>594</sup> Manuel Abendroth, Jérôme Decock, Alexandre Plennevaux, Els Vermang.

- Karsten Schmidt, *Enerugii* (2008b);
- Andreas Nicolas Fischer, *A Week in the Life* (2008b);
- FIELD,<sup>595</sup> *Animations for Aol. Rebrand* (2009);
- Paul Prudence, *Talysis II* (2009b).

*Sketch* (Lewis 1998) is a digital print produced by a computerized ‘drawing machine’. A Linux program generates drawing strokes, combining them to produce abstract drawings with a hand-drawn quality.<sup>596</sup>

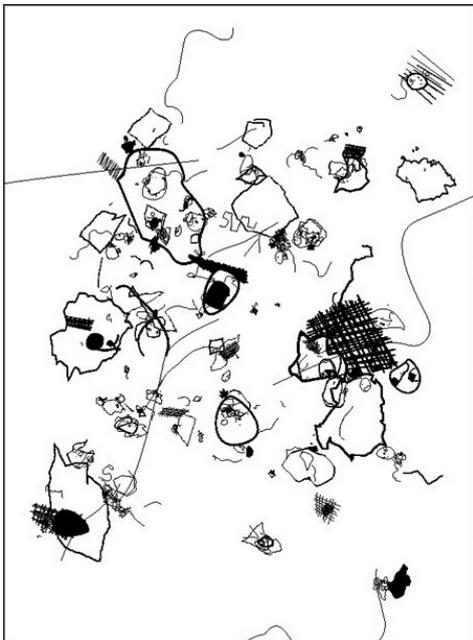


Fig. 158: *Sketch* (Lewis 1998).

*Cylinder* (Huntington and Allan 2003) was already cited in this work, as an example of mapping from one domain to another.

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<sup>595</sup> Marcus Wendt and Vera-Maria Glahn.

<sup>596</sup> Unlike other works as e.g. Cohen’s *AARON* (1973) or Burton’s *Rose* (1995; 1997), there is not a perceivable search for figuration, rather perhaps a search for expressiveness and overall composition.



Fig. 159: *Cylinder (Breath)* (Huntington and Allan 2003).

Mark Napier's *Black & White* (2003) was developed as a Carnivore<sup>597</sup> client that reads every bit from cnn.com and visualizes that information by moving two pixels, a black one horizontally whenever a 0 is read, and a white one vertically whenever a 1 is found. Furthermore, the pixels are mutually attracted, creating a chaotic motion.

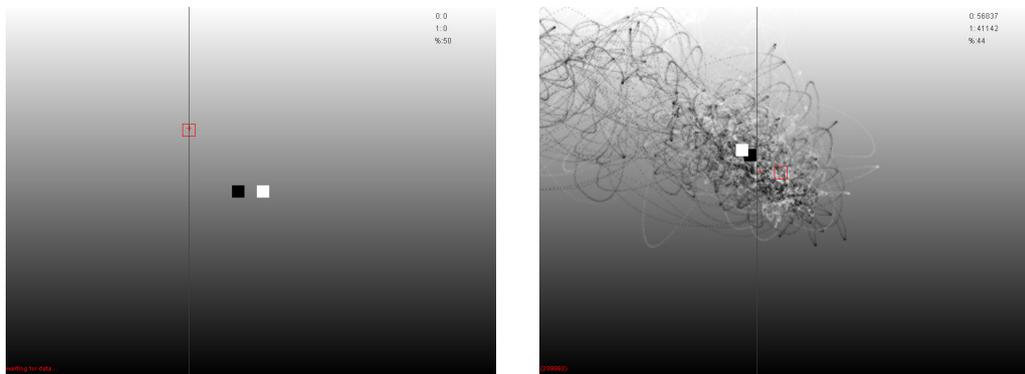


Fig. 160: *Black & White* (Napier 2003).

<sup>597</sup> 'Carnivore', also known as 'DCS1000' is a surveillance tool for data networks, developed in the USA by the Federal Bureau of Investigation to monitor email and electronic communications. In 2001 the Radical Software Group developed a 'personal edition' of DCS1000, also called carnivore, and distributed it to several artists that built interpretive interfaces to the information gathered by the system. CarnivorePE (Personal Edition) is now distributed by the RSG. "The prospect of reverse-engineering the original FBI software was uninteresting to RSG. Crippled by legal and ethical limitations, the FBI software needed improvement not emulation. (...) Reverse-engineering is not necessarily a simple mimetic process, but a mental upgrade as well. RSG has no desire to copy the FBI software and its many shortcomings. Instead, RSG longs to inject progressive politics back into a fundamentally destabilizing and transformative technology, packet sniffing. Our goal is to invent a new use for data surveillance that breaks out of the hero/terrorist dilemma and instead dreams about a future use for networked data." (Radical Software Group 2002)

Jared Tarbell's *Happy Place* (2004) is an applet that renders the resulting configuration of a system of 'friendly' nodes connected at random. Connections between nodes are considered 'friendships' and the nodes position themselves with only two goals: a) move close to friends but no closer than some minimum distance; b) distance self from non-friends as reasonably as possible. Initially all nodes are positioned around the perimeter of a circle but as the system runs, a rudimentary best-fit structure takes form and it rearranges its configuration as a result of the individual desires of the nodes it is composed of.

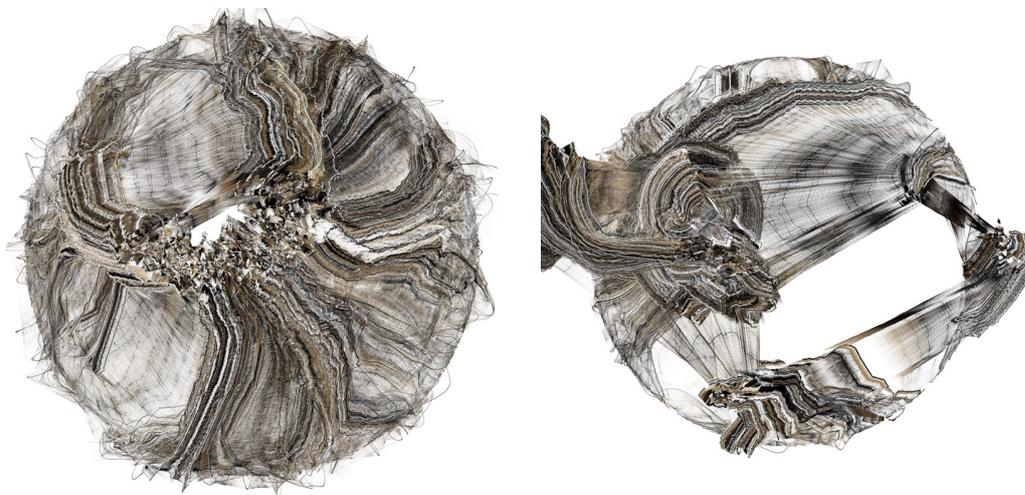


Fig. 161: *Happy Place* (Tarbell 2004) (with 500 nodes).

*Dreamlines*, by Leonardo Solaas (2005b) is presented as “a non-linear, interactive visual experience” that starts by requesting a user to input one or more keywords as a subject for a “dream”. The system then searches the Web for “images related to those words, and takes them as input to generate an ambiguous painting, in perpetual change, where elements fuse into one another, in a process analogous to memory and free association.” (2005a)

The pictures are never actually shown. The drawing itself is produced by 1500 autonomous particles in perpetual movement. The last image loaded serves as a sort of virtual terrain for them. The direction and speed of each particle is given, at each step, by the color values of the pixel they are stepping on. Different sets of formulas translate the hue, saturation and brightness of the pixel in angle and velocity values for the particle. The path of each particle is traced to the screen, and this forms the output seen by the user. Thus, the work is at the same time a study on population dynamics, or on the emergent behavior of a multitude of very simple autonomous agents. (2005a)

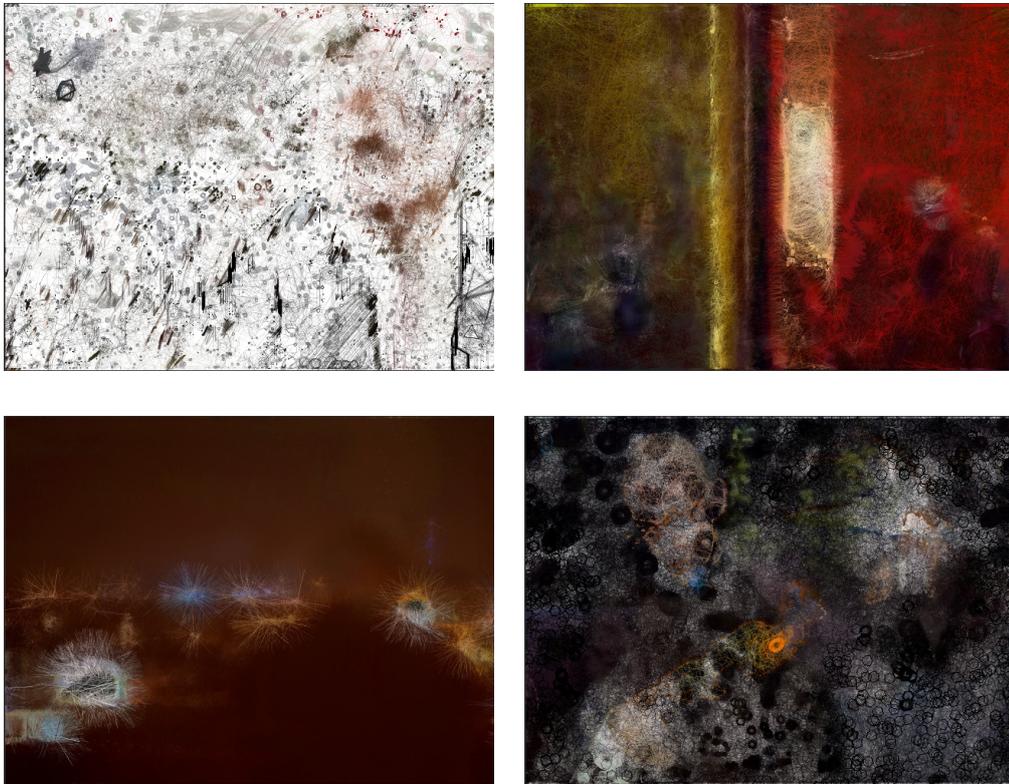


Fig. 162: *Dreamlines* (Solaas 2005b).

*Extrusions in C Major* by Alex Dragulescu (2006) is an experiment in music visualization developed from Mozart's *Trio in C-Major for Piano, Violin, and Cello*. A range of note characteristics such as value, velocity, duration, and overall tempo are analyzed (and translated as the weight, length, and rotation of different segments) and the notes of the various instruments are differentiated by color: white for piano, yellow for violin, and blue for cello.



Fig. 163: *Extrusions in C Major* (Dragulescu 2006).

Reas's *Process* is an ongoing series of works started in 2004, implemented in various programming languages and formats. All the pieces in the series have as a common ground a text from which each work is started. "The text is the Process described in English, written with the intention of translating its content into software. The software interpretation is secondary to the text. The text leaves many decisions open to be determined by a programmer. The decisions must be made using personal judgment, thus the text is interpreted through the act of translating the Process from English into a machine language."<sup>598</sup> (Reas 2008) Common to all the pieces in the series is also a library of forms and behaviors to be used in the processes.

Element 1: Form 1 + Behavior 1 + Behavior 2 + Behavior 3 + Behavior 4

Element 2: Form 1 + Behavior 1 + Behavior 5

Element 3: Form 2 + Behavior 1 + Behavior 3 + Behavior 5

Element 4: Form 1 + Behavior 1 + Behavior 3 + Behavior 5

Element 5: Form 2 + Behavior 1 + Behavior 5 + Behavior 6 + Behavior 7

Element 6: ...

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<sup>598</sup> "The hardware running this software Process is inconsequential. In time, the hardware will inevitably fail. The current hardware was selected to be as robust as is possible with current technology, but contemporary electronics are fragile. If an element of the hardware fails, it can be replaced without diminishing the work. Eventually, compatible components will no longer be available because computing technologies are continually changing. When this event inevitably occurs, a new hardware system will need to be acquired and the software should be rewritten for the new hardware to take advantage of the technical advancements since the original interpretation." (Reas 2008)

Form 1: Circle

Form 2: Line

Form 3: ...

Behavior 1: Constant linear motion

Behavior 2: Constrain to surface

Behavior 3: While touching another, change direction

Behavior 4: While touching another, move away from its center

Behavior 5: After moving off the surface, enter from the opposite edge

Behavior 6: While touching another, orient toward its direction

Behavior 7: Deviate from the current direction

Behavior 8: ...

*Process 18* (Reas 2007) is developed from the following text: “A rectangular surface filled with instances of Element 5, each with a different size and gray value. Draw a quadrilateral connecting the endpoints of each pair of Elements that are touching. Increase the opacity of the quadrilateral while the Elements are touching.” (2008) The text is displayed next to a dual projection surface, where the process is shown in execution on both sides. The mechanisms are exposed on the right and the process surface generates on the left.

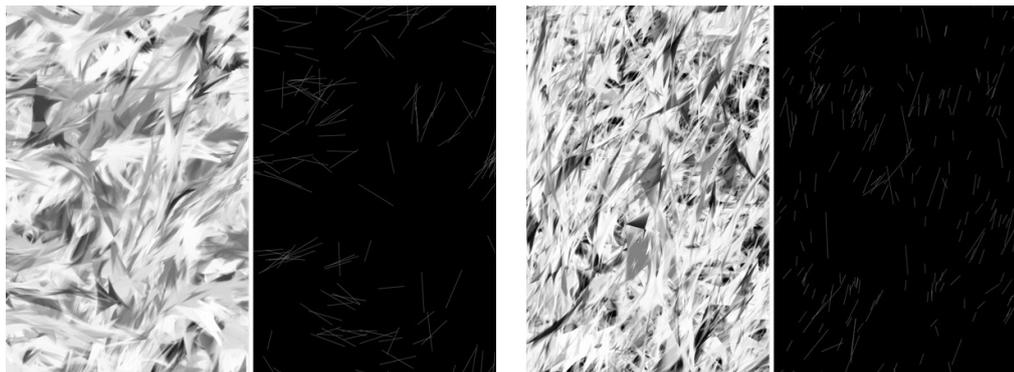


Fig. 164: *Process 18* (Reas 2007).

*Process 16* (2006f) is developed from the following text: “A rectangular surface filled with instances of Element 3, each with a different size and gray value. Draw a small, transparent circle at the midpoint of each Element. Increase the circle’s size and

opacity while it is touching another element and decrease these values while it is not.” (2008) It is presented in a dual projection, as *Process 18*.

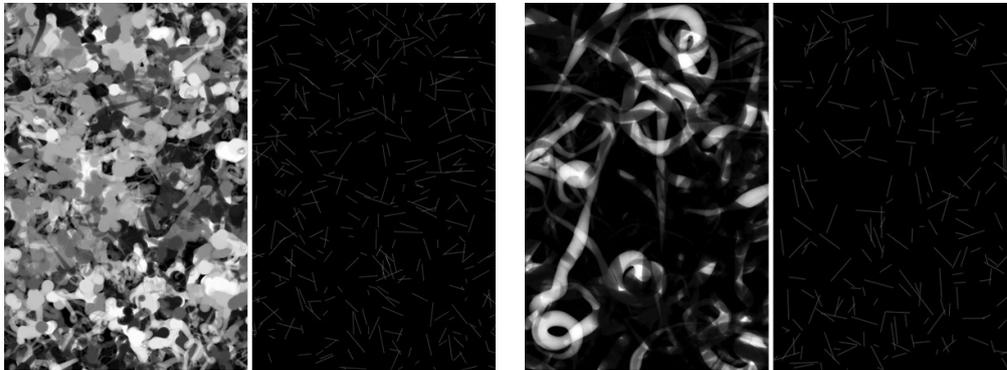


Fig. 165: *Process 16* (Reas 2006f).

*Process 14* (2006d) follows: “A rectangular surface densely filled with instances of Element 4, each with a different size and direction. Display the intersections by drawing a circle at each point of contact. Set the size of each circle relative to the distance between the centers of the overlapping Elements. Draw the smallest possible circle as black and the largest as white, with varying grays between.” (2008)

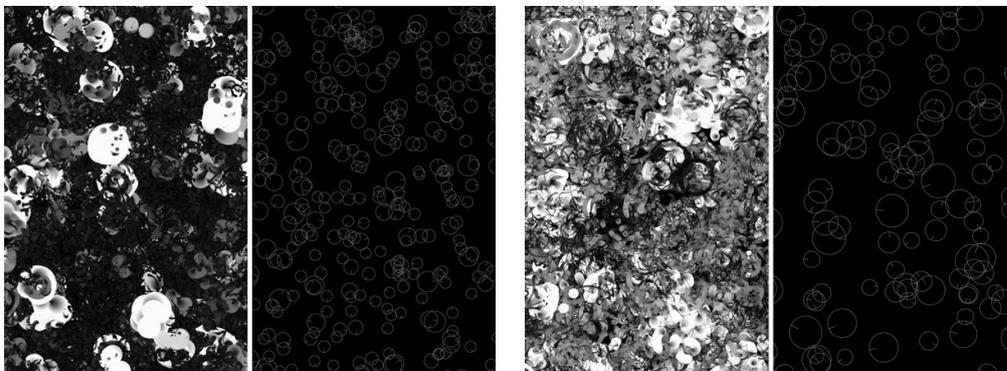


Fig. 166: *Process 14* (Reas 2006d).

We will refrain from presenting the remaining works in the series. They are all equally interesting, but, being developed from the same principles, we find that these three suffice as examples.

*Poetry on the Road* (Müller 2006a) is the visual theme for the eponymous international literature festival held every year in Bremen, Germany. Müller designs the identity of the festival since 2002 and, although the theme of the festival regularly

changes, the underlying idea for the visual identity remains constant: all the imagery is generated by a software that transforms text into images, so that every image is the direct representation of a specific text. The concept for the 2006 identity was based on an old system for encoding text: by assigning a numerical value to every letter of the alphabet and adding the values of all letters, one gets a number that represents the overall word.

Using this system, an entire poem could be arranged on a circular path. The diameter of the circle is based on the length of the poem. So you can see the short poems in the centre of the poster, while the longer ones form the outer circles. Red rings on the circular path represent a number. As many different words can share the same number ('poetry' shares the [number] 99 with words like 'thought' and 'letters'), most rings represents different words. The thickness of the ring depends on the amount of words that share the same number. Finally, gray lines connect the words of the poem in their original sequence. So solid lines represent repetitive patterns in the poem. (Müller 2006b)

Müller's software was used to generate the image for the poster and in the production of brochures and of a catalogue, introducing the poems of each writer by abstract visual representations of themselves.

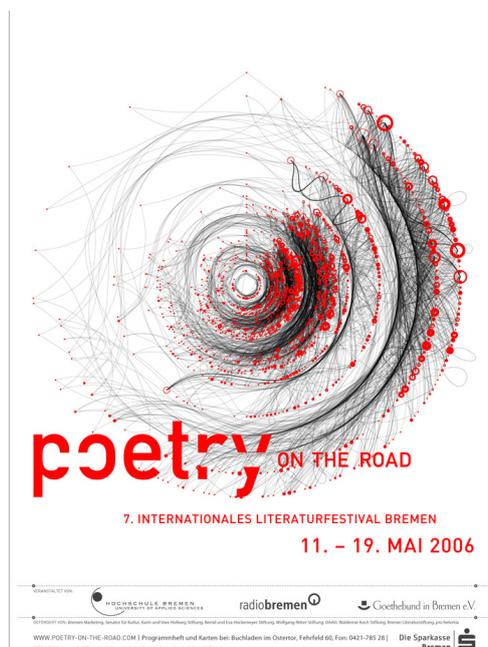


Fig. 167: Poster for *Poetry on the Road* (Müller 2006a).

*Pixflow #2* (Lab[au] 2007a) is a generative artwork based on a vector field that determines the paths of particles, shaping them into flows as their density evolves. “From the mutual influence between vectors and particles, changing their orientations as they meet, and calculating these changes according to two different number sets, integers and floating numbers, emerge due to rounding errors in between both sets an unsuspecting behaviour of particles shaping vertexes, migrating lines and turbulences by following the combinatory play of numbers. It is the use of an error in the set of a system to achieve an evolving and organic behaviour.” (2007b)<sup>599</sup>



Fig. 168: *Pixflow #2* (Lab[au] 2007a), detail and overview of the piece.

*Der Wirklichkeitsschaum*<sup>600</sup> (Henze 2007) is a  $9.47 \times 3.45$  meter computer-generated mural assembled from 288 A3 color laser prints.

<sup>599</sup> The authors further describe the set of rules built into the system. “At system launch, 1,500 particles in form of pixels and the 5,040 vectors, constituting the  $90 \times 56$  matrix of the vector field, are initialised at random (...) The particles start to move at a constant speed (...) in the direction set by its own heading vector. (...) Consequently the conception of the generative system does not rely on any random set (except at launch initialisation), but builds its evolution on a recurrence of system errors occurring between two numerical systems, one defining the pixel movement angle; floating numbers, and the other the vector orientation; integers. The set of a system producing at each iteration errors is the starting point of the generative art work and form the backbone of a highly evolving and ever varying system. The resulting fluid behaviour is visually reinforced by a trail the particles leave along their path. The trail is a buffer of the last 10 frames, an imprint of the last 10 positions of the moving particles, rendered with a decreasing alpha value ranging from the actual particles rendered at 100% opacity to its previous position rendered at 90% opacity ... This leads the moving particles leaving a 50 pixel long and progressively fading away trail. These trails on the screen are imaging the smooth movement of the particles shaping vortexes, migrating lines and turbulences.” (Lab[au] 2007b)

<sup>600</sup> Translatable as ‘The Reality Foam’.

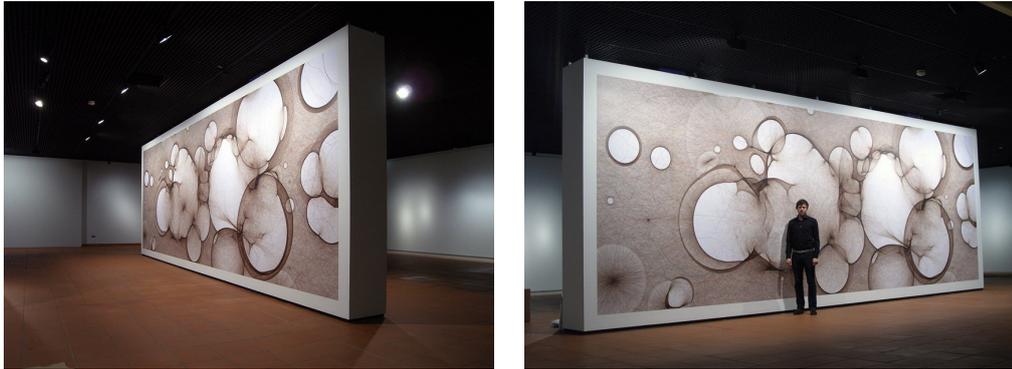


Fig. 169: *Der Wirklichkeitsschaum* (Henze 2007).

*A Confidence of Vertices* (Morse 2008) computer generated video is an exercise in tension, a procedural animation in which two structures morph and twist under their physical constraints. “Stripped-down architectural forms that ought to exhibit the rigidity of highrise buildings instead engage in a tug-of-war, the result of a string simulation distributing kinetic force through a network of nodes. (...) Unlike software-based generative artworks that exhibit endless timelines, Morse’s videos (created in the high-end animation package Houdini) display a clear dramaturgy. But rather than being a side effect of their status as ‘canned’ video, the presence of an explicit beginning and end is here part and parcel of the work’s logic, reinforcing the movement towards the inevitable.” (Watz 2008b)

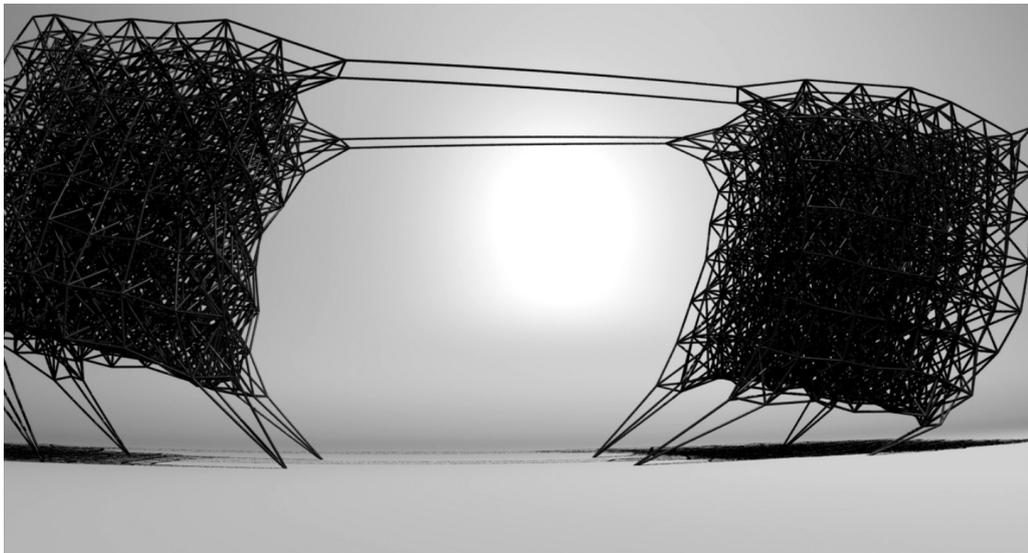


Fig. 170: *A Confidence of Vertices* (Morse 2008).

*Enerugii* (Schmidt 2008b) is also a linear video, created for *Advanced Beauty* (Universal Everything 2008a), a collaborative project curated by Matt and Simon Pyke that compiles 18 ‘sound sculptures’, audio-reactive visual pieces exploring the concept of synesthesia. Schmidt’s goal with this piece was “to create a structure which would be in a constant flux between two behaviours forming either crystalline forms or disperse into a number of polygons flocks” (2008a).



Fig. 171: *Enerugii* (Schmidt 2008b).



Fig. 172: *Enerugii* (Schmidt 2008b).

*A Week in the Life* (Fischer 2008b) is a visualization of telecommunications data, representing the author’s movement and communication with his cell phone in one week. “What can be read from the sculpture is my position in the city through the cell sites I used. The density of the cell sites reflects the speed and frequency of movement within the city. The more often I visited a place, the more cell sites were added to the map. To get the information for the data set, I wrote a software for my cell

phone which recorded all the coordinates of the antennae, which I then converted to latitude and longitude. With this data I was able to create a map of Berlin.” (2008a)



Fig. 173: *A Week in the Life* (Fischer 2008b).

In 2008 FIELD participated in Wolff Olins NYC’s rebranding project for North American Internet provider Aol. by developing a series of animations for web video, mobile, digital campaigns and outdoor LED displays. The creative direction was from Matt Pyke at Universal Everything.

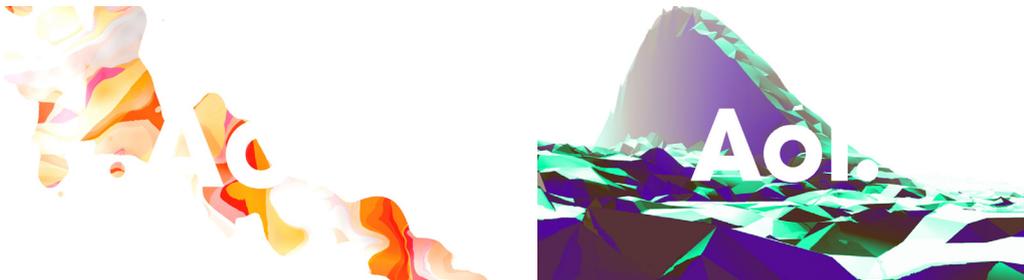


Fig. 174: *Animations for Aol. Rebrand* (FIELD 2009).

*Talysis II* (Prudence 2009b) is a real-time software, “constructed with a circuit of video renderers, each passing its output to the next renderer to produce a closed visual information loop — a software simulation of the classic analogue video feedback loop. These particular high resolution outputs were generated with unitary modulation in mind and to accentuate the hyperbolic geometric properties of the resultant form.” (2009a)

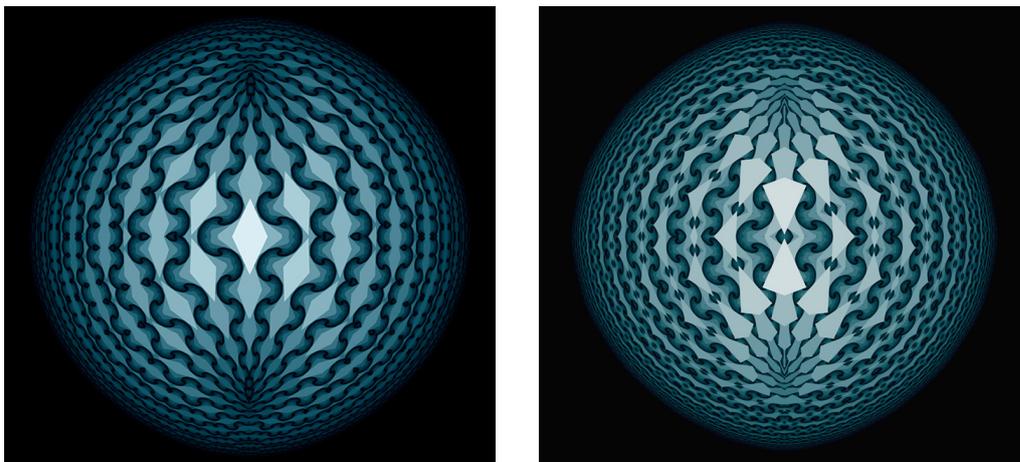


Fig. 175: *Talysis II* (Prudence 2009b)

### 3.3.3 Lia's selection

Lia selected eleven works, listed chronologically:

- Soda, *Soda Constructor* (2000);
- Marius Watz, *Amoebaabstract 01, 02 and 03* (2002a-c);
- Jared Tarbell, *Substrate* (2003);
- Meta, *Emeral* (2004) and *Folia* (2007);
- Karsten Schmidt, *Print magazine August 2008 cover design* (2008e);
- Andreas Muxel, *Connect* (2008a);
- Universal Everything and Karsten Schmidt, *Forever* (2008a);
- Erik Natzke, works from the *Colors of Nature* exhibition: *Found, Rouge, Shine* and *Crimson* (2009a-d).

The *Soda Constructor* (Soda 2000) can be described as an environment to create and manipulate virtual creatures or physical systems. It is a construction kit using virtual masses and springs. By altering physical properties like gravity, friction, and speed, curiously anthropomorphic models can be made to walk, climb, wriggle, jiggle, or collapse into a writhing heap. The creations are then shared online — at [sodaplay.com](http://sodaplay.com) — with all the users of the system.

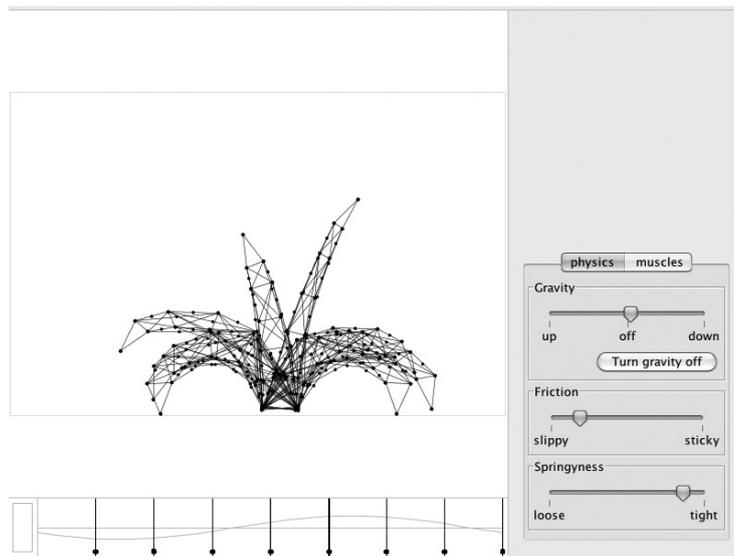


Fig. 176: *Soda Constructor* (Soda 2000).

Watz's pieces are three abstract animations. They are responsive to user input but the user is not given too many degrees of freedom inside each of the pieces. "Abstract 1 is a playful, interactive, not-quite drawing tool" (2004) that evolves complex shapes at the point where the user clicks the screen and is inactive when she does not act. "Abstract 2 is an endlessly emerging geometric pattern" that reacts to mouse movement in a very discrete way, following its coordinates in what can maybe be described as 'slow motion'. "Abstract 3 is a color study, merging bright hues fit for a lady's makeup compact" and also responsive to the user input, tracking the horizontal coordinate of the mouse and using it to control speed and hues. In abstracts 2 and 3 a user click will clear the screen and start the composition from a new set of parameters in an empty canvas. In abstract 1 the click has the opposite effect, adding information to the screen instead of removing it, the system resets the canvas after it detects a reasonably long time without user interaction.

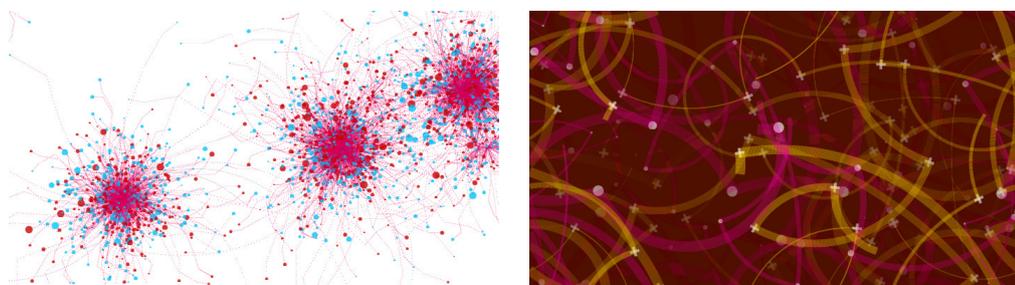


Fig. 177: *Amoebaabstract 01* (Watz 2002a) and *Amoebaabstract 02* (2002b).

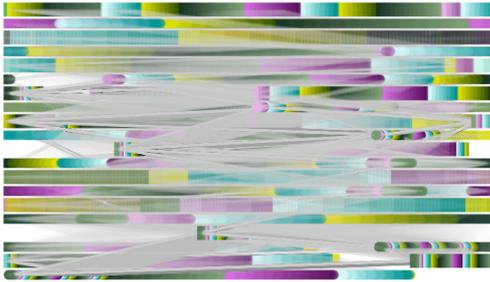


Fig. 178: *Amoebaabstract 03* (Watz 2002c).

*Substrate* (Tarbell 2003) is an applet that grows lines on a computational substrate, from a simple perpendicular growth rule that creates intricate city-like structures. This is a simple rule that produces very complex results with an enormous potential for modification.



Fig. 179: *Substrate* (Tarbell 2003).

Meta's two pieces, *Emeral* (2004) and *Folia* (2007) are, like much of his output, presented with little or no information. Although these pieces are created from time-based systems, they are documented as static images. We should therefore analyze them as images, not forgetting however, their time-based procedural genesis, testified by traces of their temporal origins, a display of their prochronism.

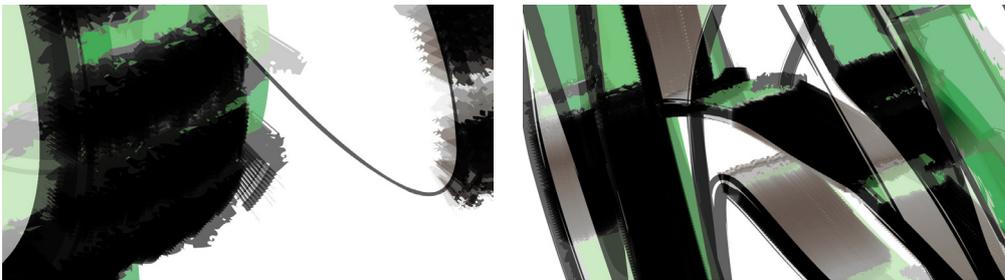


Fig. 180: *Emeral* (Meta 2004).

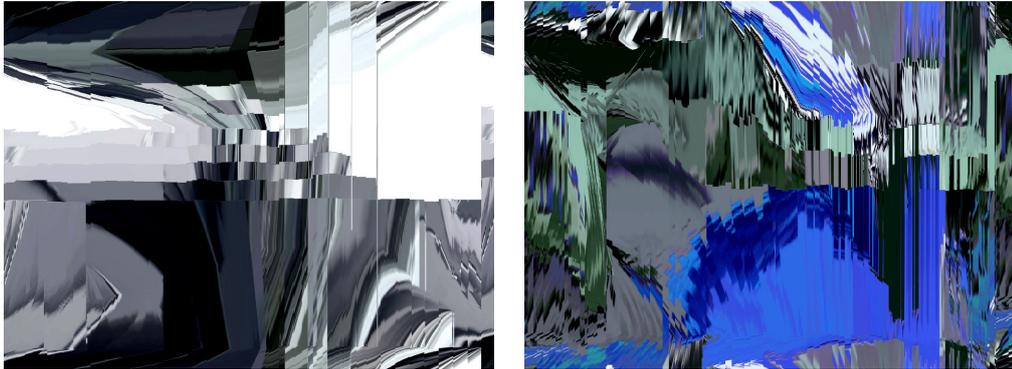


Fig. 181: *Folia* (Meta 2007).

Andreas Muxel's "feed-back driven sculpture" *Connect* (2008a) is built from thirteen modules connected to a matrix.

Each module consists of a microcontroller, a stepper motor and a sphere of steel attached to it with a rubber band. A piezo sensor is placed between motor and sphere. So each element can measure and activate its oscillation through a simple feedback mechanism programmed on each chip. An analog bar with a magnet on each side controls the action of each of the system elements. Once a sphere is connected to the bar, it starts swinging as long as the bar detaches and rebuilds a new connection to another sphere. There is no main program outside of the sculpture and no digital connection between the elements. Each module has its own simple program logic and they just start to react to each other because of the physical connections built. (...) The system produces complex behaviour, although its structure and rules are very simple. (Muxel 2008b)

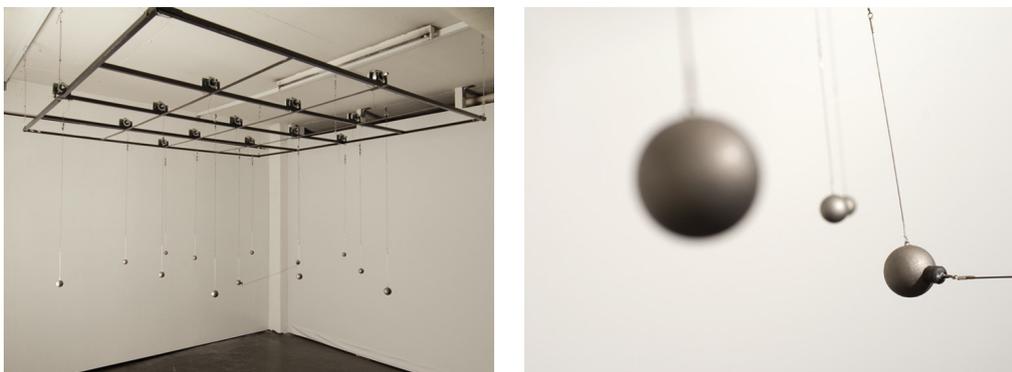


Fig. 182: *Connect* (Muxel 2008a).

*Forever* (Universal Everything and Schmidt 2008a) was an audiovisual installation presented during the winter of 2008 at the Victoria & Albert Museum in London. A large video wall presented endless animations that reacted to a permanently changing soundtrack.

Our role as designers was to define the parameters in which the work evolved. In response to the pond, the sculpture continually grows upwards from the water, all movement stems from a central ‘spine’ which reacts to the music, and it has evolutionary points set over time, causing the work to alter in appearance and intensity over its 2 month lifespan. (Universal Everything 2008b)

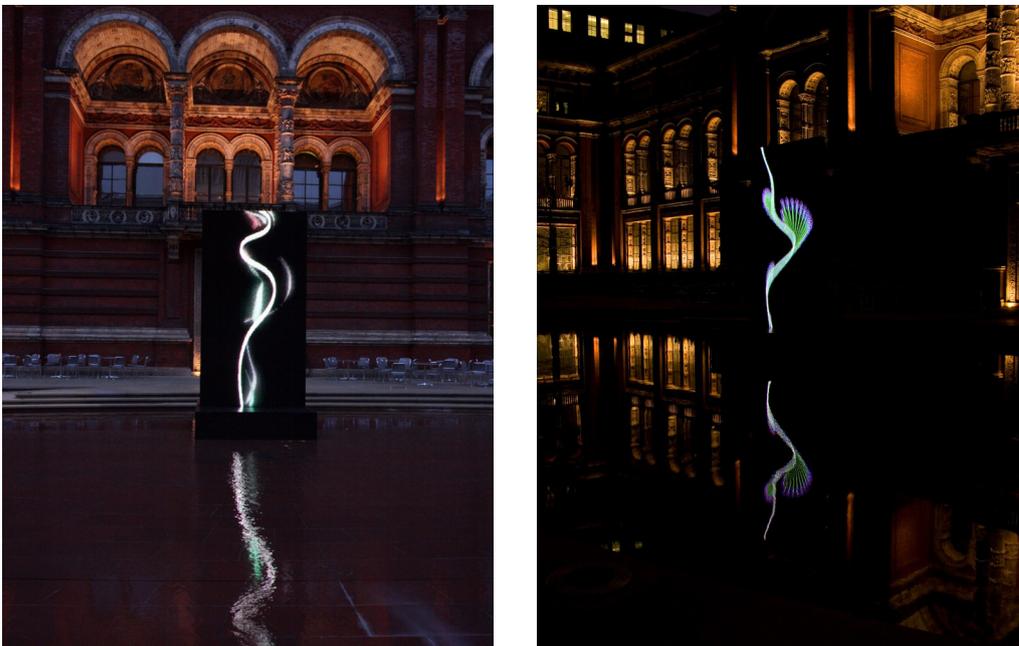


Fig. 183: *Forever* (Universal Everything and Schmidt 2008a).

The *Colors of Nature* exhibition by Erik Natzke presented a series of computer generated digital prints inspired not only by the colors but also by the forms found in nature. Natzke’s works are algorithmically created through rule-based processes yet they are reminiscent of manually created paintings.



Fig. 184: *Found* (Natzke 2009b) and *Rouge* (2009c).

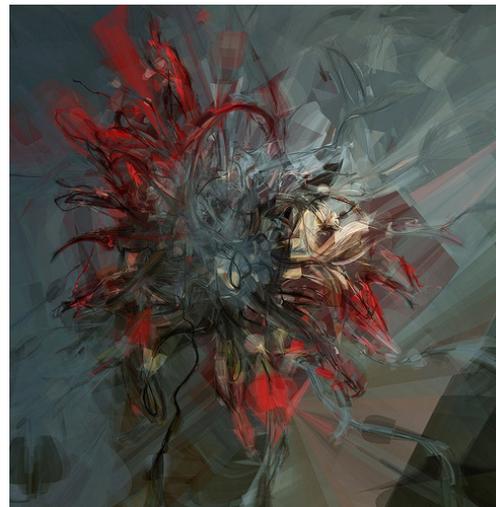


Fig. 185: *Shine* (Natzke 2009d) and *Crimson* (2009a).

### 3.4 Initial Analysis

#### 3.4.1 Notes on Dynamics

All the systems that are procedural but not computational, that is, those that are publicly presented or documented not as the system itself but rather as the outputs that the system produces — regardless of their modality or medium — were classified as being static. This is the case of pieces as *Sketch* and *Seven Sisters: The Pleiades*, but also of *Cylinder*. This is also what happens with linear video pieces such as for example *A Confidence of Vertices* or *Merce's Isosurface*, regardless of the systems that

were used in their production. Even if initially we may have considered linear video pieces as displaying SUD, upon closer study and further ponderation we concluded that it would be a mistake to classify them as such. Linear video pieces are transient, because they exist in time and their surface units change over time, but they are static because all the articulations that may be displayed are frozen in the structure of the video, and can be precisely repeated upon playback. Because it is displayed in real time, in a contextual and singular articulation, *Agrippa* was classified as having surface unit dynamics.

*Perpetual Storytelling Apparatus* was classified as having deep unit dynamics because the piece fetches information from online sources and uses this information directly in its outputs. Therefore, and following Aarseth's classification of such texts as *TinyMUD* as displaying textonic dynamics (1997, 68), we propose the classification of the *Perpetual Storytelling Apparatus* as displaying deep units dynamics.

*Page o* was classified with surface unit dynamics because it is clear that the system is not creating and composing *new* drawings (as *AARON* (Cohen 1973) and other systems are, in which case it would have deep unit dynamics, as they do) but rather only recomposing a set of predefined drawings.

*Connect* was classified as static. Although it is a kinetic sculpture its parts are arranged in fixed articulations.

### 3.4.2 Notes on Determinability

In general all the pieces classified as static regarding dynamics were also classified as being determinable. There were however four exceptions: *Agrippa*, *Every Icon*, *The Inability to Solve a War at a Cocktail Party (an Awkward Dance with Mr. Henri Van Zanten)* and *Three Buttons*. The first three of these are systems that although displaying surface unit dynamics either follow a regular and predictable process or, as in Hoogerbrugge's piece, although the system seems complex and indeterminable, upon closer inspection one notices that all its actions and every single behavior directly depend on actions from its user. If these are timed and reenacted, the system's behavior will be recreated. We are therefore in the presence of a system that can be classified as determinable. The later of these, *Three Buttons*, is somewhat different. We have classified it as displaying deep unit dynamics because the system's reaction

to every user input creates a new unit. However, the user is able to predict the reactions of the system with a very high (one could almost say absolute) degree of exactness, hence the classification as determinable.

### 3.4.3 Notes on Transiency

In most of the drawing machines that are part of *Droom Zaacht* the user's actions are necessary to make the outputs of the system vary. Furthermore, once any new structure is added to one of the compositions it stays in place until further actions of the user delete them from the screen (or clear the entire composition). This would usually be classified as an intransient behavior, however, in one of the machines (machine four) once any line is drawn, the resulting structure is permanently animated. Therefore, we have classified this work as transient.

*Inner Forests* presents an interesting example of a transient system that becomes intransient as soon as the user acts on it.<sup>601</sup> The user contributes to the system by lending her projected shadow but by not doing anything else besides observing the system's actions over that shadow. If no visitor is present, the system does not act but if a visitor is present and active, the system also does not act, remaining still while waiting for the visitor's stillness.

### 3.4.4 Notes on Access

Digital video can be seen as offering the possibility of random access, even if only in potential. Linear pieces presented as digital video can almost always be temporally controlled by the user (regardless of whether the video is accessed in a computer, in a DVD or in another playback system). In cases where the video is presented as an installation or a public projection, that control is usually not possible, but such pieces can often be found online or are also distributed as linear videos, therefore we may consider the exhibition context as something that is at least to a certain point independent of the piece itself. In our analysis we have nevertheless chosen to classify all the video systems that were not designed to be interactive and clearly

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<sup>601</sup> We can find a similar principle of interaction, of acting by not acting, in *Aus Lage [in Arbeit]* (Carvalho and Lia 2003). This installation, shown at Huddersfield's Media Centre, generated a continuous array of slowly evolving visual forms that were, as described in the project's presentation, almost 'shy' of the visitors, slowing down and desaturating colors whenever a visitor entered the room or moved inside it. Stillness of visitors was then the only strategy to be able to visualize the multiple mutations of the system.

presented as interactive systems as having controlled access, and not the random access that the playback systems may allow. With this we are not trying to directly classify the potential for interaction but we are rather recognizing that although digital media tends to permit a very high degree of manipulation, that manipulation is not always a part of the pieces that are produced to a particular medium. Unless otherwise and explicitly stated by the authors, most audiovisuals are usually conceived to be experienced as linear experiences. Although their distribution media may allow for pausing, skipping and for what is described as random access, the pieces are conceived with controlled access and linearity in mind, and this control is an intrinsic part of their aesthetic nature — it informs the composition, the narrative, and almost all the aspects of the piece. Controlled access determines the time and rhythm of the piece and once one manages to escape it — by pausing, rewinding or otherwise manipulating the video — one may actually consider to be fundamentally altering the artifact and starting to experience an altogether different artifact (or different version of the artifact).

### 3.4.5 Notes on Linking

All systems that, like *Ornamism* or *phiLia 01*, allow the user to reset the current configuration or evolution of the output and to restart the process, thus exploring new fields of possibilities, were classified as having explicit linking. *Amoebaabstract 01* was classified as conditional, while *Amoebaabstract 02* and *03* were classified as explicit. The reason for this is related to the reset mechanism programmed in *02* and *03*, while on *01* the reset is programmed to be automatically performed by the system once a prolonged lack of interaction is detected. Therefore linking is still partially controllable by the user but it is not always available, as in the later two pieces. *Inner Forests* deploys a system similar to *Amoebaabstract 01*, but is not dependent on a time-out and therefore is classified as explicit.

### 3.4.6 Notes on User Functions

While non-interactive systems are largely interpretative, we found it hard to define whether those systems where the interaction is kept to a bare minimum — typically reduced to a single click or gesture to restart the process, eventually defining new variables in the process, such as *Page 0* or *Substrate* — should be classified as interpretative, as configurative or even as explorative, given how reduced is the human

input. The fact is that even if one's actions on the system are very simple, they nevertheless may have a visible effect in it, refreshing or restarting the process, sometimes fundamentally altering it. We have therefore found it adequate to classify the majority of these systems as configurative.

During the development of our analysis we found that there was a less than clear distinction between the configurative and structural user functions. Following Aarseth's model we should rule user functions as structural only when and if the user's configurations can be permanently added to the system. In cases where the user contributes to physical (and therefore permanent) outputs this may be easy to evaluate but in all other cases it is very difficult, if not impossible, to understand the longevity of the added information, how and when it may be diluted, discarded or replaced by the system or other users. It is also difficult to evaluate the amount of control that a user may have over these configurations, because structural additions should, in principle, be controllable and not, as in *Mount Fuji* or *temporary.cc* be uncontrollable.<sup>602</sup> We have therefore chosen to simplify the model and to allow only three user functions, merging the original structural and configurative user functions into a single configurative value.

### 3.4.7 Multiple Correspondence Analysis

Using the `R` software package<sup>603</sup> we started by trying to replicate Aarseth's analysis and results from his data presented in *Cybertext* (1997, 68-69):

**Table 4:** Aarseth's analysis.

	Dynamics	Determinability	Transiency	Perspective	Access	Linking	U. Functions
<i>Adventure</i>	IDT	Determinable	Intransient	Personal	Controlled	Conditional	EF
<i>Afternoon</i>	Static	Determinable	Intransient	Impersonal	Controlled	Conditional	EF
<i>Agrippa</i>	IDT	Determinable	Transient	Impersonal	Controlled	Explicit	IF
<i>Book Unbound</i>	TDT	Indeterminable	Transient	Impersonal	Controlled	Conditional	TF
<i>Calligrammes</i>	Static	Determinable	Intransient	Impersonal	Random	None	EF

<sup>602</sup> A case in which, we may argue, the configurations are created by the system upon the user's action, not by the user, with her actions.

<sup>603</sup> `R` is a language and environment for statistical computing and graphics. It provides a wide variety of statistical as well as graphical techniques and is an integrated suite of software facilities for data manipulation, calculation and graphical display. `R` is available as free software from [r-project.org](http://r-project.org)

	Dynamics	Determinability	Transiency	Perspective	Access	Linking	U. Functions
<i>Cent mille milliards</i>	Static	Determinable	Intransient	Impersonal	Random	None	CF
<i>Composition N° 1</i>	Static	Indeterminable	Intransient	Impersonal	Controlled	None	IF
<i>Eliza</i>	IDT	Determinable	Intransient	Personal	Controlled	Conditional	CF
<i>Falcon</i>	IDT	Indeterminable	Intransient	Personal	Controlled	Conditional	EF
<i>Holzer</i>	Static	Determinable	Transient	Impersonal	Controlled	None	IF
<i>Hopscotch</i>	Static	Determinable	Intransient	Impersonal	Random	Explicit	EF
<i>I Ching</i>	Static	Indeterminable	Intransient	Personal	Controlled	Conditional	CF
<i>Moby Dick</i>	Static	Determinable	Intransient	Impersonal	Random	None	IF
<i>Money Spider</i>	IDT	Determinable	Intransient	Personal	Controlled	Conditional	EF
<i>MUDI</i>	TDT	Indeterminable	Transient	Personal	Controlled	Conditional	EF
<i>Norisbo</i>	Static	Indeterminable	Intransient	Impersonal	Controlled	None	CF
<i>Pale Fire</i>	Static	Determinable	Intransient	Impersonal	Random	Explicit	IF
<i>Racter</i>	TDT	Indeterminable	Intransient	Personal	Controlled	Conditional	CF
<i>Tale-Spin</i>	TDT	Indeterminable	Intransient	Impersonal	Controlled	None	CF
<i>TinyMUD</i>	TDT	Indeterminable	Transient	Personal	Controlled	Conditional	TF
<i>Twin Kingdom Valley</i>	TDT	Indeterminable	Intransient	Personal	Controlled	Conditional	EF
<i>Unending Adventure</i>	Static	Determinable	Intransient	Personal	Controlled	Explicit	TF
<i>Victory Garden</i>	Static	Determinable	Intransient	Impersonal	Controlled	Explicit	EF

We rebuilt the data table and performed a multiple correspondence analysis, achieving values that are close to those that Aarseth presents:<sup>604</sup>

**Table 5: Multiple correspondence analysis results calculated from Aarseth's analysis.**

Number	Eigenvalue	Inertia	Cumulated
1	0.235013	41.60	41.60
2	0.074244	13.14	54.74
3	0.057228	10.13	64.87
4	0.02248	3.98	68.85

And plotted the results in a two dimensional graphic. Although we found some minor variations in the plotting of the texts and categories, the relative positions are nevertheless consistent with Aarseth's plottings.

<sup>604</sup> We performed a multiple correspondence analysis using the 'lambda' option of 'adjusted', based on the Burt matrix with an adjustment of inertias, the default option of the CA package used in R.

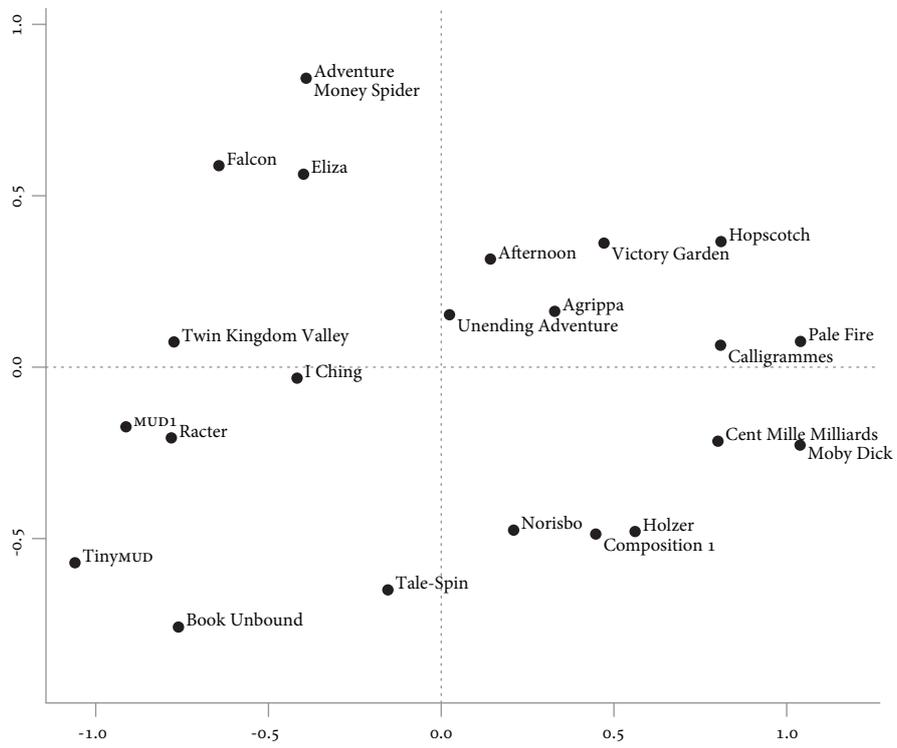


Fig. 186: Aarseth's texts, replotted in R.

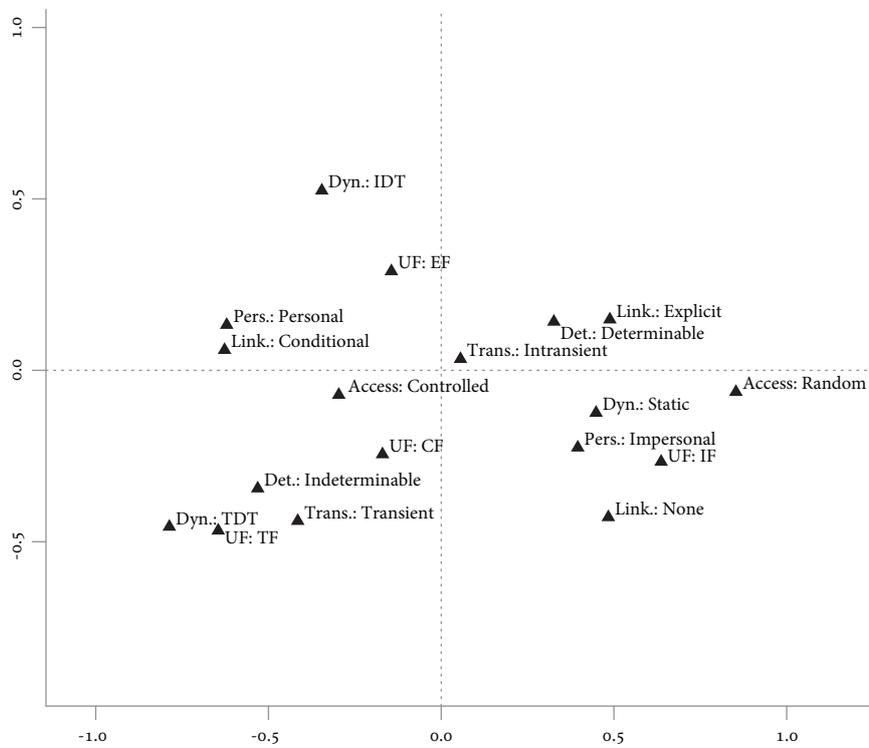


Fig. 187: Aarseth's categories, replotted in R.

Having thus confirmed the reproducibility of Aarseth's results, we proceeded to submit our initial analysis to a multiple correspondence analysis, testing different sets of Aarseth's variables and interpreting the clustering of the pieces in the plots, trying to understand: 1) if clusters were formed; 2) how significant these clusters were, that is, which pieces formed each cluster, how similar these were among themselves or how diverse were pieces that might be in the same cluster (or even in the same point in the plot) and that, owing to marked differences perhaps shouldn't be. A certain amount of clustering was naturally interpreted positively — after all it seems only natural that pieces as linear audiovisual works such as *Animations for Aol. Rebrand* or *Enerugii* are tightly plotted, and the same can be said of printed or fabricated artifacts or static images. Our first conclusion however, was that Aarseth's perspective variable was not adding information to the analysis. Testing it with something that could be regarded as a concession or as an attempt to try to make the variable work in this context we first found that the results were considerably shifted in a way that was not creating useful information, that is, it was moving pieces away from clusters but not creating new meaningful clusters. Alternatively, when classifying all the systems as impersonal, the variable simply lost any information value. We have therefore decided to drop the variable from this model, eventually reserving its use for future work where systems that are clearly narrative and diegetic are analyzed.

With the remaining seven variable, dynamics, determinability, transiency, access, user functions and linking we found that the model plotted far more satisfactory results but that if the clustering was logical it was nevertheless somewhat excessive, creating a big divide between the explorative user function and the remaining functions and between transient and intransient systems. We therefore proceeded to, as planned, testing the integration of new variables in the model.

### 3.5 New Variables

#### 3.5.1 Modes

The first potential variable to be considered was modes, in an attempt to describe how many levels of perception are involved in the outputs manifested by the systems: one when the output is only aural or visual; two when the output is audiovisual, or visual and haptic;<sup>605</sup> three in systems that are both audiovisual as haptic.

Quantifying modes is not the same thing as quantifying the number of dimensions in which the output of a system exists.<sup>606</sup> It is also different from an assessment of the medium through which a piece is created: “*Medium* is defined as the means of expression (material and other technologies); *mode* is defined as the manner of expression.” (Riley 2002) Following our phenomenological approach to these systems, the study of modes concerns the reception of their outputs. “*Reception* (...) represents the stage at which the artwork is ‘taken in’, or received within the public domain. The complexities of media (the means of expression) and modes (the manners and expression) may range from the properties of the display environment and the manner in which its *ambience* is manipulated, to the manner in which the work is publicised and reviewed. Here too, it is argued, there is the possibility of a common means of analysis based upon the recognition that selections have been made from systems of choices.” (2002)

We will follow a more physical and sensorial definition of modes, closely bound to the different regimens of human sensorial perception, as proposed by Whitelaw (2008) and by Blesser and Salter (2007). It is interesting to note that Stephanie Strickland (2007) expands the definition of modality to include not only visual, aural and haptic manners of expression, but also mathematics and motion. This suggests that the perception of motion<sup>607</sup> and the perception of mathematical structures — rhythm, harmony, etc. and the “struggle between mathematical abstractions and

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**605** Or tactile. The haptic mode may include vibration, texture, temperature, physical three-dimensional movement and so on.

**606** If they are uni-, bi-, tri- or tetra-dimensional.

**607** Steven Pinker (1999) notes how the common motions of patches in an image is used by human cognition to identify complex objects, being the top criterion in the identification of unity of form. According to this, we can consider the perception of movement or motion as a sensorial mode that, although closely related to vision can be analyzed independently from it.

words” (36) — can be regarded as altogether different modes of perception. The mathematical modality should not be understood in the Pythagorean sense or tradition, as a correspondence between art (or aesthetics) and mathematics in terms of numerical ‘harmony’ but more as the intellectual and intuitive understanding of structure and process, and the aesthetic pleasure that is felt through it.<sup>608</sup> It is the beauty of abstract understanding, not of bodily contact but of cerebral perception.<sup>609</sup>

In new media, our task is the measure of measure. To accomplish this we write less ‘with places’ and more with ‘transitions’. Space does open up, perhaps monstrously, to a world of currents and translations. We don’t see these spaces full so much as feel them fill. We don’t watch them perform; we perform them, in part, in connection with others, in processes of conjugal transfer that propagate themselves. Our probes help us draw the connections and form the perceptions needed to flow, to participate in and comprehend an increasingly complex patterning that enfolds us, from nano-techniques to cosmic extent through genetic alteration and the new world disorders. (42)

We have therefore chosen to consider five modes: visual, audial, haptic, movement and procedural. Regarding the haptic mode, pieces were qualified as using it whenever they involved the direct manipulation or physical contact of the user. *A-Volve* involves the direct manipulation of a water tank where the ‘creatures’ are projected and where they can be interacted with, while *30x1* exists in a large space that needs not only to be explored by the visitors but also leads them to feel the space (the space’s temperature and its variations, the moisture in the air, the variations in lightness of the different rooms, etc.), and therefore creates a complex sensorial experience where proprioception also plays an important role. We chose not to regard interaction as a modality, mainly because there were already variables that described user

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**608** Daniel Dennett (qtd. in Pinker 1999) notes how humans always tend to search for a design stance in inanimate objects and an intentional stance in animate objects. The first tries to assign a purpose to an object while the later tries to understand the motivations of animals or humans (which were, evolutionarily speaking, the two main classes of animate objects with which humans cohabited). The mathematical or procedural modality can be seen as the result of these stance identifiers in human perception.

**609** Sometimes we can consider that it is not only the strict (or literal) understanding of the process that triggers the procedural mode but also the curiosity about the process. Although it may not be apparent, or immediately understandable, what is the process behind the system, it may nevertheless be clear that there is some logic in the development of the outputs, that there is ultimately a cause driving the system. Therefore we can consider that the outputs of the system offer some clues, or communicate, its procedural nature.

functions, linking and access and that by doing so were in effect describing parts of the interactive experience. The mere existence of interaction was not enough to classify a system as haptic. Whenever systems were executed in computers or other universal computational devices and used their standard input devices<sup>610</sup> in what can be described as ‘standard’, or ‘normal’ ways, although there is involvement of the sense of touch with the input device, we did not consider this to endow the system with a haptic mode because such interaction devices are not part of the piece but rather a part of the computational system that runs the piece and their usage is, in most cases, absolutely transparent for the user. In this sense we should classify as haptic those systems where the sense of touch and the user’s body is involved in non-conventional and hypermediated ways. The same principle was applied to printed or physical objects.

### 3.5.2 Dimensions

After modes, the quantification of how many dimensions are used by the system’s outputs was considered as a variable. In a preliminary analysis no systems were classified as being unidimensional. Any visual system is at least bidimensional, although we can defend that (at least in an abstract analysis) a work such as *Arnulf Rainer* (Kubelka 1960) is a unidimensional visual experience (comprised as it is by a sequence of dimensionless light and dark frames) or that a musical piece is unidimensional, no systems with these characteristics were part of our analysis group. Moles proposes a dimensional classification of messages that classifies the printed line of text as a message that exists in “a single spatial dimension (L): a sequence of linearly assembled symbols”<sup>611</sup> (1966, 8), while paintings, drawings or photographs code messages in two spatial dimensions.

The messages of the plastic arts or of architecture, as arrangements of volumes or masses, those of a set of punched cards arranged in a card index box, are, in a first approximation, esthetic or utilitarian messages of three dimensions (L3). Messages such as animated cartoons or movies, having two spatial dimensions and one temporal dimension, belong to the temporal arts (L2T). In the

<sup>610</sup> Such as keyboard, mouse, trackpad, trackball or joystick, touch screen, etc.

<sup>611</sup> “The written elements of the Central American countries emerged from quipus, linear successions of symbols composed of knots on a string. By exploring the line, or the quipu, we perceive successively the elements of the message, which are arranged in an order imposed by the unidimensional character of the string.” (Moles 1966, 8)

following, we shall grant a special place to purely temporal messages, speech and music, which are modulations of duration. they correspond to the “arts of time”; the others (dance, movies, animated cartoons) have some spatial characteristics. The former will give us relatively simple examples which are more accessible than the polydimensional messages (cinerama, for example). The esthetics of such complex messages, generally belated in comparison with technical achievement, is still only beginning. (Moles 1966, 8)

As expected, most systems presented outputs in two (15) or three (35) dimensions and only a minority (5, just over 9% of the total) used all four spatial and temporal dimensions.

### 3.5.3 Prochronism

The third potential variable that we considered in this model was prochronism. In this model we should not interpret prochronism in the classical sense, that of narrative, when something appears in a temporal context in which it could not yet be present, but rather in the sense proposed by Bateson (1979) for natural sciences (and biology in particular): prochronism as a record of how, in the past configurations of a system, forms and patterns were created. Bateson defined prochronism as the “general truth that organisms carry, in their forms, evidences of their past growth. Prochronism is to ontogeny as homology (q.v.) is to phylogeny.” (229) A prochronist view of systems is also a morphological view, a regard at the way how forms are temporally created and how the systems keep perceivable traces of that process.<sup>612</sup> Dominick Chen (2008) recognizes that “we are not able of focusing on the process” and that despite “the fact that even in every action of a child when he is drawing we can observe a rich accumulation and layering, we have developed neither culture nor technology that concentrates upon the accumulation over time of the information that we daily exchange” (64). We have eliminated process from the analysis and in doing so we “classified the world in a grid-like manner and acquired technology to associate similar elements within the system of classification” (64). By developing

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<sup>612</sup> “Every natural phenomenon, however simple, is really composite, and every visible action and effect is a summation of countless subordinate actions. (...) The concept of an average the equation to a curve, the description of a froth or cellular tissue, all come within the scope of mathematics for no other reason than that they are summations of more elementary principles or phenomena. Growth and Form are throughout of this composite nature; therefore the laws of mathematics are bound to underlie them, and her methods to be peculiarly fitted to interpret them.” (Thompson 1942, 1028)

the concept of prochronism he further proposes the construction of a method for “collectively sharing not only the result but also the gradual process that leads from generation to the present. This entails the shifting of our frame of reference from form to time. It also points to the necessary experimentation towards a critical practice through which human beings can dynamically record and share the processes of all the activities that affect interpersonal structure, from conscious self-expression to unconscious bodily gestures in the everyday. Philosophy was constructed as philo-sophia or ‘love of wisdom’, but what we today should begin to consider is ‘love of process’ of information.”<sup>613</sup> (2008, 64)

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**613** “One day as [Gregory] Bateson came into the class, he abruptly placed a boiled crab that he had bought at the Fisherman’s Wharf in front of the students. He then asked the students to assume that they did not know about an entity known as a ‘crab’ and to prove that the object in front of them was the ‘remains of a living organism’. The bewildered students took some time to handle the crab to observe it, until one of them proposed an answer: ‘This object is symmetrical. As all living organisms are symmetrical this object too is a living organism.’ To this Bateson replied that ‘it [was] a good answer, but there [was] something more fundamental’, prompting a different answer from another student: ‘the sizes of the right and left claws are different and therefore its morphology isn’t symmetrical’, however ‘the two claws are made of the same pattern’.

Bateson appraised this answer as touching on the most fundamental point that can be: the evidence of the crab being connected with other living organisms. In other words, he encouraged the students to draw their attention to the crab’s embryological origin. By observing the morphology of each part of the crab and by speculating about the temporal transition that it underwent during its growth, it is possible to ‘understand’ that the crab is a living organism just like the observer. In this case, the serial homology between the parts in the object’s internal morphology forms first-order connections, the phylogenetic homology between the crab and other similar living organisms (e.g. the lobster) forms second-order connections and the homology between crabs and lobsters on one hand and human beings and other living organism (e.g. mammals) on the other form third-order connections. This shows that the homological pattern is, unlike a simplistic analogy, a hierarchical connection.

Bateson asked the students to carry out the same task with a conch shell. In this case the students could no longer rely either on the similarities between different parts nor on the symmetrical property of the object. What Bateson was here pointing to, was a law of higher order: symmetry and segmentation are only the supervening outcome of the phenomenon of growth, and growth itself follows a morphological law. He described this as both the crab and the conch shell retaining the ‘prochronism’ that presents the temporal transition that it underwent in its growth. In other words, all living organisms mark their own ecological process in their own body and exhibit this to the external world. It is because of this that living organisms can, through the observation of each other’s morphological layout, be ‘homologous’ to each other.

Bateson emphasizes that this hierarchical thinking owes itself to embryology. This means that the time that the living organism underwent from being an embryo to the present can be read ‘at once’, thus supplementing temporal observation on how the organism mutually interacts with the surrounding environment. This concept of prochronism is reminiscent of the concept of the invariant, a group of elements which persists as invariable for a significant amount of time to the observing subject, coined by James Gibson in his theory of affordance. By perceiving the layout of invariants within an environment, living organisms understand what actions are possible within that environment (affordance).” (Chen 2008, 64)

With this variable we then propose a classification of systems that display clearly perceivable traces of their past structures or configurations. These marks do not need to be permanent, although in certain cases they can be, they also do not need to account for the complete range of the system's evolution and can represent only a chronological slice or fragment. A simple example of such a system is *Three Buttons*, a system where every interaction leaves a mark that is permanently displayed until the system is reset. A more complex example can be seen in *Substrate* or *phiLia 01*, two systems where the macroscopic configuration is created from the accumulation of a large number of local (and minute) actions, almost as if by accretion. These traces do not need to be perennial, they can be erased or covered by other outputs, but for a system to be classified as displaying prochronism, it should allow the viewer or user to understand its morphology as a temporal process and to identify at least some vestiges of former configurations. It is also not strictly necessary that the traces are even visible: a system as *Every Icon* has such a clear and strong structure that just the procedural mode of its output allows a viewer to infer all of the previous configurations of the system, almost at once, from any given present configuration or any other in the future. On the other hand, it is not simply enough that a system is found to be transient to be classified as displaying prochronism — a temporal evolution of the output (or the form) of the system needs to be reinforced by remains of its past.<sup>614</sup>

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**614** Systems like *temporary.cc* are not classifiable as displaying prochronism, although they change over time and although that change is traceable to its user's influence. This is because every change is actually erasing part of its past configuration. Therefore, based on any current configuration, it will not be clear which previous configurations were displayed by the system, or how the configurations evolved to reach the previous state — an extreme case in either systems will be the final, empty or blank configuration. One knows how and why the process evolved but is left without clues as to which particular steps were taken in that process. In a system as *Amoebaabstract 01*, although one may not be able to understand what was the exact chronology of the events happening in the past of the piece's outputs, one nevertheless is able to understand which events occurred and how many.

### 3.5.4 Autonomy

By autonomy — literally the “*control of the self*, from the Greek *autos* (self) and *nomos* (a law)” (Bateson 1979, 126) — the fourth potential variable under consideration, we understand a system’s capacity to generate novelty, to be creative at least to some degree, without resorting to external input (whether machinic, human or both).<sup>615</sup> By classifying a system as autonomous we will not recognize that the system is sufficiently independent to pass the Lovelace test (in any of its possible variants), something that, if achieved, would naturally be describable by this variable.

From a Batesonian perspective, autonomy is what injects life in a system.<sup>616</sup> According to Ariza it is also what makes generative works become less human and more artificial, more machine-authored (2009, 64). Autonomy of the systems, even if only apparent, also contributes to the perception of a transparency of technology, balancing out the opacity caused by interaction (Bolter and Grusin 1999, 33) and systems to which authors confer varying degrees of freedom by granting them autonomy<sup>617</sup> are able to produce subjectivity in ways that non-autonomous systems will never be able to. This is a continual process of becoming, as Doruff puts it (2008, 119), not a simpler act of being.

The existence of autonomy is a step towards autopoiesis — also from Greek roots, *autos* and *poiesis* (the creation or production) — a concept proposed by the biologists Humberto Maturana and Francisco Varela<sup>618</sup> in the 1970s (Annunziato and Pierucci 2000) that describes how living systems are characterized by the production or transformation of themselves. This is, literally, the *self-creation* of the system and/or its outputs. As with creativity and intelligence, by classifying a system as autonomous we are not proposing that it is truly, and absolutely autopoietic in the strict sense of Maturana and Varela. This would, among other things, imply that

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**615** This should be minimally clear in the system’s operation. Otherwise one cannot, of course, understand when the system is fetching information from the World Wide Web or any other remote (and external) source of information. Likewise, internal databases or lookup tables (as those in the *Arca Musarithmica*, for example) should be seen as being part of the system and thus of its autonomy.

**616** And consequently, the removal of autonomy is the breaking up of the circuits and therefore, the death of the system. (Bateson 1979, 127)

**617** By programming it in the system, in the context being analyzed, not by achieving it through delegation to users and/or external sources of data.

**618** 1946-2001.

the systems would be able to bootstrap themselves<sup>619</sup> and that they would be ‘totally’ generative.<sup>620</sup>

The progression<sup>621</sup> of systems towards autonomy is described by Jacques Tisseau in a metaphor named after a famous story. The Pinocchio metaphor describes those systems that become autonomous and that thus free users (or creators) from controlling them. “A user, partially free from controlling his model, will also become autonomous and will take part (...) as a spectator (the user observes the model), actor (the user tries out the model) and creator (the user modifies the model to adapt it to his needs).” (2001, 8) Tisseau further proposes three classes or types of autonomy for a system: sensory-motor autonomy, where “each entity is provided with sensors and effectors that allows it to get information and respond to its environment”; decision-making autonomy, when “each entity makes decisions according to its own personality (its history, intentions, state and perceptions)”; and finally execution au-

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**619** This computer science term, *bootstrapping*, began to be used during the 1950s as a metaphor for programs that became self-sustaining processes, that is, that were able to proceed without external help from manually entered instructions. It is currently used to refer to the first steps in the starting up of a computational system, when the basic operational codes are loaded by the system. Hofstadter provides a (simplified) explanation of the process: “The first compilers were written in assembly language, rather than machine language, thus taking full advantage of the already accomplished first step up from machine language. Now as sophistication increased, people realized that a partially written compiler could be used to compile extensions of itself. In other words, once a certain minimal core of a compiler had been written, then that minimal compiler could translate bigger compilers into machine language — which in turn could translate yet bigger compilers, until the final, full-blown compiler had been compiled. This process is affectionately known as ‘bootstrapping’ (...) It is not so different from the attainment by a child of a critical level of fluency in his native language, from which point on his vocabulary and fluency can grow by leaps and bounds, since he can use language to acquire new language.” (Hofstadter 1999, 300) Dawkins also used the term, with this sense, applied to biology, particularly to the processes of cell differentiation.

**620** That the systems would be autonomous not only in the sense of defining their own progress and choices during the processes they execute but also autonomous to the point of actually being able to program themselves. In a sense this would be the ultimate generative, and machine authored, system — one that has no human intervention whatsoever during not only all the stages of the execution but also of the programming of the system. “The autonomy of an autopoietic system constitutes its minimal cognition. We must remember that an autopoietic system is a composite unit, much like an element-producing network in which the elements 1) via their interactions, recursively regenerate the network of production which produced them and 2) construct a network in which they exist by building up a frontier with their external surroundings via their preferential interactions within the network. Autopoietic systems possess the properties of emergent systems as they are able to create natural phenomena independent of those from which they were generated.” (De Loor, Manac’h and Tisseau 2009, 325)

**621** We are wary about using this term in this context, because it may imply a directed evolution, some sort of teleology. In human-authored systems this will inevitably be the case but not necessarily in machine authored, autopoietic systems (as wasn’t certainly also in biology, at least if one subscribes to a Darwinian point of view).

tonomy, when “each entity’s execution controller is independent of the other entities’ controllers” (2001, 35). He also proposes three lines of thought to understand the autonomy of systems: autonomy by essence, by necessity and by ignorance (2001, 29). The first of these characterizes all biological organisms, “from a simple cell to a human being”, the second involves the recognition of changes in the environment or context,<sup>622</sup> while the later simply “reveals our current inability to explain the behavior of complex systems through the reductionist methods of an analytical approach”<sup>623</sup> (2001, 29).

Simply put, we classify as autonomous systems all those that contain (or generate)<sup>624</sup> all the data they need to work and that, in doing so, produce novel outputs. All other systems, fed by external sources of information, are classified as being data-driven. Outputs in static media, or those that are classified as static according to their dynamics, should — as far as possible — also be classified according to these principles. A work as Verostko’s *Seven Sisters: The Pleiades* can be classified as autonomous, while *My Boyfriend Came Back from the War*, *Cylinder* or *Poetry on the Road*, because they map real-world data or are only usable through externally fed information<sup>625</sup> are classified as data-driven.

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**622** The autonomy will therefore be an outcome of the adaptability of the system and of the way it interfaces with the outside (world or other systems). “Physical modeling of mechanisms usually takes place by solving differential equation systems. Solving these systems requires knowledge about the conditions of the limits that restrict movement, but in reality, these conditions can change all the time, whether the causes in themselves are known or not (interactions, disturbances, changes in the environment). The model must then be able to perceive these changes in order to adapt its behavior during execution.” (Tisseau 2001, 29)

**623** “A complex system is an open system made up of a heterogeneous group of atomic or composite entities. The behavior of the group is the result of the individual behavior of these entities and of their different interactions in an environment that is also active. Based on schools, the behavior of the group is seen as either organized through a goal, which would be teleological behavior, or as the result of an auto-organization of the system, which would be emergence. The lack of overall behavior models for complex systems leads us to distribute control over the systems’ components and thus, autonomize the models of these components. The simultaneous evolution of these components enables a better understanding of the behavior of the entire overall system. Hence, a group of autonomous models interacting within the same space has a part in the research and experiments of complex systems.

Autonomizing models, whether by essence, necessity or ignorance, plays a part in populating virtual environments with artificial life that strengthens the impression of reality.” (Tisseau 2001, 29)

**624** A distinction that is not always possible to do by merely observing the system in operation.

**625** Which also includes user input.

### 3.5.5 Class

The computational class to which a system's output belongs can eventually be used in its classification. Following Wolfram's definitions (2002) and Rucker's interpretations (2005) we could approach this variable through at least three alternative understandings:

We could inspect the outputs trying to recognize the typical patterns created by class 1 to class 4 computations. This would certainly lead to a classification of most systems as either class 2, whenever the outputs presented static structures, or as class 4 whenever they would develop evolving and localized structures. In this case we would only find class 1 computations whenever the output would be a uniformly filled or empty canvas and class 3 would only exist in true random outputs. In this case we would be classifying the computational class of the system that produces the outputs by looking at the outputs and by trying to infer from them the properties of the system that created them.

We could alternatively use the information processing interpretation of the computational classes to classify the systems according to their capacity to process or to preserve information. This would however be difficult to infer from the system's outputs alone, whenever one was not able to interact with the system directly, or to witness its real-time operation,<sup>626</sup> thus hindering the classification of all the artifacts that do not develop real-time computation.

Finally, we could try to classify the outputs according to the class of computation that they may develop or represent. In this sense we could classify most of the static intransient outputs as being class 1,<sup>627</sup> most of the static transient outputs as being class 2<sup>628</sup> and all those outputs that exhibit complex behaviors as being class 3 or class 4. The structure of the outputs would then determine whether the system would be classified as class 3 (random, totally unpredictable) or class 4 (structured,

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<sup>626</sup> Although this is possible in some cases, it is far from being a universal possibility

<sup>627</sup> According to a pancomputationalist view, we can consider inert objects as being instances of class 1 computations.

<sup>628</sup> Class 1 is found in printed or otherwise physically immutable objects while class 2 is found in time-based, transient, outputs. Class 2 systems can be regarded as being cyclic outputs that once replayed always repeat the same pattern of surface units. There are of course exceptions to this rule of thumb, most notably *Connect*, a static, transient and yet indeterminable system that was classified as class 4.

at least locally and at least partially predictable).<sup>629</sup> We have chosen to follow this last approach in our classification.

### 3.5.6 Interstice: Autonomy and the Pleasures of Digital Environments

A system's autonomy can be regarded not only as an amount of control that is conferred to or appropriated by it, but also as a transfer of some amount of agency to the system. Returning to *Hamlet on the Holodeck* (1997), we find that Murray elaborates a description of digital media in terms of the pleasures that are characteristic to them, of their own "unique patterns of desire" as expressive media. Their "own way of giving pleasure, of creating beauty, of capturing what we feel to be true about life; its own aesthetic" (94). These pleasures are agency, navigation and transformation. From these it is the first that matters most in this context.

When things are going right on the computer, we can be both the dancer and the caller of the dance. This is the feeling of agency. Because of the vague and pervasive use of the term interactivity, the pleasure of agency in electronic environments is often confused with the mere ability to move a joystick or click on a mouse. But activity alone is not agency. For instance, in a tabletop game of chance, players may be kept very busy spinning dials, moving game pieces, and exchanging money, but they may not have any true agency. The players' actions have effect, but the actions are not chosen and the effects are not related to the players' intentions. Although gamemakers sometimes mistakenly focus on the number of interactions per minute, this number is a poor indicator of the pleasure of agency afforded by a game. Agency, then, goes beyond both participation and activity. As an aesthetic pleasure, as an experience to be savored for its own sake, it is offered to a limited degree in traditional art forms but is more commonly available in the structured activities we call games. (128-29)

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<sup>629</sup> Rucker develops a somewhat similar interpretation, stating that "in classical (prequantum) physics, a vacuum is the simplest, most orderly kind of matter: nothing is going on. A crystalline solid is orderly in a predictable, periodic way. And fluids such as liquids or gasses are fairly disorderly, more along the lines of being class three. Matter is computationally at its most interesting when it's near a phase transition, as when a liquid is freezing or coming to a boil. Matter near a phase transition to some extent has a nested class two structure, with similar kinds of features occurring at widely different scales. But the phase transition structure is very dynamic, with information-laden patterns moving about, and is, I believe, best thought of as class four." (Rucker 2005, 115)

By transferring some agency to the system and by endowing it with a degree of autonomy one could think that the system would lose part of its potential to give pleasure to the viewer, user or reader. We can however propose that an increase in the system's autonomy may create an additional pleasure besides the triad that is enunciated by Murray: a procedural pleasure.<sup>630</sup> As Rucker proposes, observing physical computations is a simple human pleasure (2005, 103). As well as generative artifacts, they are systems where the potential number of states is so high that it becomes impossible to repeat any given state<sup>631</sup> but where, in spite of this, one can intuitively grasp<sup>632</sup> an operational logic, a course of action. In procedural systems one can understand a statistical tendency for certain outputs to be produced, some attractors where the outputs tend to fall. One is rewarded when the systems behave according to our expectations (if these are proven correct).<sup>633</sup> Simple systems are not rewarding the viewer at this level, because by being so straightforward they do not imply any significant effort, and the reward is, as in so many cases, proportional to the effort. This is related to, but goes beyond what Dominic McIver Lopes calls of 'active appreciation' of an artwork (2010, 41) but it is also rather different from an interactive engagement with the system because there are no physical bidirectional exchanges of information (where those exchanges happen they exist in one single direction, from the communicating system to the viewer).

When Duchamp remarked that 'the spectator makes the picture' he was referring to how strenuous an activity is the appreciation of art. One needs to look, listen, read, "try out alternative interpretations of what is perceived, import relevant knowledge about authorship, genre and history, and imbue the whole process with personal associations, if they're relevant" (Lopes 2010, 41), one needs to fill in missing information and details of objects that are represented, to move the body to experience

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**630** It is a procedural pleasure that we can relate to the presence of the procedural mode in a system.

**631** Or at least where it is very difficult to predict any future state from the current state of the system.

**632** Grasping, not understanding, seems like a more adequate verb to use in this context, because one does not necessarily understand all the details of the processes well enough to be able to rebuild it (or even to explain it to other observers or to oneself) but, computational beings that we are, we can follow the processes, react to their algorithmic nature and even, as Hofstadter suggests (2007), somehow emulate the algorithm, by running on our brains processes that are similar (if not even identical in some cases) to those that are deployed in the system. In most cases this does not happen consciously, but it nevertheless happens, and it leads one to expect that the outputs of a procedural system will evolve in what is their 'natural' way, that which is dictated by their code and literally 'followed' by the observer (here turned to a coprocessor). "Computer art runs on computers, so if brains are computers then some computer art runs on brains." (Lopes 2010, 48-49)

**633** And where one is frustrated by failing to correctly (or approximately) predict the behaviors or results.

spatial structures (Manovich 2001, 56) and with these artifacts, to further try to fathom the system and to even come to emulate it.

### 3.5.7 Other Rejected (or Deemed Unfit) Variables

Besides the proposed new variables we have pondered several other alternative characteristics of these systems that could have eventually resulted in new variables. By and large these have not proven to be universally applicable to the analysis of all the pieces in this set or they have been found to describe aspects of the systems that were not deemed significant enough or that did not contribute to the efficaciousness of the model. Among those considered we find creative amplification, degree of repeatability, homeostasis, self-similarity, the existence of catastrophes, number and kind of attractors, the autonomous production of novelty, coherence and unity, the rate or pace of flow, and finally the scales in which the output of the system may be developed.

Creative amplification: Scott Draves proposes that in a system with “human-computer collaboration”, we can define the system’s “*creative amplification* as the ratio of total content divided by the human-created content.” (2008, 74) A variable such as this would be difficult to quantify in practice. One can understand the concept and even eventually compare systems according to their relative creative amplification ratios, but one would rapidly run into problems if trying to classify a larger number of systems according to this principle. On one hand, quantifying the total content of a system is not easy, or even always possible. A quantification of the human-created content can be easier in some cases, but still hard to compute for a group of systems with such different modes of interaction. Although appealing, creative amplification would only be applicable to interactive systems. All those systems that do not demand human action would either not be classifiable under this variable or would have to be classified as possessing a ‘maximum’ or ‘infinite’ amplification.

Homeostasis is the scientific term for systems that tend to maintain a state of equilibrium (Norman 2007, 79). Some procedural systems, as all of the biological systems, can be seen as a complex (and delicate) balance between morphogenesis and homeostasis,<sup>634</sup> two kinds of computation, the first developed by a mass of cells and the later by an organism in the world (Rucker 2005, 151). An alternative way to de-

<sup>634</sup> And reproduction (Rucker 2005, 151).

scribe this is, following Simon's metaphor, to describe the 'inner' and 'outer' environments of a system, "the substance and organization of the artifact itself (...) [and] the surroundings in which it operates" (1969, 7).

There is often a corresponding advantage in the division from the standpoint of the inner environment. In very many cases, whether a particular system will achieve a particular goal or adaptation depends on only a few characteristics of the outer environment, and not at all on the detail of the environment. Biologists are familiar with this property of adaptative systems under the label of homeostasis. It is an important property of most good designs, whether biological or artifactual. In one way or another, the designer insulates the inner system from the environment, so that an invariant relation is maintained between inner system and goal, independent of variations over a wide range in most parameters that characterize the outer environment. (9)

A variable such as homeostasis might then describe a system in terms of its organization and functioning, of its interface between inner and outer environments and of the drives that it tries to satisfy (and the balance it may or may not reach along the way). It would however also cover the same range of phenomena that the class variable describes, as noted by Rucker. "As soon as a system has two drives to satisfy, it becomes difficult for homeostasis to find a fixed point and stop. A homeostatic system with two drives may end up carrying out a periodic class two computation — akin to a thermostat-equipped furnace driven by the paired drives of 'not too hot' and 'not too cold.' In order to satisfy an opposing pair of drives, a homeostatic system will hunt across the equilibrium, often in a regular periodic fashion. Once we have more than two drives, a class three or class four computation almost inevitably ensues." (2005, 174)

Homeostasis can also be used to evaluate how a system responds to perturbations, how it preserves the information injected in it by external influences, if the system forgets this information or if it preserves it in any degree and therefore allows the external events to influence its behavior in any way.<sup>635</sup> As we have previously seen, this would also describe a characteristic of the system that is covered by the class variable.

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<sup>635</sup> Therefore this may be seen as being related to the autonomy variable.

The autonomous production of novelty, inspired by Dorin's text (2008, 289), intended to describe systems that would be independent from external sources of information or control and able to create new information (or novelty) on its own, or to "explore large design spaces independently of human input" (2008, 294). During the development of this work, this potential variable evolved to the simpler (and more encompassing) variable autonomy.

Inspired by Barratt (1980) and Alexander (2002a), we investigated the possibility of using the scales of the output units as a classification variable. Using the diversity of ratios detectable in the outputs of the systems, regardless of their modes, would eventually allow an understanding of the rate of change, of rhythmic patterns and of the recursiveness within a system and its outputs. Besides the modular units or building blocks, we could also study the grouping procedures (Barratt 1980, 140) of the system, which by permutation, combination or simple similarity order the scale. The flow rate or pace of a system's output could be seen as its temporal scale, something that could result in an expansion of the possible values of the transiency variable. However, establishing an effective way to quantify scale across several media, modes and such diverse outputs as the ones being analyzed proved to be a difficult task and an unsurpassable difficulty when working this potential variable.

Catastrophes, understood in a mathematical sense, are sudden changes in the state of a system (Buchanan 2004, 14), particularly, changes from one state of equilibrium to another where the symmetries of the system are broken and eventually reformed. Catastrophe theory was developed<sup>636</sup> as a general theory of morphogenesis, where the "growth of an organism is seen as a series of gradual changes triggered by, and in turn triggering, sudden jumps in the biochemistry" (Barratt 1980, 260). More than being mere accidents — the most common synonym for 'catastrophe' —, they are features of the systems that are connected to autcreativity (Goriunova 2008)<sup>637</sup> or a structure preserving development of the system's formal outputs.<sup>638</sup>

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**636** In the 1970s by mathematician René Thom.

**637** "(...) a dynamic process occurring in the relationship between network systems, technology and human beings; autcreativity appears as an explosion within a particular combination of forces", it is "a micro catastrophe, setting up a myriad of spaces of possibility rather than (...) annihilating", finally, it is "a process, an explosion creating the valuable, creating, like love, something that we do not possess and giving it to someone who does not need it." (Goriunova 2008, 114)

**638** "This smoothness of evolution is visible in all the examples, essentially without exception. Even in those cases where there is a catastrophe — the mathematical term for the appearance of some new feature, not visible in the symmetries of the previous state — this catastrophe always begins as a feature which is

Self-similarity could be used to evaluate the existence of fractal-like structures in the output of the systems, as well as (to a certain extent) the organization of surface units. It could also be used to evaluate the regularity of the outputs, the system's homeostasis or the tendency to an equilibrium over different runs or experimentations. If existing, this property could be searched for in magnifications of the output, or in different areas of the output, either spatial, temporal or both.

The notion of self-similarity strikes ancient chords in our culture. An old strain in Western thought honours the idea. Leibniz imagined that a drop of water contained a whole teeming universe, containing, in turn, water drops and new universes within. "To see the world in a grain of sand," Blake wrote, and often scientists were predisposed to see it. When sperm were first discovered, each was thought to be a homunculus, a human, tiny but fully formed. But self-similarity withered as a scientific principle, for a good reason. It did not fit the facts. Sperm are not merely scaled-down humans — they are far more interesting than that — and the process of ontogenetic development is far more interesting than mere enlargement. (Gleick 1998, 115)

We could also analyze the degree of repeatability to be found in the structures produced in the system's outputs, that is, whether the system's behavior leads to a stream of regular outputs, or outputs that are recognizable as regular although they may not be strictly similar. All computational structures are in principle able to produce repeating outputs, as seen in Wolfram's analysis. Class 1 and 2 structures are the most prolific in the production of repetition and of very rigid structures because they create nothing besides these. Class 3 creates very repetitive, although highly irregular outputs, and class 4 computations produce what are perhaps the less repeating of all the outputs but those that present human observers with the most meaningful structures, those that are imbued with meaning. Here we could also look for the system's coherence and unity, one of the four basic properties exhibited by generative artworks, according to Dorin (2008, 289). This property is related to homeostasis and describes the system's capacity to maintain its identity over time,

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essentially consistent with the symmetries of the earlier state, and which then develops, and continues to develop, as the new source of structure, thus still allowing a smooth and consistent evolution of structure." (Alexander 2002b, 23) "In all these natural examples, one thing stands out. The process of formation that occurs in nature — whether it happens in microseconds or over millions of years, whether it is large or small, whether it comes from the organic or the inorganic world — is in every case smoothly structure preserving." (32)

despite eventual perturbations (influences from the outer environment) or catastrophes (from the inner environment), but this does not necessarily mean that the system should preserve whatever actual configuration of its output, rather that the intellectually perceivable structures of the output should be kept, that the system is able to communicate its identity, in spite of (m)any variations it may go through.

We could eventually look for this identity in any attractors that would be manifest in the outputs of the systems. Attractors are agglomerations of common or recurrent states in the phase space of a system that are one of the most well-known topics of the investigation in dynamical systems.<sup>639</sup> An attractor is not necessarily a well-defined form or configuration in the outputs of a system, it can be seen as a statistical increase in the probabilities of the outputs generating a particular structure or sets of structures or, alternatively, a system's output may be composed of several different attractors. Describing the gnarly zone in class 4 systems, Rucker (2005, 116) uses the mathematics of chaos theory to refine what happens along the space of possibilities between ordered class 2 systems and absolutely disordered class 3. If in ordered systems we can propose the existence of a strong and absolute periodic attractor, as soon as one enters the gnarly zone one will find quasiperiodic behaviors, following into strange attractors, chaotic bifurcations and finally, just before meeting class 3 systems, we will find pseudorandomness.<sup>640</sup>

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**639** Particularly the so-called 'strange attractors' that consist "of an infinite number of curves, surfaces, or higher-dimensional manifolds — generalizations of surfaces to multidimensional space — often occurring in parallel sets, with a gap between any two members of the set" (Lorenz 1995, 48).

**640** "The most orderly kind of gnarly behavior is quasiperiodic, or nearly periodic. Something like this might be a periodic function that has a slight, unpredictable drift. Next comes the strange attractor zone in which the system generates easily visible structures — like the gliders in a CA rule, or like standing waves in a stream. Then we enter a critical transition zone, which is the heart of the gnarl. In the language of chaos theory, a system undergoes a bifurcation when a system switches to a new attractor. This is when a system begins ranging over a completely different zone of possibilities within the space of all possible phenomena. The term bifurcation is a bit misleading, as a chaotic bifurcation doesn't necessarily have anything to do with something splitting in two. Bifurcation means nothing more than changing something about a system in such a way as to make its behavior move to a different attractor. As we turn up the disorder of a gnarly system, the system begins experiencing bifurcations in which one strange attractor repeatedly gives way to another. Initially the system may be dancing around on, say, an ellipse, and a moment later, the successive points may be scattered about on something shaped like a bow tie. And at the highest end of disorder we shade into the pseudorandom chaotic systems, whose output is empirically indistinguishable from true randomness — unless you happen to be told the intrinsically random algorithm that is generating the chaos." (Rucker 2005, 116)

Homeostasis, attractors, self-similarity, repeatability and even catastrophes all lead to a certain hypothetical stability of the outputs of a system, while at last we could search for what can perhaps be the most difficult of characteristics to define, the violation of expectation. If a system establishes a pattern of anticipation in its observers, it may subsequently disrupt it, violating the observers' expectations towards the future development of the system. A class 2 system will tend to dull the receptivity of the observer, while a quasiperiodic system, already in the gnarly zone will be able to create periods of rest in which the reverberations of events "may subside, before they are repeated" (Barratt 1980, 299), the intervals permitting "time for contemplation and anticipation".<sup>641</sup> Violation of expectation is at the core of drama and counterpoint<sup>642</sup> and we believe, also at the core of artificial creativity, as only a system able to 'think outside of the box' will be capable to really create. Only a system that produces the unimaginable will be able to pass the Lovelace test.

### 3.6 Analysis

#### 3.6.1 Tables

After the ponderation of Aarseth's variables, from which we kept six, and the five proposed new variables, we arrived to the following set of variables and their possible values:

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**641** "Rhythmic grouping procedures organise the alternation of hits and rests. Robert Mitchum, the Hollywood film star, once described his films as: A sequence in which they knock me down and I get up. Then they knock me down, I think it over and get up. So they knock me down and I shake my head and I get up. So they knock me down... In a first-rate film this happens plenty of times. The (...) problem is to devise sufficient variety of ways to knock him down, revive him and wave a pattern of rests between the peaks of conflict." (Barratt 1980, 299)

**642** "Ultimately drama resolves into the juxtaposition of antitheses. Though they are interdependent, the head and tail of a coin battle for supremacy. In counterpoint, two contrasting themes which share a common space-time scale discuss, compete, debate, argue, fight for their points of view. Each must be a convincing contender and although the conflict may be resolved in the favour of one, the other cannot be obliterated. When the coin comes to rest head up, the tail must be underneath! One sustains the other. As one rises the other declines and the discourse is maintained through variations upon the two themes and and alternation of supremacy. Drama, counterpoint can be enriched beyond bald competition between two themes by the use of transitions and interweaving sub-plots." (Barratt 1980, 301)

**Table 6: Variables and possible values.**

Variable	Possible value
Dynamics	Static, SUD, DUD
Determinability	Determinable, indeterminable
Transiency	Transient, intransient
Access	Random, controlled
Linking	None, conditional, explicit
User Functions	Interpretative, configurative, explorative
Modes	1 – 5
Autonomy	Autonomous, data-driven
Prochronism	Yes, no
Dimensions	1 – 4
Class	1, 2, 3, 4

Our classification of the 54 different systems is laid out in the following table:

**Table 7: Our analysis of the 54 works.**

	Dyn.	Det.	Trans.	Access	Linking	U.F.	Modes	Aut.	Prochr.	Dim.	Class
<i>1. Cent mille milliards...</i>	Static	Det.	Int.	Random	None	CF	3	Aut.	No	2	1
<i>2. Cent mille milliards... (web)</i>	DUD	Ind.	Int.	Cont.	Cond.	CF	1	Aut.	No	2	2
<i>3. Agrippa</i>	SUD	Det.	Trans.	Cont.	None	IF	3	Aut.	No	3	2
<i>4. A-Volve</i>	DUD	Ind.	Trans.	Cont.	Cond.	CF	5	DD	Yes	4	4
<i>5. Evolved Virtual...</i>	DUD	Ind.	Trans.	Cont.	None	CF	3	DD	Yes	4	4
<i>6. My Boyfriend...</i>	Static	Det.	Int.	Cont.	Cond.	EF	2	DD	No	2	2
<i>7. Every Icon</i>	SUD	Det.	Trans.	Cont.	None	IF	3	Aut.	Yes	3	2
<i>8. Sketch</i>	Static	Det.	Int.	Random	None	IF	2	Aut.	No	2	1
<i>9. Seven Sisters...</i>	Static	Det.	Int.	Random	None	IF	2	Aut.	Yes	2	1
<i>10. Text Rain</i>	SUD	Ind.	Trans.	Cont.	None	CF	4	DD	No	3	4
<i>11. Yellowtail</i>	DUD	Ind.	Trans.	Cont.	Explicit	CF	3	DD	No	3	4
<i>12. Soda Constructor</i>	DUD	Ind.	Trans.	Cont.	Explicit	CF	3	DD	No	3	4
<i>13. Amoebaabstract 01</i>	SUD	Ind.	Trans.	Cont.	Cond.	CF	3	DD	Yes	3	4
<i>14. Amoebaabstract 02</i>	SUD	Ind.	Trans.	Cont.	Explicit	CF	3	Aut.	Yes	3	4
<i>15. Amoebaabstract 03</i>	SUD	Ind.	Trans.	Cont.	Explicit	CF	3	Aut.	Yes	3	4
<i>16. Cylinder</i>	Static	Det.	Int.	Random	None	IF	2	DD	Yes	3	1

	Dyn.	Det.	Trans.	Access	Linking	U.F.	Modes	Aut.	Prochr.	Dim.	Class
17. <i>Substrate</i>	SUD	Ind.	Trans.	Cont.	Explicit	CF	3	Aut.	Yes	3	4
18. <i>Black &amp; White</i>	SUD	Ind.	Trans.	Cont.	None	IF	3	DD	Yes	3	2
19. <i>For All Seasons</i>	SUD	Ind.	Trans.	Cont.	Explicit	CF	2	DD	No	3	2
20. <i>Droom Zaacht</i>	DUD	Ind.	Trans.	Cont.	Explicit	CF	3	DD	Yes	3	4
21. <i>Page 0</i>	SUD	Ind.	Int.	Cont.	Explicit	EF	2	DD	No	2	4
22. <i>Happy Place</i>	SUD	Ind.	Trans.	Cont.	Explicit	CF	3	Aut.	Yes	3	4
23. <i>Emeral</i>	Static	Det.	Int.	Random	None	IF	1	Aut.	Yes	2	1
24. <i>Three Buttons</i>	DUD	Det.	Trans.	Cont.	None	CF	2	DD	Yes	3	2
25. <i>Dreamlines</i>	DUD	Ind.	Trans.	Cont.	Explicit	CF	3	DD	Yes	3	4
26. <i>Ornamism</i>	SUD	Ind.	Trans.	Cont.	Explicit	CF	3	Aut.	Yes	3	4
27. <i>30x1</i>	SUD	Ind.	Trans.	Cont.	None	IF	4	Aut.	No	4	4
28. <i>Extrusions in C Major</i>	Static	Det.	Int.	Random	None	IF	2	DD	Yes	3	1
29. <i>Poetry on the Road</i>	Static	Det.	Int.	Random	None	IF	1	DD	Yes	2	1
30. <i>Process 16</i>	SUD	Ind.	Trans.	Cont.	None	IF	3	Aut.	Yes	3	4
31. <i>We Feel Fine</i>	SUD	Ind.	Trans.	Cont.	Explicit	CF	3	DD	No	3	4
32. <i>Moving Pixel Portraits</i>	Static	Det.	Int.	Cont.	Explicit	CF	3	DD	No	2	2
33. <i>Process 18</i>	SUD	Ind.	Trans.	Cont.	None	IF	3	Aut.	Yes	3	4
34. <i>Der Wirklichkeitsschaum</i>	Static	Det.	Int.	Random	None	IF	1	Aut.	Yes	2	1
35. <i>Reface...</i>	DUD	Ind.	Trans.	Cont.	Cond.	CF	3	DD	Yes	3	2
36. <i>Pixflow #2</i>	SUD	Ind.	Trans.	Cont.	None	IF	3	Aut.	No	3	4
37. <i>Folia</i>	Static	Det.	Int.	Random	None	IF	1	Aut.	Yes	2	1
38. <i>Inner Forests</i>	DUD	Ind.	Trans.	Cont.	Explicit	CF	3	DD	No	3	4
39. <i>A Week in the Life</i>	Static	Det.	Int.	Random	None	IF	1	DD	No	3	1
40. <i>Connect</i>	Static	Ind.	Trans.	Random	None	IF	4	Aut.	No	4	4
41. <i>A Confidence of Vertices</i>	Static	Det.	Trans.	Cont.	None	IF	2	Aut.	No	3	2
42. <i>Enerugii</i>	Static	Det.	Trans.	Cont.	None	IF	3	DD	No	3	2
43. <i>Print cover</i>	Static	Det.	Int.	Random	None	IF	1	Aut.	No	2	1
44. <i>Nokia Friends</i>	DUD	Ind.	Trans.	Cont.	None	IF	4	Aut.	No	3	4
45. <i>Forever</i>	SUD	Ind.	Trans.	Cont.	None	IF	3	DD	No	3	4
46. <i>Colors of Nature</i>	Static	Det.	Int.	Random	None	IF	1	Aut.	No	2	1
47. <i>Animations for Aol.</i>	Static	Det.	Trans.	Cont.	None	IF	3	Aut.	No	3	2
48. <i>Merce's Isosurface</i>	Static	Det.	Trans.	Cont.	None	IF	2	DD	No	3	2
49. <i>Perpetual Storytelling...</i>	DUD	Ind.	Trans.	Cont.	None	IF	3	DD	No	4	4
50. <i>phiLia 01</i>	SUD	Ind.	Trans.	Cont.	Explicit	CF	4	DD	Yes	3	4
51. <i>Talysis II</i>	DUD	Ind.	Trans.	Cont.	None	IF	2	Aut.	Yes	3	4

	Dyn.	Det.	Trans.	Access	Linking	U.F.	Modes	Aut.	Prochr.	Dim.	Class
52. <i>temporary.cc</i>	DUD	Ind.	Trans.	Cont.	Cond.	CF	2	DD	No	2	1
53. <i>Vanitas</i>	SUD	Ind.	Trans.	Cont.	Explicit	CF	4	DD	No	3	4
54. <i>The Inability to Solve...</i>	SUD	Det.	Trans.	Cont.	None	CF	3	DD	No	3	2

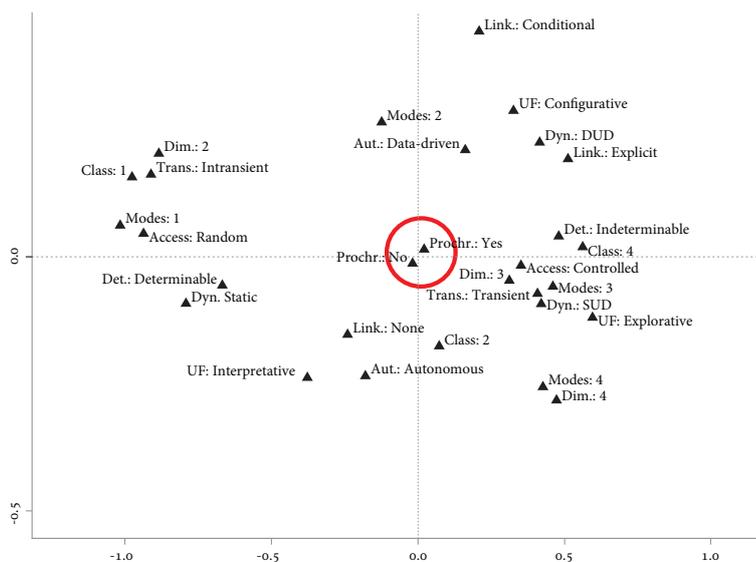
### 3.6.2 Multiple Correspondence Analysis

Using R and the CA package (Nenadić and Greenacre 2007), we developed a Multiple Correspondence Analysis on the data, arriving to the following results:

**Table 8: Multiple correspondence analysis results calculated from our analysis.**

Number	Eigenvalue	Inertia	Cumulated
1	0.263767	53.5	53.5
2	0.032176	6.5	60.0
3	0.028604	5.8	65.8
4	0.021469	4.4	70.2

Plotting the results of the first two synthetic axes (that account for 60 percent of the total variance in the data) and performing the initial analysis of the plot, we came to discover that the Prochronism variable was not positively contributing to the description of the systems.



**Fig. 188: Plot of the first two synthetic axes of the multiple correspondence analysis with eleven variables.**

The two values of the prochronism variable are not only plotted very close to each other and near the center of the axes as the removal of the variable from the model does not significantly affect the distribution of the pieces. Comparing multiple component analysis with and without the variable, we found that the differences were small enough to the point of being negligible, and also that when the number of total variables was reduced from eleven to ten, the multiple correspondence analysis would (predictably) result in a higher representation of the variance in the data with the same amount of synthetic variables.

When analyzing the relevance of the dimensions variable we have found that its contribution to the description of the systems, although positively separating the bi- and the tridimensional systems in the plot — in the single instance where this separation was not caused by other variables — was not doing much more besides that and, as a side effect, also led to the compression of the three and four dimensional systems in the right hemisphere of the plot, thus actually having a somewhat negative contribution to the model.

With a reduction to nine variables, we arrived to the following multiple correspondence analysis results:

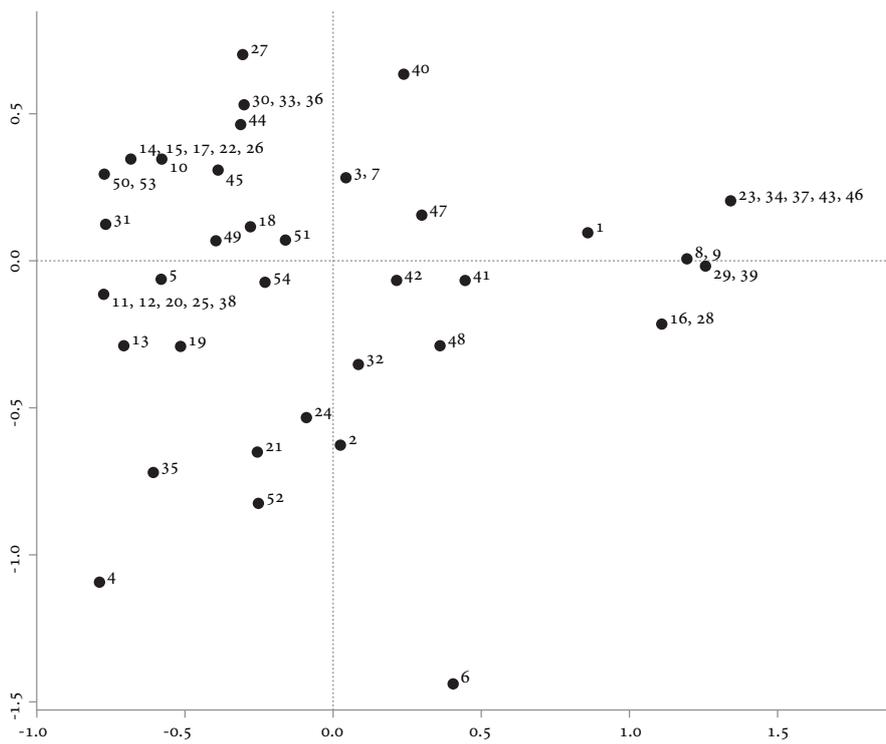
**Table 9: Multiple correspondence analysis results calculated from our analysis with nine variables.**

Number	Eigenvalue	Inertia	Cumulated
1	0.342199	54.1	54.1
2	0.054562	8.6	62.7
3	0.032972	5.2	68.0
4	0.023009	3.6	71.6

We have therefore chosen to drop the prochronism and dimensions variables from the model, in an attempt to simplify it through the removal of variables that did not really contribute to its perceived effectiveness in describing the systems. The final analysis was performed with the following variables and possible values:

**Table 10: Variables and their possible values in the final model.**

Variable	Possible Value
Dynamics	Static, SUD, DUD
Determinability	Determinable, indeterminable
Transiency	Transient, intransient
Access	Random, controlled
Linking	None, conditional, explicit
User Functions	Interpretative, configurative, explorative
Modes	1 – 5
Autonomy	Autonomous, data-driven
Class	1, 2, 3, 4



**Fig. 189: Plot of the first two synthetic axes of the MCA with nine variables, showing only the systems.**



of the map, *My Boyfriend Came Back from the War* [6] is still plotted in a logical location. The east edge of the plot is populated by printed or otherwise static outputs, while the west area is predominantly populated by interactive systems. If we circumscribe the area occupied by interactive systems and non-interactive systems, we find that they do not overlap and create two very defined islands in the graph.

Looking closely to the determining categories that are encompassed by each of these areas may allow us to understand which values are most typically associated with each group. In the east quadrant we find that the non-interactive pieces are mostly static, determinable, intransient and randomly accessible, with no linking and characterized by an interpretative user function. The interactive systems in the west quadrant are characterized by deep unit dynamics, conditional linking and explorative and configurative user functions. They also tend to concentrate more modalities and to develop higher computational classes.

The only system that in this circumscription calls our attention because of its relative placement is Queneau's *Cent mille milliards de poèmes* [1] that sits in the middle of the non-interactive 'island'. Albeit not a traditional one, this is the only book among the pieces we studied. Its placement obviously raises the question of whether books can be seen as interactive devices or if they are simply artifacts that can be manipulated into different configurations. Andersen's semiotic definition of interactivity, stating that an "interactive work is a work where the reader can physically change the discourse in a way that is interpretable and produces meaning within the discourse itself" (qtd. in Aarseth 1997, 49) is not too helpful in this context. However, if we follow the definition presented by Schubiger, that an interactive system is one that supports communication in both directions, from user to system and back, one where the "system reacts accordingly, perhaps by displaying information, perhaps by activating machinery or performing some other useful service" (2005, 343), or that of Andrew Lippman, who sees interaction as "mutual and simultaneous activity on the part of both participants, usually working towards some goal, but not necessarily" (qtd. in Aarseth 1997, 49) then we must certainly not consider a book as being an interactive device or its text as an interactive system.<sup>644</sup>

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<sup>644</sup> A book is never capable to react or respond to a user, although the user can certainly interpret its (rearranged) contents as responding to a certain question or change of context. As what happens with the *I Ching* or with a game of Tarot, where the user thinks that the reconfiguration of the system or the random selections are meaningful when in reality it is the interpretation of those changes that creates the meaning.

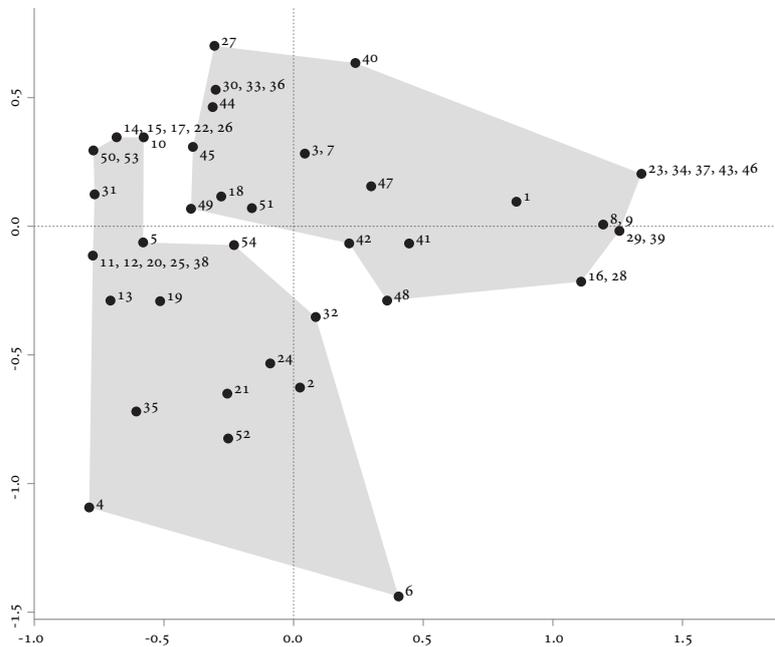


Fig. 191: Interactive (south-west quadrant) and non-interactive (north-east quadrant) systems.

The same happens when we circumscribe systems whose outputs are computer-based and those that are not. This is not simply a split between class 4 systems and class 1 and 2 systems, rather it can be seen as a separation between systems that produce outputs that are real-time computations from those that do not.

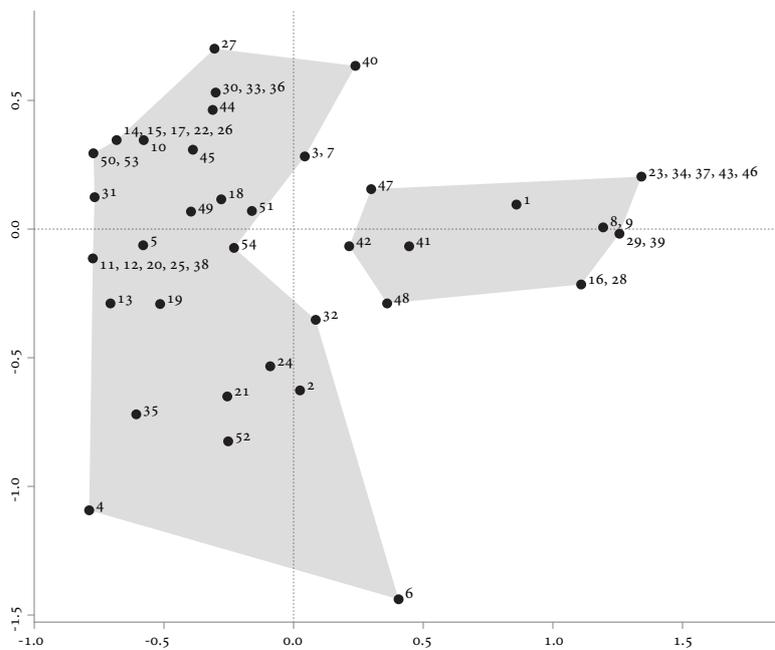


Fig. 192: Computer-based (west) and non computer-based (east) systems.

The plot does not allow us to infer much about an eventual genre partitioning of the systems, and we wonder whether this can be seen as a shortcoming of the model or if, on the other hand, genres are simply too undefined, broad or blurred in computational media to be able to recognize encompassing genre definitions that can be applied to multiple pieces. If we look at the groups of pieces plotted in the same dot, we find that even when trying to fit traditional genre descriptions such as sculpture, painting or drawing, the boundaries are not clear. We can for example find two of the most rapidly identifiable sculptural works, *Cylinder* [16] and *A Week in the Life* [39], plotted near each other but in different coordinates nevertheless, and sharing their respective positions with two visual-only outputs that could be classified as drawing, illustration or graphic arts. We do find that all linear videos are plotted in neighboring positions, but still not ever sharing the same exact coordinates, something that is far more common among the printed or plotted outputs. It is also interesting to discover that two of the pieces where a certain directionality (and irreversibility) of time is patent — *Agrippa* [3] and *Every Icon* [7] — share the same coordinates and are therefore plotted in the same location, although at first sight they may seem to be different systems, working in somewhat different media and belonging to different genres or artistic typologies.

### 3.6.3 Control Analysis

We have tried to devise this analytical model in such a way that it would allow objective classifications, reducing the subjectivity of the classifier to the minimum possible. It is however almost impossible to be certain that no subjective factors have influenced our classification of the selected systems. On the other hand, a clear definition of the variables is determinant for the success of the model and the reduction of subjectivity. Trying to test both our analysis as the definitions that were elaborated for each of the variables, we have decided to elaborate a second analysis, providing documentation of all the systems as well as a description of the model to an external analyzer, in order to assess whether (and to what extent) her classification would match ours. We approached a colleague, lecturer in communication design at the School of Fine Arts of the University of Lisbon, holding a masters degree in multimedia art and, at the time, developing a doctoral thesis on audiovisual interactive media. The sharing of a common repertoire of references was naturally an influential aspect in the selection but this did not mean that the understanding of the variables was immediate and without any problems.

Determinability, transiency, access, user functions, linking and autonomy were clearly and swiftly understood, and the analysis (that was developed independently and without prior knowledge of our classifications) of these variables was fast and largely uneventful. Dynamics, modes and class proved to be more difficult, albeit each for different reasons. The goal of the dynamics and modes variables was clarified after some examples were discussed, still some systems raised doubts that, upon further discussion were solved. When classifying modes there was at first a tendency to classify all systems with which the user could interact as being haptic, something that was gradually revised, and also to classify a vast majority of the systems as displaying the procedural mode. We believe that the knowledge that an output was produced by a procedural system in many cases influenced this classification. A procedural system does not necessarily create outputs that communicate or give clues of that procedurality. Although in some cases this may happen, it is also true that often an output without the proper contextualization is not able to express the least of its procedural origin. As we will see, the modes variable was the one where a greater divergence from our analysis was found. Finally, when addressing the class variable, there were (as expected) a few doubts as whether to classify systems as class 2 or 4<sup>645</sup> but, more importantly, some difficulty in differentiating the systems from the outputs they produce (and that are, in some cases, the analyzed artifacts). As with the procedural mode, the differences between the system and its outputs, between the capacity that one may have to develop a class 4 computational process and the other to develop merely a class 1 or 2 were in the basis of these doubts. After further discussion, all the pending doubts were cleared and the analysis finished.

**Table 11: Control analysis of the 54 works.**

	Dyn.	Det.	Trans.	Access	Linking	U.F.	Modes	Aut.	Class
1. <i>Cent mille milliards de poèmes</i>	Static	Det.	Int.	Random	None	CF	3	Aut.	1
2. <i>Cent mille milliards de... (web)</i>	Static	Ind.	Int.	Cont.	Cond.	CF	2	Aut.	1
3. <i>Agrippa</i>	SUD	Det.	Trans.	Cont.	None	IF	3	Aut.	1
4. <i>A-Volve</i>	DUD	Ind.	Trans.	Cont.	Cond.	CF	5	DD	4
5. <i>Evolved Virtual Creatures</i>	DUD	Ind.	Trans.	Cont.	None	IF	3	Aut.	4
6. <i>My Boyfriend Came Back...</i>	Static	Det.	Int.	Cont.	Cond.	EF	2	DD	2
7. <i>Every Icon</i>	SUD	Det.	Trans.	Cont.	None	IF	3	Aut.	2

<sup>645</sup> As Rucker noted, class 2 systems are invariantly periodic, while quasiperiodic systems already cross the class boundary and are already classifiable as being class 4.

	Dyn.	Det.	Trans.	Access	Linking	U.F.	Modes	Aut.	Class
8. <i>Sketch</i>	Static	Det.	Int.	Random	None	IF	2	Aut.	1
9. <i>Seven Sisters: The Pleiades</i>	Static	Det.	Int.	Random	None	IF	2	Aut.	1
10. <i>Text Rain</i>	SUD	Ind.	Trans.	Cont.	None	CF	4	DD	4
11. <i>Yellowtail</i>	DUD	Ind.	Trans.	Cont.	None	CF	4	DD	4
12. <i>Soda Constructor</i>	DUD	Ind.	Trans.	Cont.	Explicit	CF	4	DD	4
13. <i>Amoebaabstract 01</i>	DUD	Ind.	Trans.	Cont.	Cond.	CF	4	DD	4
14. <i>Amoebaabstract 02</i>	SUD	Ind.	Trans.	Cont.	Explicit	CF	3	Aut.	4
15. <i>Amoebaabstract 03</i>	SUD	Ind.	Trans.	Cont.	Explicit	CF	3	Aut.	4
16. <i>Cylinder</i>	Static	Det.	Int.	Random	None	IF	2	DD	1
17. <i>Substrate</i>	SUD	Ind.	Trans.	Cont.	Explicit	CF	3	Aut.	4
18. <i>Black &amp; White</i>	SUD	Ind.	Trans.	Cont.	None	IF	3	DD	4
19. <i>For All Seasons</i>	SUD	Ind.	Trans.	Cont.	Explicit	CF	4	DD	4
20. <i>Droom Zaacht</i>	DUD	Ind.	Trans.	Cont.	Explicit	CF	4	DD	4
21. <i>Page 0</i>	SUD	Ind.	Int.	Cont.	Explicit	EF	2	DD	4
22. <i>Happy Place</i>	SUD	Ind.	Trans.	Cont.	Explicit	CF	3	Aut.	4
23. <i>Emeral</i>	Static	Det.	Int.	Random	None	IF	2	Aut.	1
24. <i>Three Buttons</i>	DUD	Det.	Trans.	Cont.	None	CF	2	DD	2
25. <i>Dreamlines</i>	DUD	Ind.	Trans.	Cont.	Explicit	CF	3	DD	4
26. <i>Ornamism</i>	SUD	Ind.	Trans.	Cont.	Explicit	CF	3	Aut.	4
27. <i>30×1</i>	SUD	Ind.	Trans.	Cont.	None	IF	4	Aut.	4
28. <i>Extrusions in C Major</i>	Static	Det.	Int.	Random	None	IF	2	DD	1
29. <i>Poetry on the Road</i>	Static	Det.	Int.	Random	None	IF	2	DD	1
30. <i>Process 16</i>	SUD	Ind.	Trans.	Cont.	None	IF	3	Aut.	4
31. <i>We Feel Fine</i>	SUD	Ind.	Trans.	Cont.	Explicit	CF	4	DD	4
32. <i>Moving Pixel Portraits</i>	Static	Det.	Int.	Cont.	Explicit	CF	4	DD	2
33. <i>Process 18</i>	SUD	Ind.	Trans.	Cont.	None	IF	3	Aut.	4
34. <i>Der Wirklichkeitsschaum</i>	Static	Det.	Int.	Random	None	IF	1	Aut.	4
35. <i>Reface [Portrait Sequencer]</i>	DUD	Ind.	Trans.	Cont.	Cond.	CF	4	DD	4
36. <i>Pixflow #2</i>	SUD	Ind.	Trans.	Cont.	None	IF	3	Aut.	4
37. <i>Folia</i>	Static	Det.	Int.	Random	None	IF	2	Aut.	1
38. <i>Inner Forests</i>	DUD	Ind.	Trans.	Cont.	Explicit	CF	4	DD	4
39. <i>A Week in the Life</i>	Static	Det.	Int.	Random	None	IF	2	DD	1
40. <i>Connect</i>	Static	Ind.	Trans.	Random	None	IF	3	Aut.	4
41. <i>A Confidence of Vertices</i>	Static	Det.	Trans.	Cont.	None	IF	3	Aut.	2
42. <i>Enerugii</i>	Static	Det.	Trans.	Cont.	None	IF	4	DD	2

	<b>Dyn.</b>	<b>Det.</b>	<b>Trans.</b>	<b>Access</b>	<b>Linking</b>	<b>U.F.</b>	<b>Modes</b>	<b>Aut.</b>	<b>Class</b>
43. <i>Print cover</i>	Static	Det.	Int.	Random	None	IF	2	Aut.	1
44. <i>Nokia Friends</i>	DUD	Ind.	Trans.	Cont.	None	IF	3	Aut.	4
45. <i>Forever</i>	SUD	Ind.	Trans.	Cont.	None	IF	4	DD	4
46. <i>Colors of Nature</i>	Static	Det.	Int.	Random	None	IF	1	Aut.	1
47. <i>Animations for Aol.</i>	Static	Det.	Trans.	Cont.	None	IF	2	Aut.	2
48. <i>Merce's Isosurface</i>	Static	Det.	Trans.	Cont.	None	IF	2	DD	2
49. <i>Perpetual Storytelling...</i>	DUD	Ind.	Trans.	Cont.	None	IF	3	DD	4
50. <i>phiLia 01</i>	DUD	Ind.	Trans.	Cont.	Explicit	CF	4	DD	4
51. <i>Talysis II</i>	DUD	Ind.	Trans.	Cont.	None	IF	3	Aut.	4
52. <i>temporary.cc</i>	DUD	Ind.	Trans.	Cont.	Cond.	CF	2	DD	4
53. <i>Vanitas</i>	SUD	Ind.	Trans.	Cont.	Explicit	CF	5	DD	4
54. <i>The Inability to Solve a War...</i>	SUD	Det.	Trans.	Cont.	Cond.	CF	4	DD	2

The test analysis revealed a divergency of the classification in 7.4% of the total number of variables analyzed: 36 differing classifications in a total of 486. It is however important to understand which variables presented the higher and lower divergencies between classifications.

**Table 12: Divergencies between our analysis and the control analysis (total and percentage).**

<b>Variable</b>	<b>Total Divergencies</b>	<b>Percentage</b>
Dynamics	3	5.55%
Determinability	0	0%
Transiency	0	0%
Access	0	0%
User Functions	1	1.85%
Linking	2	3.7%
Modes	23	42.59%
Autonomy	0	0%
Class	7	12.96%

We therefore find that the biggest culprit for the divergency in classification was, by far, the modes variable, followed (with less than a third of the occurrences) by the class variable. The very high divergency in the modes classification is not, as it may seem at first sight, a sign of arbitrariness in the classification but rather, we believe,

a reflection of differences in the understanding of the nature of the procedural and haptic modes and on their positive identification in much more instances than those that were accounted for in our analysis. It is certain that this is perhaps the most subjective of all the variables, especially when it comes to the evaluation of the procedural mode. And in fact, when comparing both analyses of the modes variable, one finds that in almost all divergent cases, the difference in classification is explained by having classified (or not) the procedural (in eight cases) or haptic (in twelve cases) modes for a given system and that only in three of the divergencies the control analysis identified a lower number of modes than our initial analysis did. We could therefore alternatively interpret this divergency as being much smaller, around 5.55% (if accounting the three divergencies) should we decide not to consider the disagreeing understanding of the modalities (or, what we could eventually call ‘false negatives’ of our analysis or ‘false positives’ of the control analysis).<sup>646</sup> The haptic mode was identified in several pieces with which the user interacts with gestures, not only on those where the interaction devices are not standard computer input devices, but also those systems where these devices are used in more expressive manners. With class, we found that most of the divergencies were linked with the identification of systems that we had classified as class 2 as being class 4.<sup>647</sup> Only in six of the systems we found a divergency in the classification of two of the variables.<sup>648</sup>

The summary of the multiple correspondence analysis was the following, again, close to the results of our analysis:

**Table 13: Multiple correspondence analysis of the control analysis.**

Number	Eigenvalue	Inertia	Cumulated
1	0.336384	53.0	53.0
2	0.067925	10.7	63.7
3	0.028829	4.5	68.2
4	0.021316	3.4	71.6

<sup>646</sup> In such case the total number of divergencies would also be much lower: 16 or 3.29%.

<sup>647</sup> Both classes bordering with each other so subtly as they do, this would almost be an expectable outcome of the comparison of multiple analysis.

<sup>648</sup> The web version of *Cent mille milliards de poèmes*, *Yellowtail*, *Amoebaabstract 01*, *For All Seasons*, *Reface [Portrait Sequencer]* and *The Inability to Solve a War at a Cocktail Party (an Awkward Dance with Mr. Henri Van Zanten)*. In 24 other systems we registered differences in the classification of a single variable, in a large majority of the cases, modes.



## CONCLUSION

### Summary

This work proposed the development of an analytical model for a diverse and heterogeneous set of aesthetic artifacts, an array of objects that for the lack of a better term could be described as sharing procedural characteristics. As computational tools and media become more ubiquitous in the cultural landscape, we discover a growing number of artworks and communication systems that are not only digital but also computational. A survey of several fields of art and design creation allows us to understand that the production of computational aesthetic artifacts is very widespread and that in spite of contextual variations inherent to each field, and regardless of each artifact's function, subject, background or setting of production, there are several points of contact and similarities between artifacts, and furthermore, that most of these spring from their procedural or computational nature. Computational media are not only excellent remediators — something that contributes to a quantitative transformation — as they are also programmable and potentially autonomous from their creators and users — a trait that contributes to a profound qualitative transformation.

These media are also relatively recent and, although artists and designers have been exploring them for some decades now, they are still simultaneously discovering, learning and defining these media, in a process balanced by the dialectics between the pre-computational media — that for the most part shape our historic experience, our knowledge, skills, training and lexicon — and the new forms — that inherit

from their forerunners but also transform them almost beyond recognition. We live in a period of computational incunabula and in order to study, understand and further develop them to the fullest, we need to unravel their specificities, not only technical as also aesthetic and communicational. We need to grasp their creative potential and their uniqueness.<sup>649</sup> We need a framework for their critique and we need an established and rigorous common terminology for their analysis. And we need it to be versatile, plastic and adaptable enough to accompany the ongoing transformation of the media, something we believe not to be a transitory phenomenon.

We resorted to Espen Aarseth's model for the analysis of cybertexts (1997) — texts that involve procedurality in their production — as a starting point for this work. With seven variables and eighteen possible values, this model is not only broad and able to provide accurate classifications of the texts analyzed by its author, as it has a series of other advantages that led us to choose it: 1) it is not focused on the surface characteristics of the texts as it is on their structural, functional or procedural traits; 2) it is broad enough to encompass different media and expressions;<sup>650</sup> 3) its emphasis is on common features found across most of the texts and not on specific aspects particular to some of these; 4) it recognizes the interactive capacity of the media without establishing its precedence over other characteristics<sup>651</sup> and; 5) it is workable, with only two to four possible values for each variable, defining a large space of 576 unique positions<sup>652</sup> that is nevertheless easy to navigate.

We tried to assert the model's adequacy and to adapt and expand it in search of a better and more comprehensive description of the works under consideration. While Aarseth's model is focused in the analysis and description of ergodic texts, we wanted to make it fit for the study of ergodic visual and audiovisual pieces, therefore we tested its seven variables for suitability, adapting them whenever necessary. Ultimately we managed to use all but one variable in the new model. *Dynamics*, *determinability*, *transiency*, *access*, *linking* and *user functions* proved to describe relevant aspects of the pieces — repurposing possible values only in dynamics and user functions — while *perspective* was, at least for the time being, demonstrably

<sup>649</sup> A uniqueness that, owing to their remediative potential is not necessarily easy to fathom.

<sup>650</sup> Aarseth uses it in the analysis of texts from the fourth century BCE to the twentieth century CE, texts in traditional paper media and texts in electronic media, etc.

<sup>651</sup> Something that happens in other models that seem to be grounded in the interactive potential of the media and not in their procedural nature.

<sup>652</sup>  $3 \times 2 \times 2 \times 2 \times 2 \times 3 \times 4 = 576$ .

not contributing to our model. We also pondered over potential new variables, in an attempt to expand and ameliorate the model, deciding for the inclusion of three new variables: *modes*, *autonomy* and *class*, thus bringing the total number of variables in the model to nine.<sup>653</sup>

We developed our analysis from a set of samples that represented diverse approaches to procedural creation, but focusing particularly on visual aesthetic creation and communication. We compiled a series of pieces drawn from the examples presented or discussed in the literature review chapters of this work, but we were aware that a personal selection of pieces could always be biased towards the model under development, and tried to avoid this by requesting an external selection of works to analyze. We therefore approached three artists that also happen to have experience in teaching, critique or curation of media and computer arts. After being briefly informed about the objectives of the work, but without a full disclosure of the model, the methods or even of which works were previously selected, Lia, Marius Watz and Golan Levin contributed with a total of 36 works that were added to our original list for a total of 54 different pieces.

Whenever possible the works were analyzed based on direct access and experimentation. When this was not possible — something that happened in 11 cases — we had to resort to the available documentation, either provided by the authors or by secondary sources. We developed a phenomenological analysis of the works, based on those aspects that could be inferred by readers from their usage, or from whatever information was communicated with and through the artifacts themselves — either willingly, through titles, instructions or any other information explicitly conveyed in the pieces or subtextually. We are aware that the audiences of these works are diverse in terms of procedural literacy and that a procedural understanding of these pieces is not necessarily a technical understanding, not necessarily a comprehension of the actual code of the pieces, but rather an understanding of the principles of action that are enunciated in the code.

The process of analysis of the 54 pieces was developed with the variables of Aarseth's model added by our tentative variables, and was used to test the individual contribution of each of them to the model. Still following Aarseth's methodology — and as

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**653** And the total of possible values to 24, expanding the multidimensional space of the model to 4,320 unique positions ( $3 \times 2 \times 2 \times 2 \times 3 \times 2 \times 5 \times 2 \times 3$ ), from the 576 in Aarseth's model.

a way to be able to compare our findings with his — we developed a multiple correspondence analysis of the data<sup>654</sup> and plotted it using two synthetic axes — a number that we deemed acceptable based on the results of the multiple correspondence analysis, encoding 62.7% of the data's variance.

Although the goal was the development of the model so as to allow an objective classification, reducing the classifier's subjective inferences to the minimum possible, we could not be certain of having achieved this without subjecting our analysis (and the model) to a control analysis. Only when laying pieces and model in the hands of a third-party and witnessing the handling of the tool, could we be certain of its usability and usefulness. We have therefore provided an external analyzer with the documentation of the pieces and a description of the model to assess whether (and to what extent) her classification would match ours. Some discrepancies were found between our analysis and this control analysis but in general the divergency was relatively low: 7.4% of the total variables analyzed, with 36 differing results in a total of 486. As important as corroborating our analysis, and attesting the accessibility of the definition of the variables, through a study of the divergencies this control analysis also allowed us to understand which variables need to be adjusted — or better described — in the future.

As a result of this work we have tested the partial adequacy of Aarseth's model for the study of other artifacts beyond text-based systems, and expanded it to better suit the objects of our study. We believe that the model we elaborated produces a good description of the pieces, clustering them logically, reflecting stylistic and procedural affinities between systems that, if analyzed under a different light, would probably not be immediately found to be similar. These similitudes are not superficial or sensorial, they are rather structural or procedural, attesting the importance of the computational characteristics for the aesthetic enjoyment of the pieces. We verified our initial conjecture about the importance of procedurality not only for the implementation and development of the works but also as conceptual grounding and aesthetic focus in artistic creation, as an aesthetic pleasure comparable to others that were already identified in computational media.<sup>655</sup> Through the development of this model we understood that, in a field of work promoted by practitioners hailing from so many and so diverse backgrounds — visual arts, design, engineering, sci-

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<sup>654</sup> Using the R software and the CA package.

<sup>655</sup> Such as e.g. agency, navigation and transformation, identified by Murray (1997).

ences, architecture, industrial design, music and performance arts, etc. — there are grounds for the establishment of a common terminology to which all contributors, from creators to users, academics and critics, can resort.

### **Interpretation of Findings**

We cannot understand any phenomenon or set of phenomena if we are not able to formulate their description. With this work we proposed to contribute to that task by attempting to develop a schema of the systems based on their procedural characteristics rather than on their aesthetic traits, not only because these aesthetic traits have been thoroughly studied in several of the fields of work where these systems are used, but also because we believe that the procedural characteristics are themselves a fundamental part of the aesthetic appeal of these works, although they can be studied independently from the traits that traditionally fall under the definition of the term.

We alternatively defined these pieces as ‘computational aesthetic artifacts’ or as ‘procedural computational artifacts’, deviating from the more common definition of ‘generative artworks’ and the definition proposed by Aarseth (1997) of ‘ergodic’ media or artworks. Many of the artifacts that we studied can accurately be described as ‘generative’, as defined by Galanter (2003), but we believe that this term is better suited to a subset of the works, as are such terms as ‘evolutionary’, ‘chaotic’, ‘fractal’, ‘stochastic’, etc. Among these, the ‘evolutionary’ and ‘generative’ epithets are those that describe what we believe to be the most interesting and important aspects of these pieces in terms of their implementation and development, they are also those that better describe where the future development of these systems will most likely be focused, and what we consider to be the best strategies to get the most out of them. They are not, however, the lowest level description that we could use. Should we be describing life and biology, we could likewise use terms as evolution, emergence and generative potential to describe the creation of life and the diversity that is found in the natural world, but we would need to resort to terms as ‘procedural’ or ‘computational’ to be able to explain the mechanisms that allow creation and evolution to take place in the first hand.

The same can almost be said of defining them as ‘ergodic’, a term that depicts a set of interpretative or communicational interactions that may not always be present

(at least as Aarseth defined them).<sup>656</sup> And naturally, defining them as ‘artificial’ art, design or aesthetic artifacts could also be adequate, wouldn’t it be for the excessively broad scope of this definition, that encompasses both procedural as non-procedural systems.

One may defend the existence of a difference between computational and procedural systems, based on the fact that although both depend on the definition of rules, algorithms or effective procedures and on the creation based on these, computational aesthetic artifacts will develop these procedures in real-time and in their outputs, unlike what happens with procedural aesthetic artifacts. If in procedural aesthetic artifacts the process may be represented but not be present — that is, if the process can be found only in the past of the artifact — in computational aesthetic artifacts the process *must* be present — i.e. found in the present of the artifact. During this work we often used both terms interchangeably, not eschewing the semantic distinction but recognizing a broader equivalence between both systems and their coexistence in contemporary media, artistic practices and design. Either is an adequate definition to many of the works we discussed, although ‘procedural’ may naturally be of a broader use, especially if one considers historical examples. Currently, and in any case, most procedural systems are computational, because media have been progressing towards a total digitalization, and this digitalization is of course dependent on computational systems.<sup>657</sup> Therefore we can find a peculiar case of entanglement between the computational and the procedural natures of these systems. They are not quite the same thing but, more often than not, they may be difficult to differentiate. The pairing of ‘procedural’ with ‘aesthetic’ is also very interesting because it summarizes the dialectic nature of these systems: due to their computational nature, they are artifacts in motion and they stand in the balance between how they produce their outputs and how they communicate them. They hang in the dynamic tension between processes, between algorithms and aesthetics, and therefore they need to be approached non-conventionally in their creation and study.

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**656** “(...) we may define an ergodic text as one in which at least one of the four user functions, in addition to the obligatory interpretative function, is present. Not incidentally, this figure might also be seen as a depiction of a cybernetic feedback loop between the text and the user, with information flowing from text to user (through the interpretative function) and back again (through one or more of the other functions).” (Aarseth 1997, 65)

**657** But as we have seen, even if the outputs are digital and the processes are developed in computers, they are not necessarily ‘computational’ according to this definition.

Although we developed a phenomenological analysis of the pieces we examined — and although in most cases, as mentioned, this is all one is able to do — as practitioners it is not enough to confront the systems, when one rather needs to create them. Hence the extreme importance of procedural literacy. Artists and designers do much more than to create the superficial aesthetic layers, or the surface structures of these systems, they create processes and it is then up to these processes, in their turn, to create the surface structures. Even when and if artists and designers work in collaboration with engineers, scientists or technicians, they will need to speak the procedural language, a language that is not only made of code but also of the manifestations of the code, of what the code becomes. An adequate terminology is therefore an integral part of the description of procedural aesthetic artifacts.

Arts and sciences have been crossing paths regularly (if not permanently) for as long as we have historical records, perhaps even longer. We did not delve much into the details of these relations during this work, partially because we believe that art and science are themselves articulated in a dialectic relation, that they are two aspects of human activity and two expressions of our need for self-expression, knowledge of the world and hope of (some limited) control over an uncontrollable universe. Depending as they do on what is still regarded as high-tech apparatus, and on the knowledge of computation and “the arcane art of computer programming” (Maeda 2004, 113), computational approaches to art and design are very often regarded as being ‘scientific’. This can either be in the mistaken sense that these are two absolutely independent aspects of human life and experience, that cannot but mutually influence each other at times or, what may be worst, it can be something born of demeaning and paternalist feelings from those who see computational arts as being unhuman and consequently lesser than human-produced arts, or that alternatively fear that they may turn human artists or human-produced arts obsolete. One of the reasons why we believe that computational approaches to so many arts are becoming common, is because of the way in which, in spite of being artificial — like all arts except perhaps those that are exclusively somatic — and in spite of being produced by means that may seem to many to be closer to magic or alchemy than to science and *techné*, they produce artifacts that are very human. These are artifacts that speak to us in ways that noncomputational artworks are not — and will never be — able to, while being able to, due to their capabilities for remediation, communicate at all (or most of) the levels that noncomputational works do, to be as grand, dramatic, deep and moving as any other artworks. Granted that in many cases, and

due to the Eliza effect, this may be so much of our doing as the merit of the artifacts, but there are nevertheless grounds for evolution and amelioration. As noted, we are just starting to discover what can be done with these systems, how can it be done and, more importantly, why it should be done.

We are also able to start to draw some inferences regarding the effects of the development of procedural aesthetic artifacts and of the metacreation allowed by these, for all the parties that contribute to their creation, usage and acceptance. Artists will need to learn how to deal with the dissolution of authorship that is brought by these systems and will most certainly discover new and unforeseen ways to take advantage of the possibility to create unique multiples, endless variation, massive customization and personalization of artifacts, and of the participative and collaborative potential of these media. They will also be able to create works of a far higher complexity and far broader reach (spatial as well as temporal), but will need to understand processes as artworks, not just the form, not just the conceptual layers or the narratives, as also the effective procedures and their development.

Designers will discover that, when working with these media and tools, the focus of their work will no longer be just the surface level of the artifacts (if it ever was), but that they will need to be involved to a much lower level in the production or authorship of the artifacts. They will not only produce forms as they will need to always produce systems, they will need to become programmers while (and because) they are designers. As so many of the things that are touched by computational systems, the work of designers is transforming. This happens to all designers, regardless of their specialities, and even those working in fields that are still (somewhat) less touched by computational media and tools may be certain of having to face the transformations in a not too distant future. It is not hard to foresee a future when not only what we traditionally call media are endowed with computational abilities but when most objects, regardless of their purpose or role in our lives, are also computational, not only in their inception but also in their formalization. This is a future where computers will really be ubiquitous but will simultaneously be invisible, because they will not sit on desks or be carried around in suitcases and backpacks but will be, very literally, everywhere. In this future, as now, the designer's work will be less of a finishing or formal work but it will rather be an epigenetic work, a work that needs to be developed from deep within the structure of the artifacts, creating their forms, their functions, and their behaviors.

Audiences, as they grow more familiar and intimate with computational media, will no longer expect or be expected to be merely passive, they will become more participative as they are confronted with artworks and designs that are ergodic. Participation is physical, because so many of these works demand interaction, and is also (one could even say mainly) intellectual and emotional, because even the less demanding explorative systems are ergodic and challenging in their traversal. We do not expect interaction to be the preeminent feature of all these systems, if there is something that our personal experience, the literature, the history of art and (to a degree) this study show is that the role of the non-intervening spectator is at many levels very rewarding.

Critics, academics and historians need to learn how to study these works — and we hope that this study provides some help — how to frame them in the broader artistic context, how to document and preserve them.<sup>658</sup> They need to rethink the definition of the work, again, not as an object, a set of objects or concepts but also as a dynamic system and the outputs it produces. And they will need to, as all other actors, be ready to discover artifacts that challenge their expectations and imaginations. As Murray puts it, “one hundred years after the arrival of the motion picture camera, we have the arrival of the modern computer (...) Can we imagine the future of electronic narrative any more easily than Gutenberg’s contemporaries could have imagined *War and Peace* or than the Parisian novelty seekers of 1895 could have imagined *High Noon*?” (1997, 66)

If in Aarseth’s analysis we find that electronic and paper-based texts are largely overlapping and therefore that the medium is not as determinant to the ergodic nature of texts as one would suppose, in our analysis we do not reach the same conclusions. We believe that happens because, unlike in *Cybertext*, there are two large sets of data being analyzed in this work: the procedural, where the system and its output are different artifacts, where when examining outputs one can only recognize traces of the system, and on the other hand, those that are truly computational from source to output, where system and output are the same process and artifact.

One of the things we have learned from the history of the media in the twentieth-century is that media are not static and immutable. Although they are created to

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<sup>658</sup> When sometimes the works themselves contradict or even forbid efforts for preservation, as we have often seen along this work.

make information static and immutable, they are themselves dynamic evolving systems, affected by the usage that is made of them (by creators, communicators and audiences or readers), by market pressures, by social and technological changes, among many other factors. As we have seen, the current transformation can in a sense be traced back to the ongoing metamorphosis of media, but it also results in a profound qualitative change of the media. Computational media do not only deliver more, faster or better (whatever these terms may actually mean in any given context) than previous media, but they deliver something entirely different. As the transformation continues, when sometime in the future we are faced with works that were not at least partially produced by humans, will we be able to recognize, value and cherish artificial creation? We so often regard arts as a pinnacle of human achievement, as something that defines what *being human* is, so what will we do when faced with artificial arts? Boden argues about this problem in her answer to the fourth Lovelace question: “whether computers can *really* be creative — is [a] very different [question]. It involves controversial debate about metaphysics and morals. (...) It raises the problem, for instance, of whether, having admitted that we were faced with computers satisfying all the scientific criteria for creative intelligence (whatever those may be), we would *in addition* choose to take a certain moral/political decision. This decision amounts to dignifying the computer: allowing it a moral and intellectual respect comparable with the respect we feel for fellow human beings.” (2004, 21)

### Limitations

An evaluation of the limitations of this work may start with the data available for analysis. We studied 54 works but could maybe have compiled a longer list of pieces. We did not do it for practical considerations, as increasing the list of works would necessarily make our own and the control analysis more time-consuming. Compared with Aarseth’s analysis, we considerably increased the number of works analyzed — more than doubling it from 23 to 54 — we nevertheless recognize that a broader set would allow to sample an increased diversity of works. Nevertheless we find that the number of works contemplated in the study and the results of the analysis are satisfying, even if eventually not conclusive. We intentionally limited our analysis to works that could be classified either as visual arts or as communication design, preserving a few pieces that were also analyzed by Aarseth and that can be classified as literary. We recognize that a broader field of analysis would be desir-

able, incorporating works from other fields of design or art. Although this was not done in the present work, the common characteristics among the works that were analyzed lead us to believe that such a work should be developed in future follow-up studies.

Further control analyses could have allowed us to better detect possible flaws in the definition of the variables and to better attune their descriptions. The one control analysis we developed was extremely useful for our own understanding of the difficulties presented in the model and a very valuable contribution to this work. We hope that subsequent work allows the development of successive, and gradually more precise validations of the model we propose, extending the scope of the study to larger sets of works and necessarily producing more analyses.

### **Future Research**

By defining an analytical model for computational aesthetic artifacts that is both independent from media and not-modal, we contributed towards the study of computational arts and media. Helping to establish a common terminology for computational arts and artifacts was one of our goals and we believe to have succeeded to contribute to this purpose. There is however plenty more research work waiting to be developed in the future. First of all in refining the model: as a consequence of both our own as well as of the control analyses, we understood that both the procedural and haptic modes need to be the subject of deeper study. Both need better definitions in order to eliminate as much subjectivity as possible from the classification and their exhaustive study can contribute to a better understanding by artists and designers.

The research of ways to describe systems through and beyond their outputs (when the system itself is not available anymore) is another interesting subject for future research. The prochronism variable seemed promising in this aspect, but as we saw it did not contribute much to the model and therefore was not included in its final version. The study of temporal scales in the objects, or of other characteristics that can be read in scales, can maybe give us some clues towards this, as well as an investigation into coherence and unity in the outputs of the systems. Cross-studying the works of Thompson (1942), Flake (1998), Alexander (2002a-b; 2004; 2005) and other authors that strive to understand the generative properties of natural forms can be

a starting point for this work, understanding form as a chronological phenomenon and trying to reverse the prochronist manifestations in order to comprehend the different processes that originate it. Another would be an enquiry as to whether all the positions in the multidimensional space of the model are equally valid, possible, or probable. Such a study would be very interesting follow-up research, but it would naturally need to be developed from much larger datasets that we could be able to explore statistically.

This work may also be expanded by studying not only the works but also their users and creators. The observation of the interactions between users and systems may provide valuable information to enrich this model, particularly at the level of the perception of procedurality and of the ergodic traversal of the systems. The observation and study of the users' engagement with the works may also contribute to a better understanding of the haptic modality, of when a user feels that she is interacting with the work in a physical way, not when she feels that she is acting over a computer and through this, acting on the work.

A more thorough study of the authors' motivations and of their working methods and processes may also be an interesting sequence of this work. Some of the authors' concerns are present in this work through various texts and artist statements, but a more comprehensive study, comprising interviews and surveys can also be realized, and may result in very useful insights, namely on how authorship is transformed by computational media.

Although computational media and its practitioners tend to blend borders and fields of activity or specialization, this does not by any means mean that those fields must lose their specificity, or their history and tradition, sometimes established over centuries of practice. Individual clusters of activity can and should be independently studied, regarding the effects of computational aesthetics and the transformations there operated by them.

Furthermore, characteristics related to the narrative aspects of these systems were not considered in this study. Not all systems are narrative in a classic sense of the term, maybe a large majority of the systems are not, however many are and we can consider that many of those that are not still contain some narrative properties. All computational systems are actions and processes and these always constitute some

sort of narrative. A complete study of procedural media needs to include their narrative properties without losing sight of the remaining procedural aspects. As the study of computer games — that are, of course procedural systems — is split between research in ludology and research in narratology, studying action and gaming (or rule-based systems) and narrative aspects (or story-based systems), we can imagine a similar partition in the study of all procedural aesthetic artifacts. But we can also long for a dialectic model that can be used in the study of narrative procedural systems, one where we can perhaps manage to reincorporate *perspective* as it was originally defined by Aarseth. Recognizing that in this context narrative art forms are complex, and that at present their study should be complementary to that of the procedurality of the systems, we have intentionally left narrative out of this study. We incorporated some clearly narrative pieces in the analysis, but their inclusion was motivated by form, structure and behavior, not by their narrative aspects. In the future we hope to test and further develop the model with narrative systems, including games, as well as other forms, studying narrative as a phenomenon that emerges from procedurality, particularly from the procedural modality and from the human desire to witness the unfolding of processes.

Computational media are not only already indispensable to our society, as their importance and ubiquity are growing by the day, as if they too were subjected to Moore's law. They allow the development of unprecedented aesthetic artifacts but in order to use and develop them to their fullest potential, we need a deeper understanding of how they can be used, and of why and to what extent they should be used. We need an improved knowledge of their strengths and weaknesses, of how similar they can be to those media with which we are accustomed — with which we have grown and which they eventually will replace — but especially of how profoundly different they are from them, how alien they may be if we try to understand them under the same schema.

We will perhaps never again have another period of several centuries over which to develop a medium, as we had with books, maybe not even decades, but what we have been discovering with computational media is that not only they are able of remediation — and therefore of preserving and reusing what we deem positive or useful from previous media — but also that in spite of the continuous transformation, several common traits between different media are preserved through the vortex of the metamorphosis. A theory of computational media may therefore dispense with

traditional rules or canons, or should only regard them as being as transitory as any particular medium is, and can be based on the juggling of history and the unknown ahead, knowing fully well that every new work that is created, every new system that is designed, are incursions towards the unknown and steps forward in the construction of new media.

## BIBLIOGRAPHY

- Aarseth, Espen J.** "Nonlinearity and Literary Theory." *Hyper / Text / Theory*. Ed. George P. Landow. Baltimore, Maryland: The Johns Hopkins University Press, 1994. 51-86.
- . *Cybertext: Perspectives on Ergodic Literature*. Baltimore, Maryland: The Johns Hopkins University Press, 1997.
- . "We All Want to Change the World: The Ideology of Innovation in Digital Media." *Digital Media Revisited: Theoretical and Conceptual Innovation in Digital Domains*. Eds. Gunnar Liestøl, Andrew Morrison and Terje Rasmussen. Cambridge, Massachusetts: The MIT Press, 2003. 415-439.
- Albert, Saul.** "Artware." *Proud to Be Flesh: A Mute Magazine Anthology of Cultural Politics After the Net*. 1999. Eds. Josephine Berry Slater and Pauline van Mourik Broekman. London: Mute Publishing, 2009. 89-92.
- Aldersey-Williams, Hugh.** "Applied Curiosity." *Design and the Elastic Mind*. Ed. Paola Antonelli. New York: The Museum of Modern Art, 2008. 46-57.
- Alexander, Christopher.** *Notes on The Synthesis of Form*. Cambridge, Massachusetts: Harvard University Press, 1964. 1971.
- . *The Timeless Way of Building*. New York: Oxford University Press, 1979.
- . *The Nature of Order: An Essay on the Art of Building and the Nature of the Universe. Book One: The Phenomenon of Life*. 1980. Berkeley, California: The Center for Environmental Structure, 2002a.
- . *The Nature of Order: An Essay on the Art of Building and the Nature of the Universe. Book Two: The Process of Creating Life*. 1980. Berkeley, California: The Center for Environmental Structure, 2002b.
- . *The Nature of Order: An Essay on the Art of Building and the Nature of the Universe. Book Four: The Luminous Ground*. 1980. Berkeley, California: The Center for Environmental Structure, 2004.
- . *The Nature of Order: An Essay on the Art of Building and the Nature of the Universe. Book Three: A Vision of a Living World*. 1980. Berkeley, California: The Center for Environmental Structure, 2005.
- Alexander, Christopher, Sara Ishikawa, Murray Silverstein, Max Jacobson, Ingrid Fiksdahl-King, and Shlomo Angel.** *A Pattern Language: Towns, Buildings, Construction*. New York: Oxford University Press, 1977.
- Allen, Graham.** *Intertextuality*. London: Routledge, 2000.
- Alves, Bill.** "Digital Harmony of Sound and Light." *Computer Music Journal* 29:4. Winter (2005): 45-54.
- Amerika, Mark.** *Meta / Data: A Digital Poetics*. Cambridge, Massachusetts: The MIT Press, 2007.

- Amirkhanian, Charles, and Brian Eno.** "Brian Eno Interviewed on KPFA's Ode to Gravity". Berkeley, California, 1980. 5/8/2010. <[www.archive.org/details/BrianEno](http://www.archive.org/details/BrianEno)>.
- Andersen, Peter Bøgh.** "Acting Machines." *Digital Media Revisited: Theoretical and Conceptual Innovation in Digital Domains*. Eds. Gunnar Liestøl, Andrew Morrison and Terje Rasmussen. Cambridge, Massachusetts: The MIT Press, 2003. 183-214.
- Anderson, Chris.** *Free: The Future of a Radical Price*. London: Arrow Books, 2009.
- Annunziato, Mauro, and Piero Pierucci.** "Towards Artificial Societies." *Generative Art*. Milan, 2000.
- Antoneli, Paola**, ed. *Design and the Elastic Mind*. New York: The Museum of Modern Art, 2008.
- . "Design and the Elastic Mind." *Design and the Elastic Mind*. Ed. Paola Antoneli. New York: The Museum of Modern Art, 2008b. 14-27.
- Antonini, Riccardo.** "The Darwinian Structure of the Design Process." *Generative Art*. Milan, 2001.
- Appleton, Brad.** "Patterns and Software: Essential Concepts and Terminology". 2000. 10/8/2008. <[www.cmcrossroads.com/bradapp/docs/patterns-intro.html](http://www.cmcrossroads.com/bradapp/docs/patterns-intro.html)>.
- Ariza, Christopher.** "The Interrogator as Critic: The Turing Test and the Evaluation of Generative Music Systems." *Computer Music Journal* 33. 2 (2009): 48-70.
- Arnheim, Rudolf.** *O Poder do Centro: Um Estudo da Composição nas Artes Visuais*. 1988. Trans. Maria Elisa Costa. Lisboa: Edições 70, 1990.
- Ascott, Roy.** *Telematic Embrace: Visionary Theories of Art, Technology, and Consciousness*. Berkeley, California: University of California Press, 2003.
- Ash, Robert B.** *Information Theory*. 1965. New York: Dover Publications, Inc., 1990.
- Ashby, W. Ross.** *Introduction to Cybernetics*. London: Chapman & Hall, 1956. 1999.
- Atkins, Barry.** *More Than a Game: The Computer Game as Fictional Form*. Manchester: Manchester University Press, 2003.
- Atkinson, Paul.** "The Best Laid Plans of Mice and Men: The Computer Mouse in the History of Computing." *Design Issues* 23. 3 (2007): 46-61.
- Auer, Johannes.** "Screaming Screen and Binary Idealism." 2001. 3/2/2010. <[netzliteratur.net/erfurt2001/screenidealism.htm](http://netzliteratur.net/erfurt2001/screenidealism.htm)>.
- Babbage, Charles.** "Of the Analytical Engine." *Cyber Reader: Critical Writings for the Digital Era*. Ed. Neil Spiller. London: Phaidon Press, 1864. 22-27. 2002.
- Bachelier, Günter.** "Embedding of Pixel-Based Evolutionary Algorithms in My Global Art Process." *The Art of Artificial Evolution: A Handbook on Evolutionary Art and Music*. Eds. Juan Romero and Penousal Machado. Berlin: Springer, 2008. 249-268.
- Badman, Derik.** "Composition N° 1 by Marc Saporta". 2004. 10/9/2009. <[madinkbeard.com/blog/archives/composition-no-1-by-marc-saporta](http://madinkbeard.com/blog/archives/composition-no-1-by-marc-saporta)>.
- Bailey, Cameron.** "Virtual Skin: Articulating Race in Cyberspace." *Immersed in Technology*. Eds. Mary Anne Moser and Douglas MacLeod. Cambridge, Massachusetts: The MIT Press, 1996. 29-49.
- Ball, Philip.** *The Self-Made Tapestry: Pattern Formation in Nature*. 1999. Oxford: Oxford University Press, 2004.
- Balvedi, Fabianne.** "Free Studios." *FLOSS + Art*. Eds. Aymeric Mansoux and Marloes de Valk. Poitiers: GOTO10, 2008. 262-269.
- Barabási, Albert-László.** *Linked: How Everything is Connected to Everything Else and What It Means for Business, Science, and Everyday Life*. 2002. London: Plume, 2003.
- Baranauskas, M. Cecilia C., and Rodrigo Bonacin.** "Design: Indicating Through Signs." *Design Issues* 24. 3 (2008): 30-45.
- Barbadillo, Manuel.** "My Way to Cybernetics." *Artist and Computer*. Ed. Ruth Leavitt. Morristown, New Jersey: Creative Computing Press, 1976.
- Barratt, Krome.** *Logic and Design: in Art, Science & Mathematics*. Guilford, Connecticut: Design Books, 1980. 1989.
- Barrett, Edward**, ed. *The Society of Text: Hypertext, Hypermedia, and the Social Construction of Information*. Cambridge, Massachusetts: The MIT Press, 1989.

- Batchelor, David.** *Minimalismo*. 1998. Trans. Fátima Araújo. Lisboa: Presença, 2000.
- Bateson, Gregory.** *Mind and Nature: A Necessary Unity*. New York: E. P. Dutton, 1979.
- Baudrillard, Jean.** *Simulacra and Simulation*. 1981. Trans. Sheila Faria Glaser. Ann Arbor, Michigan: The University of Michigan Press, 1994.
- Baume, Nicholas, ed.** *Sol LeWitt: Incomplete Open Cubes*. Cambridge, Massachusetts: The MIT Press, 2001.
- Bell, David.** *Cyberculture Theorists: Manuel Castells and Donna Haraway*. London: Routledge, 2007.
- Berge, Claude.** "For a Potential Analysis of Combinatory Literature." *The New Media Reader*. 1973. Eds. Noah Wardrip-Fruin and Nick Montfort. Cambridge, Massachusetts: The MIT Press, 2003. 177-181.
- Bergson, Henri.** *Creative Evolution*. Trans. Arthur Mitchell. New York: The Modern Library, 1911. 1944.
- Berkun, Scott.** *The Myths of Innovation*. Sebastopol, California: O'Reilly Media, 2007.
- Berlekamp, Elwyn R., John H. Conway, and Richard K. Guy.** *Winning Ways for Your Mathematical Plays*. Second ed. Wellesley, Massachusetts: A. K. Peters, 2001.
- Berlinski, David.** *The Advent of the Algorithm: The 300-Year Journey From an Idea to the Computer*. San Diego, California: Harcourt, 2000.
- . *Infinite Ascent: A Short History of Mathematics*. London: Weidenfeld & Nicolson, 2006.
- Bijsterveld, Karin.** *Mechanical Sound: Technology, Culture, and Public Problems of Noise in the Twentieth Century*. Cambridge, Massachusetts: The MIT Press, 2008.
- Blais, Joline, and Jon Ippolito.** *At the Edge of Art*. London: Thames & Hudson, 2006.
- Block, Friedrich W.** "How to Construct the Genre of Digital Poetry." 2009. 3/2/2010. <netzliteratur.net/block/digital\_poetry.pdf>.
- Boden, Margaret A.** *The Creative Mind: Myths and Mechanisms*. 1990. Second ed. London: Routledge, 2004.
- Bogost, Ian.** *Unit Operations: An Approach To Videogame Criticism*. Cambridge, Massachusetts: The MIT Press, 2006.
- . *Persuasive Games: The Expressive Power of Videogames*. Cambridge, Massachusetts: The MIT Press, 2007.
- . "The Rhetoric of Video Games." *The Ecology of Games: Connecting Youth, Games and Learning*. Ed. Katie Salen. Cambridge, Massachusetts: The MIT Press, 2008. 117-140.
- Bolter, Jay David.** *Turing's Man: Western Culture in the Computer Age*. Chapel Hill, North Carolina: The University of North Carolina Press, 1984.
- . *Writing Space: Computers, Hypertext and the Remediation of Print*. Second ed. Mahwah, New Jersey: Lawrence Erlbaum Associates, 2001.
- . "Critical Theory and the Challenge of New Media." *Eloquent Images: Word and Image In The Age Of New Media*. Eds. Mary E. Hocks and Michelle R. Kendrick. Cambridge, Massachusetts: The MIT Press, 2003. 19-36.
- Bolter, Jay David, and Diane Gromala.** *Windows and Mirrors: Interaction Design, Digital Art, and the Myth of Transparency*. Cambridge, Massachusetts: The MIT Press, 2003.
- Bolter, Jay David, and Richard Grusin.** *Remediation: Understanding New Media*. Cambridge, Massachusetts: The MIT Press, 1999. 2002.
- Bolz, Norbert.** "Rethinking Media Aesthetics." *Uncanny Networks: Dialogues with the Virtual Intelligentsia*. Ed. Geert Lovink. Cambridge, Massachusetts: The MIT Press, 2004. 18-27.
- Boole, George.** *An Investigation of the Laws of Thought on Which Are Founded The Mathematical Theories of Logic and Probabilities*. New York: Dover Publications, 1854. 2003.
- Bordewijk, Jan L., and Ben van Kaam.** "Towards a New Classification of Tele-Information Services." *The New Media Reader*. 1986. Eds. Noah Wardrip-Fruin and Nick Montfort. Cambridge, Massachusetts: The MIT Press, 2003. 576-586.
- Boulez, Pierre.** "Alea." *Stocktakings from an Apprenticeship*. 1966. New York: Oxford University Press, 1991. 26-38.
- Bourgoin, J.** *Arabic Geometrical Pattern & Design*. 1879. New York: Dover Publications, 1973.

- Brand, Stewart.** *Two Cybernetic Frontiers*. New York: Random House, 1974.
- Brea, José Luis.** *La Era Postmedia*. Salamanca: Editorial Centro de Arte de Salamanca, 2002.
- Bringsjord, Selmer, Paul Bello, and David Ferrucci.** "Creativity, the Turing Test, and the (Better) Lovelace Test." *Minds and Machines* 11. 1 (2001): 3-27.
- Brown, Paul.** "Networks and Artworks: The Failure of the User-Friendly Interface." *Computers & Art*. Ed. Stuart Mealing. Exeter: Intellect Books, 1997. 129-142.
- Brown, Sheldon.** "The Future Was Then." *Soft Cinema. Navigating the Database*. Ed. Lev Manovich. Cambridge, Massachusetts: The MIT Press, 2005.
- Bryson, Bill.** *Breve História de Quase Tudo*. 2003. Trans. Daniela Garcia. Lisboa: Quetzal Editores, 2008.
- Buchanan, Mark.** *Ubiquity: The Science of History... Or Why The World Is Simpler Than We Think*. 2000. London: Phoenix, 2004.
- Burgess, Helen, Jeanne Hamming, and Robert Markley.** "The Dialogics of New Media: Video, Visualization, And Narrative in Red Planet: Scientific And Cultural Encounters with Mars." *Eloquent Images: Word and Image In The Age Of New Media*. Eds. Mary E. Hocks and Michelle R. Kendrick. Cambridge, Massachusetts: The MIT Press, 2003. 61-85.
- Burnham, Jack.** "System Esthetics." *Art Forum* 1968.
- Burroughs, William S.** "The Cut-Up Method of Brion Gysin." *The New Media Reader*. 1961. Eds. Noah Wardrip-Fruin and Nick Montfort. Cambridge, Massachusetts: The MIT Press, 2003. 90-91.
- Burton, Ed.** "Thoughtful Drawings: A Computational Model of the Cognitive Nature of Children's Drawing." *Eurographics* 14. 3 (1995): 159-170.
- . "Artificial Innocence: Interactions Between the Study of Children's Drawings and Artificial Intelligence." 1996. 6/8/2009. <[web.archive.org/web/20030624231545/www.cea.mdx.ac.uk/CEA/External/Researchers/Ed/Work/ArtInn/artInn.html](http://web.archive.org/web/20030624231545/www.cea.mdx.ac.uk/CEA/External/Researchers/Ed/Work/ArtInn/artInn.html)>.
- . "Representing Representation: Artificial Intelligence and Drawing." *Computers & Art*. Ed. Stuart Mealing. Exeter: Intellect Books, 1997. 55-75.
- Bush, Vannevar.** "As We May Think." *The New Media Reader*. Eds. Noah Wardrip-Fruin and Nick Montfort. Cambridge, Massachusetts: The MIT Press, 1945. 35-47. 2003.
- Buurman, Gerhard M.,** ed. *Total Interaction: Theory and Practice of a New Paradigm for the Design Disciplines*. Basel: Birkhäuser, 2005.
- Byfield, Ted.** "Information." *Software Studies: A Lexicon*. Ed. Matthew Fuller. Cambridge, Massachusetts: The MIT Press, 2008. 125-132.
- Cage, John.** *A Year From Monday*. Middletown, Connecticut: Wesleyan University Press, 1967.
- . *Silence: Lectures and Writings by John Cage*. 1961. Hanover, New Hampshire: Wesleyan University Press, 1973.
- Callahan, Gene.** "Semiotics and GUI Design." *Software Development*. (1994).
- Calvino, Italo.** "Prose and Anticombinatorics." *The New Media Reader*. 1981. Eds. Noah Wardrip-Fruin and Nick Montfort. Cambridge, Massachusetts: The MIT Press, 2003. 183-187.
- Campbell, Jeremy.** *Grammatical Man: Information, Entropy, Language and Life*. Middlesex: Penguin Books, 1982.
- Carranza, Pablo Miranda.** "Self-Design and Ontogenic Evolution." *Generative Art*. Milano, 2001.
- Carvalhais, Miguel.** "Code Acts." *Abstraction Now*. Eds. Norbert Pfaffenbichler and Sandro Droschl. Vienna: Edition Camera Austria, 2004. 86-89.
- . "O Século dos Computadores Merece uma Música Própria." *Vector*, 2005.
- Cascone, Kim.** "The Aesthetics of Failure: 'Post-Digital' Tendencies in Contemporary Computer Music." *Computer Music Journal* 24. 4 (2000): 12-18.
- Castells, Manuel.** *The Internet Galaxy: Reflections on the Internet, Business, and Society*. New York: Oxford University Press, 2001.
- Ceccato, Cristiano.** "Integration: Master [Planner | Programmer | Builder]." *Generative Art*. Milan, 2001.

- Chen, Chun-Houh, Wolfgang Härdle, and Antony Unwin**, eds. *Handbook of Computational Statistics (Volume III): Data Visualization*. Heidelberg: Springer-Verlag, 2006.
- Chen, Dominick**. "Prochronist Manifestation." *Video Vortex Reader: Responses to Youtube*. Eds. Geert Lovink and Sabine Niederer. Amsterdam: Institute of Network Cultures, 2008. 63-77.
- Chion, Michel**. *Audio-Vision: Sounds on Screen*. 1990. Trans. Claudia Gorbman. New York: Columbia University Press, 1994.
- . *The Voice in Cinema*. 1982. Trans. Claudia Gorbman. New York: Columbia University Press, 1999.
- . "The Silence of the Loudspeakers, or Why With Dolby Sound it is the Film That Listens To Us." *Soundscape: The School of Sound Lectures 1998-2001*. Eds. Larry Sider, Diane Freeman and Jerry Sider. London: Wallflower Press, 2003. 150-154.
- . *Film: A Sound Art*. 2003. Trans. Claudia Gorbman. New York: Columbia University Press, 2009a.
- . *Guide to Sound Objects: Pierre Schaeffer and Musical Research*. 1983. Trans. John Dack and Christine North. Leicester: De Montfort University, 2009b.
- Chomsky, Noam**. "Three Models for the Description of Language." Cambridge, Massachusetts: Department of Modern Languages and Research Laboratory of Electronic, Massachusetts Institute of Technology, 1956.
- . *Syntactic Structures*. 'S-Gravenhage: Mouton & Co, 1957.
- Chun, Wendy Hui Kyong**. "Programmability." *Software Studies: A Lexicon*. Ed. Matthew Fuller. Cambridge, Massachusetts: The MIT Press, 2008. 224-229.
- Cicero, Marcus Tullius, Joseph B. Mayor, and J. H. Swainson**. *De Natura Deorum: Libri Tres. Vol. 1*. Cambridge: Cambridge University Press, 1880a.
- . *De Natura Deorum: Libri Tres. Vol. 2*. Cambridge: Cambridge University Press, 1880b.
- . *De Natura Deorum: Libri Tres. Vol. 3*. Cambridge: Cambridge University Press, 1880c.
- Cohen, Harold**. "Parallel to Perception: Some Notes on the Problem of Machine-Generated Art." San Diego, California, 1973b. 6/2/2009. <[crca.ucsd.edu/%7Ehcohen/cohenpdf/paralleltoperception.pdf](http://crca.ucsd.edu/%7Ehcohen/cohenpdf/paralleltoperception.pdf)>
- . "On Purpose: An Enquiry into the Possible Roles of the Computer In Art." San Diego, California, 1974. 6/2/2009. <[crca.ucsd.edu/%7Ehcohen/cohenpdf/onpurpose.pdf](http://crca.ucsd.edu/%7Ehcohen/cohenpdf/onpurpose.pdf)>
- . "The Material of Symbols." *First Annual Symposium on Symbols and Symbol Processes*. Las Vegas, Nevada, 1976.
- . "What is an Image?" San Diego, California, 1979. 6/2/2009. <[crca.ucsd.edu/%7Ehcohen/cohenpdf/whatisanimage.pdf](http://crca.ucsd.edu/%7Ehcohen/cohenpdf/whatisanimage.pdf)>
- . "Off the Shelf." San Diego, California, 1986. 6/2/2009. <[crca.ucsd.edu/%7Ehcohen/cohenpdf/offtheshelf.pdf](http://crca.ucsd.edu/%7Ehcohen/cohenpdf/offtheshelf.pdf)>
- . "How to Draw Three People in a Botanical Garden." San Diego, California, 1988. 6/2/2009. <[crca.ucsd.edu/%7Ehcohen/cohenpdf/how2draw3people.pdf](http://crca.ucsd.edu/%7Ehcohen/cohenpdf/how2draw3people.pdf)>
- . "Brother Giorgio's Kangaroo." 1990. 6/2/2009. <[www.kurzweilcyberart.com/aaron/pdf/brothergkanga.pdf](http://www.kurzweilcyberart.com/aaron/pdf/brothergkanga.pdf)>
- . "The Further Exploits of AARON, Painter." San Diego, California, 1994. 6/2/2009. <[crca.ucsd.edu/%7Ehcohen/cohenpdf/furtherexploits.pdf](http://crca.ucsd.edu/%7Ehcohen/cohenpdf/furtherexploits.pdf)>
- . "Colouring Without Seeing: a Problem in Machine Creativity." San Diego, California, 1999. 6/2/2009. <[crca.ucsd.edu/%7Ehcohen/cohenpdf/colouringwithoutseeing.pdf](http://crca.ucsd.edu/%7Ehcohen/cohenpdf/colouringwithoutseeing.pdf)>
- Collins, Nick**. "Generative Music and Laptop Performance." *Contemporary Music Review* 22. 4 (2003): 67-79.
- Collins, Nick, Alex McLean, Julian Rohrhuber, and Adrian Ward**. "Live Coding in Laptop Performance." *Organised Sound* 8. 3 (2003): 321-329.
- Colson, Richard**. *The Fundamentals of Digital Art*. Lausanne: AVA, 2007.
- Conway, John H., and Simon Kochen**. "The Strong Free Will Theorem." *Notices of the AMS* 56. 2 (2009): 226-232.

- Cooper, Alan, Robert Reimann, and David Cronin.** *About Face 3: The Essentials Of Interaction Design*. Indianapolis, Indiana: Wiley Publishing, 2007.
- Cope, David.** *Computer Models of Musical Creativity*. Cambridge, Massachusetts: The MIT Press, 2005.
- Cox, Christoph, and Daniel Warner,** eds. *Audio Culture: Readings in Modern Music*. New York: Continuum, 2004. 2008.
- Cox, Geoff, and Joasia Krysa,** eds. *Engineering Culture: On the Author as (Digital) Producer*. Brooklyn, New York: Autonomedia, 2005.
- Cramer, Florian.** "Free Software as Collaborative Text." 2000. 3/2/2010. <netzliteratur.net/cramer/free\_software\_as\_text.html>.
- . "Digital Code and Literary Text." 2001a. 3/2/2010. <netzliteratur.net/cramer/digital\_code\_and\_literary\_text.html>.
- . "Program Code Poetry." 2001b. 3/2/2010. <netzliteratur.net/cramer/programm.htm>.
- . "Concepts, Notations, Software, Art." 2002. 16/02/2009. <netzliteratur.net/cramer/concepts\_notations\_software\_art.html>.
- . *Words Made Flesh: Code, Culture, Imagination*. Rotterdam: Piet Zwart Institute, 2005.
- . "The Creative Common Misunderstanding." *FLOSS + Art*. Eds. Aymeric Mansoux and Marloes de Valk. Poitiers: GOTO10, 2008a. 128-137.
- . "Language." *Software Studies: A Lexicon*. Ed. Matthew Fuller. Cambridge, Massachusetts: The MIT Press, 2008b. 168-174.
- Cramer, Florian, and Matthew Fuller.** "Interface." *Software Studies: A Lexicon*. Ed. Matthew Fuller. Cambridge, Massachusetts: The MIT Press, 2008. 149-153.
- Cramer, Florian, and Ulrike Gabriel.** "Software Art." 2001. 19/02/2009. <netzliteratur.net/cramer/software\_art\_-\_transmediale.html>.
- Cramer, Florian, and Stewart Home.** "Pornographic Coding." 2005. 3/2/2010. <netzliteratur.net/cramer/pornography/london-2005/pornographic-coding.html>.
- Criqui, Jean-Pierre,** ed. *Christian Marclay: Replay*. Zurich: JRP|Ringier, 2007.
- Crow, David.** "Magic Box, Craft And The Computer." *Eye Winter* 2008: 20-25.
- Crumlish, Christian, and Erin Malone.** *Designing Social Interfaces*. Sebastopol, California: O'Reilly, 2009.
- Cruz, João.** "Inter-Média." Universidade do Porto, 2002.
- Csuri, Charles.** "Statistics as an Interactive Art Object." *Artist and Computer*. Ed. Ruth Leavitt. Morristown, New Jersey: Creative Computing Press, 1976.
- Cubbit, Sean.** *The Cinema Effect*. Cambridge, Massachusetts: The MIT Press, 2004.
- Daniels, Dieter, and Sandra Naumann.** "Introduction." *See This Sound. Audiovisuology. Compendium: An Interdisciplinary Survey of Audiovisual Culture*. Eds. Dieter Daniels, Sandra Naumann and Jan Thoben. Köln: Verlag der Buchhandlung Walther König, 2010. 5-16.
- Daniels, Dieter, Sandra Naumann, and Jan Thoben,** eds. *See This Sound. Audiovisuology. Compendium: An Interdisciplinary Survey of Audiovisual Culture*. Köln: Verlag der Buchhandlung Walther König, 2010.
- Dannenberg, Roger B.** "Interactive Visual Music: A Personal Perspective." *Computer Music Journal* 29:4. Winter 2005 (2005): 25-35.
- Danto, Arthur C.** *After the End of Art: Contemporary Art and the Pale of History*. Princeton, New Jersey: Princeton University Press, 1997.
- . "The End of Art: A Philosophical Defense." *History and Theory* 37. 4 (1998): 127-143.
- Darley, Andrew.** *Visual Digital Culture: Surface Play and Spectacle in New Media Genres*. London: Routledge, 2000.
- Davis, Douglas.** "The Work of Art in the Age of Digital Reproduction: An Evolving Thesis / 1991-1995". 1995. 22/4/2010. <cristine.org/borders/Davis\_Essay.html>
- Davis, Erik.** *TechGnosis: Myth, Magic + Mysticism in the Age of Information*. New York: Serpent's Tail, 1998.

- Davis, Martin.** *O Computador Universal*. 2000. Trans. Maria Alice Gomes da Costa. Lisboa: Editorial Bizâncio, 2004.
- Dawkins, Richard.** *Decompondo o Arco-Íris*. 1998. Trans. Paulo Cartaxana. Lisboa: Gradiva, 2000.  
———. *The Greatest Show on Earth: The Evidence for Evolution*. London: Free Press, 2009.
- de Chardin, Pierre Theilhard.** *The Phenomenon of Man*. 1955. Trans. Bernard Wall. New York: Harper Perennial, 1959. 2008.
- De Cisneros, Roc Jiménez.** “Blackout Representation, Transformation and De-Control in the Sound Work of Yasunao Tone.” *Quaderns D’Audio*. Barcelona: MACBA, 2010.
- De Landa, Manuel.** “Policing the Spectrum.” *Cyber Reader: Critical Writings for the Digital Era*. Ed. Neil Spiller. London: Phaidon Press, 1991a. 144-149. 2002.  
———. *War in the Age of Intelligent Machines*. New York: Zone Books, 1991b. 2003.  
———. *A Thousand Years of Nonlinear History*. Brooklyn, New York: Zone Books, 1997. 2005.  
———. *Intensive Science and Virtual Philosophy*. London: Continuum, 2002. 2004.
- De Loor, Pierre, Kristen Manac’h, and Jacques Tisseau.** “Enaction-Based Artificial Intelligence: Toward Co-evolution with Humans in the Loop.” *Mind & Machines*. 19 (2009): 319-343.
- Deleuze, Gilles, and Félix Guattari.** *A Thousand Plateaus*. Trans. Brian Massumi. London: Continuum, 1988. 2004.
- Deutsch, Stephen.** “Music for Interactive Moving Pictures.” *Soundscape: The School of Sound Lectures 1998-2001*. Eds. Larry Sider, Diane Freeman and Jerry Sider. London: Wallflower Press, 2003. 28-34.
- Dorin, Alan.** “A Survey of Virtual Ecosystems in Generative Electronic Art.” *The Art of Artificial Evolution: A Handbook on Evolutionary Art and Music*. Eds. Juan Romero and Penousal Machado. Berlin: Springer, 2008. 289-309.
- Douglas, Evan.** *Autogenic Structures*. New York: Taylor & Francis, 2009.
- Downey, Jonas.** “Searching for New Understanding in Computation: An Exploration of Language and Meaning in Encoded Artworks”. University of Illinois at Urbana-Champaign, 2005.
- du Sautoy, Marcus.** *The Music of the Primes: Why an Unsolved Problem in Mathematics Matters*. London: Harper Perennial, 2003. 2004.
- Dunne, Anthony.** *Hertzian Tales: Electronic Products, Aesthetic Experience, and Critical Design*. Cambridge, Massachusetts: The MIT Press, 2005.
- Dürer, Albrecht.** *Underweysung der Messung, mit dem Zirckel und Richtscheyt*. Nürnberg, 1525.
- Eco, Umberto.** *Obra Aberta*. Trans. João Rodrigo Narciso Furtado. Second ed. Lisboa: Difel, 1962. 2009.  
———. “The Theory of Signs and the Role of the Reader.” *The Bulletin of the Midwest Modern Language Association* 14. 1 (1981): 35-45.
- Edwards, John Stephan.** “The Carmina of Publilius Optatianus Porphyrius and the Creative Process.” *Studies in Latin Literature and Roman History, Volume XII*. Ed. Carl Deroux. Brussels: Collection Latomus, 2005. 447-466.
- Emmer, Michele.** “Visual Mathematics: Mathematics and Art.” *The Visual Mind II*. Ed. Michele Emmer. Cambridge, Massachusetts: The MIT Press, 2005a. 59-90.  
———. ed. *The Visual Mind II*. Cambridge, Massachusetts: The MIT Press, 2005b.
- Engelbart, Douglas.** “Augmenting Human Intellect: A Conceptual Framework.” *The New Media Reader*. 1962. Eds. Noah Wardrip-Fruin and Nick Montfort. Cambridge, Massachusetts: The MIT Press, 2003. 95-108.
- Eskelinen, Markku.** “Cybertext Theory: What An English Professor Should Know Before Trying.” 2001. 22/02/2010. <[www.electronicbookreview.com/thread/electropoetics/notmetaphor](http://www.electronicbookreview.com/thread/electropoetics/notmetaphor)>.
- Evans, Brian.** “Foundations of a Visual Music.” *Computer Music Journal* 29:4. Winter 2005 (2005): 11-24.
- Evans, Aden.** *Sound Ideas: Music, Machines, and Experience*. Minneapolis, Minnesota: University of Minnesota Press, 2005.
- Fallon, Kjetil.** “De-scribing Design: Appropriating Script Analysis to Design History.” *Design Issues* 24. 4 (2008): 61-75.

- Ferris, Timothy.** *The Whole Shebang: A State-of-the-Universe(s) Report*. New York: Simon & Schuster, 1997. 1998.
- Fischer, Steven Roger.** *A History of Writing*. 2001. London: Reaction Books, 2003.
- Fishwick, Paul A.**, ed. *Aesthetic Computing*. Cambridge, Massachusetts: The MIT Press, 2006a.
- . "An Introduction to Aesthetic Computing." *Aesthetic Computing*. Ed. Paul A. Fishwick. Cambridge, Massachusetts: The MIT Press, 2006b. 3-27.
- Flake, Gary William.** *The Computational Beauty of Nature: Computer Explorations of Fractals, Chaos, Complex Systems, and Adaptation*. Cambridge, Massachusetts: The MIT Press, 1998.
- Flammenkamp, Achim.** "Most Seen Natural Occurring Ash Objects in Game of Life." 2004. 4/11/2009. <[www.homes.uni-bielefeld.de/achim/freq\\_top\\_life.html](http://www.homes.uni-bielefeld.de/achim/freq_top_life.html)>.
- Flichy, Patrice.** *Dynamics of Modern Communication: The Shaping and Impact of New Communication Technologies*. London: Sage Publications, 1991. 1995.
- . *The Internet Imaginaire*. 2001. Trans. Liz Carey-Libbrecht. Cambridge, Massachusetts: The MIT Press, 2007.
- Flynt, Henry.** "Concept Art." 1961. 14/9/2009. <[www.henryflynt.org/aesthetics/conart.html](http://www.henryflynt.org/aesthetics/conart.html)>.
- Forlizzi, Jodi, John Zimmerman, and Shelly Evenson.** "Crafting a Place for Interaction Design Research in HCI." *Design Issues* 24. 3 (2008): 19-29.
- Fournel, Paul.** "Computer and Writer: The Centre Pompidou Experiment." *The New Media Reader*. 1981. Eds. Noah Wardrip-Fruin and Nick Montfort. Cambridge, Massachusetts: The MIT Press, 2003. 182-183.
- Franke, Herbert.** "The Expanding Medium: The Future of Computer Art." *Leonardo* 20. 4 (1987): 335-338.
- Fredkin, Edward.** "Finite Nature." 1992a. <[www.digitalphilosophy.org/Home/Papers/FiniteNature/tabid/106/Default.aspx](http://www.digitalphilosophy.org/Home/Papers/FiniteNature/tabid/106/Default.aspx)>.
- . "A New Cosmogony On The Origin Of The Universe." 1992b. <[www.digitalphilosophy.org/Home/Papers/ANewCosmogony/tabid/107/Default.aspx](http://www.digitalphilosophy.org/Home/Papers/ANewCosmogony/tabid/107/Default.aspx)>.
- . "A Physicist's Model of Computation." 2001. <[www.digitalphilosophy.org/LinkClick.aspx?fileticket=QgVpvRIx6Gg%3d&tabid=61&mid=494&forcedownload=true](http://www.digitalphilosophy.org/LinkClick.aspx?fileticket=QgVpvRIx6Gg%3d&tabid=61&mid=494&forcedownload=true)>.
- Friendly, Michael.** "A Brief History of Data Visualization." *Handbook of Computational Statistics (Volume III): Data Visualization*. Eds. Chun-Houh Chen, Wolfgang Härdle and Antony Unwin. Heidelberg: Springer-Verlag, 2006.
- Fry, Ben.** "All Streets." 2008b. 20/4/2010. <[benfry.com/allstreets](http://benfry.com/allstreets)>.
- Fuller, Matthew.** *Behind The Blip: Essays on the Culture of Software*. Brooklyn, New York: Autonomedia, 2003.
- . *Media Ecologies: Materialist Energies in Art and Technoculture*. Cambridge, Massachusetts: The MIT Press, 2005.
- . ed. *Software Studies: A Lexicon*. Cambridge, Massachusetts: The MIT Press, 2008.
- . "Ten Reasons Why the Art World Loves Digital Art." *Proud to Be Flesh: A Mute Magazine Anthology of Cultural Politics After the Net*. 1998. Eds. Josephine Berry Slater and Pauline van Mourik Broekman. London: Mute Publishing, 2009. 86-88.
- Gage, Zach.** "Temporary.cc" 2009a. 18/11/2009. <[www.stfj.net/index2.php?project=art/2009/temporary](http://www.stfj.net/index2.php?project=art/2009/temporary)>.
- Galanter, Philip.** "Foundations of Generative Art Systems: A Hybrid Survey and Studio Class for Graduate Students." *Generative Art*. Milan, 2001.
- . "What is Generative Art? Complexity theory as a context for art theory." *Generative Art*. Milan, 2003.
- . "Generative Art and Rules-Based Art." *Vague Terrain*, 2006.
- . "A Brief Taxonomy of Chance in Art." *Generative Art Wiki*, 2008a.

- . “Complexism and the Role of Evolutionary Art.” *The Art of Artificial Evolution: A Handbook on Evolutionary Art and Music*. Eds. Juan Romero and Penousal Machado. Berlin: Springer, 2008b. 311-332.
- . “Thoughts on Computational Creativity.” *Schloss Dagstuhl Seminar*, 2009a.
- . “Truth to Process: Evolutionary Art and the Aesthetics of Dynamism.” *Generative Art*. Milan, 2009b.
- . “The Problem with Evolutionary Art Is...” *Evomusart 2010*. Istanbul, 2010.
- Galloway, Alexander R.** *Protocol: How Control Exists After Decentralization*. Cambridge, Massachusetts: The MIT Press, 2004.
- . *Gaming: Essays on Algorithmic Culture*. Minneapolis, Minnesota: University of Minnesota Press, 2006.
- Galloway, Alexander R., and Eugene Thacker.** *The Exploit: A Theory of Networks*. Minneapolis, Minnesota: University of Minnesota Press, 2007.
- Garcia Pereira, Henrique.** *Arte Recombinatória*. Lisboa: Editorial Teorema, 2000.
- Gardner, Martin.** *Wheels, Life and Other Mathematical Amusements*. New York: W.H. Freeman & Co. Ltd., 1983.
- Gelernter, David.** *Mirror Worlds: or The Day Software Puts the Universe in a Shoebox... How It Will Happen and What Will It Mean*. Oxford: Oxford University Press, 1991. 1992.
- . *The Muse in the Machine: Computerizing the Poetry of Human Thought*. New York: The Free Press, 1994.
- . *The Aesthetics of Computing*. London: Weidenfeld & Nicolson, 1998a.
- . *Machine Beauty: Elegance and the Heart of Technology*. New York: Basic Books, 1998b.
- Gere, Charlie.** *Art, Time and Technology*. Oxford: Berg, 2006.
- Giorgini, Aldo.** *Artist and Computer*. Ed. Ruth Leavitt. Morristown, New Jersey: Creative Computing Press, 1976.
- Gleick, James.** *Chaos: Making A New Science*. London: Vintage, 1998.
- Glimcher, Marc, and Bernice Rose**, eds. *Logical Conclusions: 40 Years of Rule-Based Art*. New York: Pace Wildenstein, 2005.
- Glissant, Édouard.** *Poetics of Relation*. 1990. Trans. Betsy Wing. Ann Arbor, Michigan: The University of Michigan Press, 1997.
- Goffey, Andrew.** “Algorithm.” *Software Studies: A Lexicon*. Ed. Matthew Fuller. Cambridge, Massachusetts: The MIT Press, 2008a. 15-20.
- . “Intelligence.” *Software Studies: A Lexicon*. Ed. Matthew Fuller. Cambridge, Massachusetts: The MIT Press, 2008b. 132-142.
- Goldberg, Ken**, ed. *The Robot in the Garden: Telerobotics and Telepistemology in the Age of the Internet*. Cambridge, Massachusetts: The MIT Press, 2000. 2001.
- Goldstein, Rebecca.** *Incompletude: A Demonstração e o Paradoxo de Kurt Gödel*. 2005. Trans. David Gaspar. Lisboa: Gradiva, 2009.
- Gombrich, E. H.** *The Sense of Order: A Study in the Psychology of Decorative Art*. 1979. Second ed. London: Phaidon Press, 1984. 2006.
- . *The Uses of Images*. 1999. Studies in the Social function of Art and Visual Communication. London: Phaidon, 2000.
- Goodman, Nelson.** *Languages of Art: An Approach To a Theory of Symbols*. Second ed. Indianapolis, Indiana: Hackett, 1976.
- . *Of Mind and Other Matters*. Cambridge, Massachusetts: Harvard University Press, 1984.
- Goodman, Steve.** “Sonic Algorithm.” *Software Studies: A Lexicon*. Ed. Matthew Fuller. Cambridge, Massachusetts: The MIT Press, 2008a. 229-235.
- . “Timeline (sonic).” *Software Studies: A Lexicon*. Ed. Matthew Fuller. Cambridge, Massachusetts: The MIT Press, 2008b. 256-259.

- Goucher, Adam P.** "A Design for a Universal Computer". 2009. 9/11/2009. <[www.calcyman.co.uk/life/universal-CC/index.htm](http://www.calcyman.co.uk/life/universal-CC/index.htm)>.
- Gould, Glenn.** "The Prospects of Recording." *The Glenn Gould Reader*. 1966. Ed. Tim Page. New York: Vintage Books, 1984a. 331-353.
- . "Strauss and the Electronic Future." *The Glenn Gould Reader*. 1964. Ed. Tim Page. New York: Vintage Books, 1984b. 92-99.
- Graham, Gordon.** *The Internet: A Philosophical Inquiry*. London: Routledge, 1999. 2001.
- Grassmuck, Volker.** "Into the Muddy Waters of the Turing Galaxy." *ISEA*, 1994.
- Grau, Oliver.** *Virtual Art: From Illusion to Immersion*. 2001. Trans. Gloria Custance. Cambridge, Massachusetts: The MIT Press, 2003.
- Griffiths, Dave.** "On Free Software Art, Design, Communities and Committees." *FLOSS + Art*. Eds. Aymeric Mansoux and Marloes de Valk. Poitiers: GOTOIO, 2008. 248-253.
- Haacke, Hans.** "Untitled Statement." *Directions in Kinetic Sculpture*. Ed. Peter Selz. Berkeley, California: University of California Press, 1966.
- Haeckel, Ernst.** *Art Forms in Nature*. Munich: Prestel, 1904. 1998.
- Hall, Peter.** "Critical Visualization." *Design and the Elastic Mind*. Ed. Paola Antonelli. New York: The Museum of Modern Art, 2008. 120-131.
- Halpern, Mark.** "The Trouble with the Turing Test." *The New Atlantis*. 11 (2006): 42-63.
- Hansen, Mark B. N.** *New Philosophy for New Media*. Cambridge, Massachusetts: The MIT Press, 2004.
- Haraway, Donna**, ed. *The Haraway Reader*. New York: Routledge, 2004a.
- . "A Manifesto for Cyborgs: Science, Technology, and Socialist Feminism in the 1980s." *The Haraway Reader*. 1985. Ed. Donna Haraway. New York: Routledge, 2004b. 7-45.
- Harris, Jonathan, and Sep Kamvar.** "We Feel Fine: Methodology." 2006b. 4/5/2010. <[www.wefeelfine.org/methodology.html](http://www.wefeelfine.org/methodology.html)>.
- Harvey, Auriea, and Michaël Samyn.** "Realtime Art Manifesto." *Gaming Realities: The Challenge of Digital Culture. Mediaterra Festival of Art and Technology*. Athens, 2006.
- Hayles, N. Katherine.** "Virtual Bodies and Flickering Signifiers." *October* 66. (1993): 69-91.
- . "Refiguring the Posthuman." *Comparative Literature Studies* 41. 3 (2004): 311-316.
- . "Traumas of Code." *Critical Enquiry*. Autumn (2006): 136-157.
- . "Intermediation: The Pursuit of a Vision." *New Literary History* 38. (2007): 99-125.
- Helfand, Jessica.** *Screen: Essays on Graphic Design, New Media, and Visual Culture*. New York: Princeton Architectural Press, 2001.
- Heller, Steven, and Karen Pomeroy.** *Design Literacy: Understanding Graphic Design*. New York: Allworth Press, 1997.
- Hemberg, Martin, Una-May O'Reilly, Achim Menges, Katrin Jonas, Michel da Costa Gonçalves, and Steven R. Fuchs.** "Genr8: Architects' Experience with an Emergent Design Tool." *The Art of Artificial Evolution: A Handbook on Evolutionary Art and Music*. Eds. Juan Romero and Penousal Machado. Berlin: Springer, 2008. 167-188.
- Heuman, Michael.** "Ghost in the Machine: Sound and Technology in Twentieth Century Literature." University of California, 1998.
- Hoffman, Justin, and Sandra Naumann.** "Artist-Musicians and Musician-Artists." *See This Sound. Audiovisuology. Compendium: An Interdisciplinary Survey of Audiovisual Culture*. Eds. Dieter Daniels, Sandra Naumann and Jan Thoben. Köln: Verlag der Buchhandlung Walther König, 2010. 53-60.
- Hofstadter, Douglas R.** "Reflections on Mind, Brains, and Programs." *The Mind's I: Fantasies and Reflections on Self and Soul*. Eds. Douglas R. Hofstadter and Daniel C. Dennet. New York: Basic Books, 1981. 373-382. 2000.
- . *Metamagical Themas: Questing for the Essence of Mind and Pattern*. New York: Basic Books, 1985.

- . *Fluid Concepts and Creative Analogies: Computer Models of the Fundamental Mechanisms of Thought*. London: Allen Lane, 1995.
- . *Gödel, Escher, Bach: An Eternal Golden Braid*. 1979. 20th-anniversary ed. London: Penguin, 1999.
- . *I Am a Strange Loop*. Cambridge, Massachusetts: Basic Books, 2007.
- Hofstadter, Douglas R., and Daniel C. Dennet**, eds. *The Mind's I: Fantasies and Reflections on Self and Soul*. New York: Basic Books, 1981. 2000.
- Holland, John H.** *Emergence: From Chaos to Order*. 1998. Oxford: Oxford University Press, 2000.
- Holmes, Thom.** *Electronic and Experimental Music: Pioneers in Technology and Composition*. 1985. Second ed. New York: Routledge, 2002.
- Holtzman, Steven R.** *Digital Mantras: The Languages of Abstract and Virtual Worlds*. Cambridge, Massachusetts: The MIT Press, 1994.
- Huff, Karen E.** "Computer Weaving: Modern Technology Confronts an Ancient Craft." *Artist and Computer*. Ed. Ruth Leavitt. Morristown, New Jersey: Creative Computing Press, 1976.
- Ihnatowicz, Edward.** "Towards a Thinking Machine." *Artist and Computer*. Ed. Ruth Leavitt. Morristown, New Jersey: Creative Computing Press, 1976.
- Ince, D.C.**, ed. *Mechanical Intelligence*. Amsterdam: Elsevier Science Publishers, 1992.
- Ingold, Tim.** *Lines: A Brief History*. London: Routledge, 2007. 2008.
- Jacob, Christian, and Gerald Hushlak.** "Evolutionary and Swarm Design in Science, Art, and Music." *The Art of Artificial Evolution: A Handbook on Evolutionary Art and Music*. Eds. Juan Romero and Penousal Machado. Berlin: Springer, 2008. 145-166.
- Jaschko, Susanne.** "Space-Time Correlations Focused in Film Objects and Interactive Video." 2002. 27/04/2009. <[www.sujaschko.de/en/research/pr1/spa.html](http://www.sujaschko.de/en/research/pr1/spa.html)>.
- . "Segmentation and Reassembly of the Digital Moving Image." 2004. 27/04/2009. <[www.sujaschko.de/en/research/pr1/pub2.html](http://www.sujaschko.de/en/research/pr1/pub2.html)>.
- . "Process as Aesthetic Paradigm: A Nonlinear Observation of Generative Art." 2005. 27/04/2009. <[www.sujaschko.de/downloads/170/generatortalk](http://www.sujaschko.de/downloads/170/generatortalk)>.
- Jefferson, Geoffrey.** "The Mind of Mechanical Man." *British Medical Journal* 1. 4616 (1949): 1105-1110.
- Jenkins, Henry.** *Convergence Culture: Where Old and New Media Collide*. New York: New York University Press, 2006. 2008.
- Joly, Martine.** *Introdução à Análise da Imagem*. 1994. Trans. José Eduardo Rodil. Lisboa: Edições 70, 2008.
- Joyce, Michael.** *Of Two Minds: Hypertext Pedagogy and Poetics*. Ann Arbor, Michigan: The University of Michigan Press, 1995. 1996.
- . *Othermindedness: The Emergence of Network Culture (Studies in Literature & Science)*. Ann Arbor, Michigan: The University of Michigan Press, 2001.
- . "Siren Shapes: Exploratory and Constructive Hypertexts." *The New Media Reader*. 1988. Eds. Noah Wardrip-Fruin and Nick Montfort. Cambridge, Massachusetts: The MIT Press, 2003. 614-624.
- Julier, Guy.** "From Visual Culture to Design Culture." *Design Issues* 22. 1 (2006): 64-76.
- Kac, Eduardo**, ed. *Media Poetry: An International Anthology*. Bristol: Intellect, 2007.
- Kahn, Douglas.** *Noise, Water, Meat: A History of Sound in the Arts*. Cambridge, Massachusetts: The MIT Press, 1999.
- Kamper, Dietmar.** "We Don't Know What it is We Invented." *Uncanny Networks: Dialogues with the Virtual Intelligentsia*. Ed. Geert Lovink. Cambridge, Massachusetts: The MIT Press, 2004. 12-17.
- Kandinsky, Wassily.** *Gramática da Criação*. 1970. Trans. José Eduardo Rodil. Lisboa: Edições 70, 2008.
- Kaul, Mani.** "The Rambling Figure." *Soundscape: The School of Sound Lectures 1998-2001*. Eds. Larry Sider, Diane Freeman and Jerry Sider. London: Wallflower Press, 2003. 209-220.
- Kawano, Hiroshi.** "What is Computer Art?" *Artist and Computer*. Ed. Ruth Leavitt. Morristown, New Jersey: Creative Computing Press, 1976.

- Kelly, Caleb.** *Cracked Media: The Sound of Malfunction*. Cambridge, Massachusetts: The MIT Press, 2009.
- Kelly, Kevin.** "An Open Universe." *Cyber Reader: Critical Writings for the Digital Era*. Ed. Neil Spiller. London: Phaidon Press, 1994. 216-221. 2002.
- . "The Arc of Complexity." 2009a. 28/06/2009. <[www.kk.org/thetechnium/archives/2009/05/the\\_arc\\_of\\_comp.php](http://www.kk.org/thetechnium/archives/2009/05/the_arc_of_comp.php)>.
- . "Infinite In Some Directions." 2009b. 28/06/2009. <[www.kk.org/thetechnium/archives/2009/05/infinite\\_in\\_som.php](http://www.kk.org/thetechnium/archives/2009/05/infinite_in_som.php)>.
- Kinder, Marsha.** "The Conceptual Power Of On-Line Video: 5 Easy Pieces." *Video Vortex Reader: Responses to Youtube*. Eds. Geert Lovink and Sabine Niederer. Amsterdam: Institute of Network Cultures, 2008. 53-62.
- King, Mike.** "Artificial Consciousness — Artificial Art." *Computers & Art*. Ed. Stuart Mealing. Exeter: Intellect Books, 1997. 33-53.
- Kittler, Friedrich A.** "There is No Software." 1995. 16/02/2009. <[www.cttheory.net/articles.aspx?id=74](http://www.cttheory.net/articles.aspx?id=74)>.
- . *Gramophone, Film, Typewriter*. 1986. Trans. Geoffrey Winthrop-Young and Michael Wutz. Stanford, California: Stanford University Press, 1999.
- . "Code (or, How You Can Write Something Differently)." *Software Studies: A Lexicon*. Ed. Matthew Fuller. Cambridge, Massachusetts: The MIT Press, 2008. 40-47.
- Klanten, Robert, Nicolas Bourquin, Thibaud Tissot, and Sven Ehmann,** eds. *Data Flow: Visualizing Information in Graphic Design*. Berlin: Gestalten, 2008.
- Knowlton, Kenneth.** *Artist and Computer*. Ed. Ruth Leavitt. Morristown, New Jersey: Creative Computing Press, 1976.
- Knuth, Donald.** "Computer Programming as an Art." 1974. <[www.paulgraham.com/knuth.html](http://www.paulgraham.com/knuth.html)>.
- Koenig, H., and Dave Greene.** "Pi In a Cloudy Sky." *Game of Life News*, 2009.
- Kolb, David.** "Socrates in the Labyrinth." *Hyper / Text / Theory*. Ed. George P. Landow. Baltimore, Maryland: The Johns Hopkins University Press, 1994. 323-344.
- Kolomyjec, William J.** "The Appeal of Computer Graphics." *Artist and Computer*. Ed. Ruth Leavitt. Morristown, New Jersey: Creative Computing Press, 1976.
- Krause, Jeffrey.** "Reflections: The Creative Process of Generative Design in Architecture." 2003. <[arch.blacksquare.com/docs/krause\\_gen2003\\_press.pdf](http://arch.blacksquare.com/docs/krause_gen2003_press.pdf)>
- Krause, Tara.** "'High Gnarl' as La Forza d'Arte: Complexity & Abstract Painting." *International Journal of Unconventional Computing*. May (2005).
- . "Insights Into a Cellular Automata Model of Abstract Painting." *Journal of Cellular Automata* 1. 2 (2006).
- Krysa, Joasia, and Grzesiek Sedek.** "Source Code." *Software Studies: A Lexicon*. Ed. Matthew Fuller. Cambridge, Massachusetts: The MIT Press, 2008. 236-243.
- Kurzweil, Ray.** *The Age of Spiritual Machines: When Computers Exceed Human Intelligence*. London: Penguin Books, 1999.
- . ed. *The Ray Kurzweil Reader*. KurzweilAI.net, 2004a.
- . "Reflections on Stephen Wolfram's 'A New Kind of Science'." *The Ray Kurzweil Reader*. Ed. Ray Kurzweil: KurzweilAI.net, 2004b. 101-114.
- Lab[au].** "Pixflow Generative Process." 2007b. 6/5/2010. <[lab-au.com/projects/pixflow-art-console/#/projects/pixflow-art-console](http://lab-au.com/projects/pixflow-art-console/#/projects/pixflow-art-console)>.
- LaBelle, Brandon.** *Background Noise: Perspectives on Sound Art*. New York: Continuum, 2006.
- LaBelle, Brandon, and Steve Roden,** eds. *Site of Sound: Of Architecture & The Ear*. Los Angeles, California: Errant Bodies Press, 2002.
- Lafuente, Ricardo.** "Appropriation and Type: Before and Today." *FLOSS + Art*. Eds. Aymeric Mansoux and Marloes de Valk. Poitiers: GOTO10, 2008. 192-205.
- Landow, George P.,** ed. *Hyper / Text / Theory*. Baltimore, Maryland: The Johns Hopkins University Press, 1994a.

- . “What’s a Critic to Do? Critical Theory in the Age of Hypertext.” *Hyper / Text / Theory*. Ed. George P. Landow. Baltimore, Maryland: The Johns Hopkins University Press, 1994b. 1-48.
- . *Hypertext 3.0: Critical Theory and New Media in an Era of Globalization*. Baltimore, Maryland: The Johns Hopkins University Press, 2006.
- Lansdown, John.** “Some Trends in Computer Graphic Art.” *Computers & Art*. Ed. Stuart Mealing. Exeter: Intellect Books, 1997. 11-21.
- Lanza, Robert, and Robert Berman.** *Biocentrism: How Life and Consciousness are the Keys to Understanding the True Nature of the Universe*. Dallas, Texas: Benbella Books, 2009.
- Lapprand, Marc.** *Poétique de l’Oulipo*. Amsterdam: Rodopi, 1998.
- Latour, Bruno.** “The Social After Gabriel Tarde: Debates and Assessments.” 2010. 6/7/2010. <www.bruno-latour.fr/articles/article/116-TARDE-CANDEA.pdf>
- Latour, Bruno, and Peter Weibel,** eds. *Iconoclasm: Beyond the Image Wars in Science, Religion, and Art*. Karlsruhe: ZKM, 2002.
- Lauckner, Kurt F.** “Microprocessors and Intelligent Sculpture.” *Artist and Computer*. Ed. Ruth Leavitt. Morristown, New Jersey: Creative Computing Press, 1976.
- Laurel, Brenda.** *Computers as Theatre*. Reading, Massachusetts: Addison-Wesley, 1993.
- Leal, Miguel.** “A Imaginação Cega: Mecanismos de Indeterminação na Prática Artística Contemporânea.” Universidade do Porto, 2009.
- Leavitt, Ruth,** ed. *Artist and Computer*. Morristown, New Jersey: Creative Computing Press, 1976a.
- . “Preface.” *Artist and Computer*. Ed. Ruth Leavitt. Morristown, New Jersey: Creative Computing Press, 1976b.
- Lee, Edward A.** “Computing Needs Time.” 2009. EECs Department, University of California, Berkeley. <www.eecs.berkeley.edu/Pubs/TechRpts/2009/EECS-2009-30.html>.
- Lee, John.** “Goodman’s Aesthetics and the Languages of Computing.” *Aesthetic Computing*. Ed. Paul A. Fishwick. Cambridge, Massachusetts: The MIT Press, 2006. 29-42.
- Lescure, Jean.** “Brief History of the Oulipo.” *The New Media Reader*. 1973. Eds. Noah Wardrip-Fruin and Nick Montfort. Cambridge, Massachusetts: The MIT Press, 2003. 172-176.
- Lessig, Lawrence.** *The Future of Ideas: The Fate of the Commons in a Connected World*. New York: Vintage Books, 2001. 2002.
- . *Free Culture: How Big Media Uses Technology and the Law to Lock Down Culture and Control Creativity*. New York: The Penguin Press, 2004.
- . *Code: Version 2.0*. New York: Basic Books, 2006.
- . *Remix: Making Art and Commerce Thrive in the Hybrid Economy*. London: Bloomsbury, 2008.
- Levin, Golan.** “Painterly Interfaces for Audiovisual Performance.” Massachusetts Institute of Technology, 2000a.
- . “Project Report for Yellowtail.” 2000b. 12/02/2010. <www.flong.com/texts/reports/report\_yellowtail>.
- . “Is The Computer a Tool?” *Creative Code*. Ed. John Maeda. London: Thames & Hudson, 2004. 140.
- . “Special Topics in Interactive Art & Computational Design.” 2010. 4/5/2010. <golancourses.net/2010spring/lectures>.
- Levin, Golan, Lia, Meta, and Adrian Ward.** *Generative Design: Beyond Photoshop*. Ed. Jim Hannah. Birmingham: Friends of ED, 2001.
- Levy, David M.** *Scrolling Forward: Making Sense of Documents in the Digital Age*. New York: Arcade Publishing, 2001.
- Lévy, Pierre.** *Collective Intelligence: Mankind’s Emerging World in Cyberspace*. Trans. Robert Bononno. Cambridge, Massachusetts: Perseus Books, 1997.
- Lewis, Matthew.** “Evolutionary Visual Art and Design.” *The Art of Artificial Evolution: A Handbook on Evolutionary Art and Music*. Eds. Juan Romero and Penousal Machado. Berlin: Springer, 2008. 3-37.
- LeWitt, Sol.** “Paragraphs on Conceptual Art.” *Art-Language* 1. 1 (1969b).

- Lialina, Olia, and Dragan Espenschied**, eds. *Digital Folklore: To Computer Users, with Love and Respect*. Stuttgart: Merz & Solitude, 2009.
- Licht, Alan**. *Sound Art: Beyond Music, Between Categories*. New York: Rizzoli, 2007.
- Licklider, J. C. R.** "Man-Computer Symbiosis." *IRE Transactions on Human Factors in Electronics HFE-1*. (1960): 4-11.
- Liestøl, Eva**. "Computer Games and the Ludic Structure of Interpretation." *Digital Media Revisited: Theoretical and Conceptual Innovation in Digital Domains*. Eds. Gunnar Liestøl, Andrew Morrison and Terje Rasmussen. Cambridge, Massachusetts: The MIT Press, 2003. 327-358.
- Liestøl, Gunnar**. "Wittgenstein, Genette, and the Reader's Narrative in Hypertext." *Hyper / Text / Theory*. Ed. George P. Landow. Baltimore, Maryland: The Johns Hopkins University Press, 1994. 87-120.
- . "Gameplay: From Synthesis to Analysis (and Vice Versa). Topics of Conceptualization and Construction in Digital Media." *Digital Media Revisited: Theoretical and Conceptual Innovation in Digital Domains*. Eds. Gunnar Liestøl, Andrew Morrison and Terje Rasmussen. Cambridge, Massachusetts: The MIT Press, 2003. 389-414.
- Liestøl, Gunnar, Andrew Morrison, and Terje Rasmussen**, eds. *Digital Media Revisited: Theoretical and Conceptual Innovation in Digital Domains*. Cambridge, Massachusetts: The MIT Press, 2003.
- Life Wiki**. "Life Wiki." 2008. 4/11/2009. <[www.conwaylife.com/wiki](http://www.conwaylife.com/wiki)>.
- Lloyd, Seth**. "Measures of Complexity: a Nonexhaustive List." *Control Systems Magazine, IEEE* 21. 4 (2001): 7-8.
- . *Programming the Universe: A Quantum Computer Scientist Takes on The Cosmos*. London: Jonathan Cape, 2006.
- Longson, Tony**. *Artist and Computer*. Ed. Ruth Leavitt. Morristown, New Jersey: Creative Computing Press, 1976.
- Lopes, Dominic McIver**. *A Philosophy of Computer Art*. Oxon: Routledge, 2010.
- Lorenz, Edward N.** *The Essence of Chaos*. 1993. Seattle, Washington: University of Washington Press, 1995.
- Lovink, Geert**. *Dark Fiber: Tracking Critical Internet Culture*. Cambridge, Massachusetts: The MIT Press, 2003.
- . *Uncanny Networks: Dialogues with the Virtual Intelligentsia*. Cambridge, Massachusetts: The MIT Press, 2004.
- . "The Art of Watching Databases: Introduction to the Video Vortex Reader." *Video Vortex Reader: Responses to Youtube*. Eds. Geert Lovink and Sabine Niederer. Amsterdam: Institute of Network Cultures, 2008. 9-12.
- Lovink, Geert, and Sabine Niederer**, eds. *Video Vortex Reader: Responses to Youtube*. Amsterdam: Institute of Network Cultures, 2008.
- Löwgren, Jonas, and Erik Stolterman**. *Thoughtful Interaction Design: A Design Perspective on Information Technology*. Cambridge, Massachusetts: The MIT Press, 2004.
- Ludden, Geke D.S., Hendrik N.J. Schifferstein, and Paul Hekkert**. "Surprise As a Design Strategy." *Design Issues* 24. 2 (2008): 28-38.
- Ludovico, Alessandro**, ed. *UBERMORGEN.COM: Media Hacking vs. Conceptual Art*. Basel: Christoph Merian Verlag, 2009.
- Luining, Peter**. "NEW.WRITING: Interview with Jan Robert Leegte." 2004. 22/03/2004. <[www.netartreview.net/weeklyFeatures/2004\\_03\\_21\\_archive.html](http://www.netartreview.net/weeklyFeatures/2004_03_21_archive.html)>
- Lund, Andreas**. "Evolving the Shape of Things to Come: A Comparison of Direct Manipulation and Interactive Evolutionary Design." *Generative Art*. Milan, 2000.
- Machado, Penousal**. "Inteligência Artificial e Arte." Faculdade de Ciências e Tecnologia, Universidade de Coimbra, 2006.
- Maeda, John**. *Maeda @ Media*. London: Thames & Hudson, 2000.
- . *Creative Code*. London: Thames & Hudson, 2004.

- . *The Laws of Symplicity*. Cambridge, Massachusetts: The MIT Press, 2006.
- Magnusson, Thor.** "Expression and Time: The Question of Strata and Time Management in Creative Practices Using Technology." *FLOSS + Art*. Eds. Aymeric Mansoux and Marloes de Valk. Poitiers: GOTO10, 2008. 232-247.
- Mallory, Robert.** *Artist and Computer*. Ed. Ruth Leavitt. Morristown, New Jersey: Creative Computing Press, 1976.
- Manetas, Miltos.** "Websites Are the Art of Our Times." 2002. 29/10/2005. <www.manetas.com/txt/websitesare.htm>
- Manning, Peter.** *Electronic and Computer Music*. New York: Oxford University Press, 2004.
- Manovich, Lev.** *The Language of New Media*. Cambridge, Massachusetts: The MIT Press, 2001.
- . "The Anti-Sublime Ideal in New Media." 2002. 11/09/2005. <www.chairemetal.com/cm07/manovich-complet.htm>.
- . "Don't Call it Art: Ars Electronica 2003." *Vector*, 2003.
- . "Abstraction and Complexity." *Abstraction Now*. Eds. Norbert Pfaffenbichler and Sandro Droschl. Vienna: Edition Camera Austria, 2004a. 80-85.
- . "Cinema and Software." *Soft Cinema: Navigating the Database*. Ed. Lev Manovich. Cambridge, Massachusetts: The MIT Press, 2005a.
- . "Soft Cinema: Ambient Narrative." 2005b. 16/3/2010. <softcinema.net>.
- . "Import / Export." *Software Studies: A Lexicon*. Ed. Matthew Fuller. Cambridge, Massachusetts: The MIT Press, 2008a. 119-125.
- . "The Practice of Everyday (Media) Life." *Video Vortex Reader: Responses to Youtube*. Eds. Geert Lovink and Sabine Niederer. Amsterdam: Institute of Network Cultures, 2008b. 33-44.
- Manovich, Lev, and Andreas Kratky.** *Soft Cinema: Navigating the Database*. Cambridge, Massachusetts: The MIT Press, 2005.
- Mansoux, Aymeric, and Marloes de Valk,** eds. *FLOSS + Art*. Poitiers: GOTO10, 2008a.
- . "Preface." *FLOSS + Art*. Eds. Aymeric Mansoux and Marloes de Valk. Poitiers: GOTO10, 2008b. 6-13.
- Marcus, Aaron.** *Artist and Computer*. Ed. Ruth Leavitt. Morristown, New Jersey: Creative Computing Press, 1976.
- Mateas, Michael.** "Procedural Literacy: Educating the New Media Practitioner." *On The Horizon. Special Issue: Future of Games, Simulations and Interactive Media in Learning Contexts* 13. 1 (2005).
- . "Weird Languages." *Software Studies: A Lexicon*. Ed. Matthew Fuller. Cambridge, Massachusetts: The MIT Press, 2008. 267-275.
- Mathews, Harry, and Alastair Brotchie,** eds. *Oulipo Compendium*. Second Revised ed. London: Atlas Press, 2005.
- Mauro-Flude, Nancy.** "Linux for Theatre Makers: Embodiment & Nix Modus Operandi." *FLOSS + Art*. Eds. Aymeric Mansoux and Marloes de Valk. Poitiers: GOTO10, 2008. 206-223.
- Mayer-Schönberger, Viktor.** *Delete: The Virtue of Forgetting in the Digital Age*. Princeton, New Jersey: Princeton University Press, 2009.
- McAllister, James W.** "Mathematical Beauty and the Evolution of the Standards of Mathematical Proof." *The Visual Mind II*. Ed. Michele Emmer. Cambridge, Massachusetts: The MIT Press, 2005. 15-34.
- McCloud, Scott.** *Understanding Comics: The Invisible Art*. 1993. New York: Paradox Press, 1999.
- . *Reinventing Comics*. New York: Paradox Press, 2000.
- McCullough, Malcolm.** *Abstracting Craft: The Practiced Digital Hand*. 1996. Cambridge Massachusetts: The MIT Press, 1998.
- McDonald, Kyle.** "Only Everything Lasts Forever." Rensselaer Polytechnic Institute, 2010b.
- McLean, Alex.** "Live Coding for Free." *FLOSS + Art*. Eds. Aymeric Mansoux and Marloes de Valk. Poitiers: GOTO10, 2008. 224-231.

- McLuhan, Marshall.** *The Gutenberg Galaxy: The Making of Typographic Man*. Toronto: University of Toronto Press, 1962.
- . *Understanding Media: The Extensions of Man*. New York: Routledge Classics, 1964. 2006.
- McLuhan, Marshall, and Eric McLuhan.** *Laws Of The Media: The New Science*. Toronto: University of Toronto Press, 1988.
- Meaney, Ewan.** "On Glitching." 2008. 14/11/2009. <[www.evanmeaney.com/glitching/theory/evan\\_meaney\\_onglitching.pdf](http://www.evanmeaney.com/glitching/theory/evan_meaney_onglitching.pdf)>.
- Merleau-Ponty, Maurice.** *Phenomenology of Perception*. 1945. Trans. Colin Smith. London: Routledge, 1962. 2006.
- Mestres, Lluís Eloi Puig.** "Alear: Arte Procesual-Aleatorio. La Aleatoriedad en el Computer-art." Universitat de Barcelona, 2004.
- Milner, Greg.** *Perfecting Sound Forever: The Story of Recorded Music*. London: Granta Publications, 2009.
- Milthorp, Rob.** "Fascination, Masculinity, and Cyberspace." *Immersed in Technology*. Eds. Mary Anne Moser and Douglas MacLeod. Cambridge, Massachusetts: The MIT Press, 1996. 129-150.
- Minsky, Marvin.** "Steps Toward Artificial Intelligence." Cambridge, Massachusetts: Research Lab. of Electronics, MIT, 1960.
- . *Semantic Information Processing*. Cambridge, Massachusetts: The MIT Press, 1968.
- . *Computation: Finite and Infinite Machines*. 1967. London: Prentice-Hall International, 1972.
- . "A Framework for Representing Knowledge." Cambridge, Massachusetts: MIT-AI Laboratory, 1974.
- . "Music, Mind, and Meaning." *Computer Music Journal* 5. 3 (1981).
- . *The Society of Mind*. London: Picador, 1985. 1988.
- Miranda, Eduardo Reck.** *Computer Sound Synthesis for the Electronic Musician*. Oxford, Massachusetts: Focal Press, 1998.
- Mohr, Manfred.** *Artist and Computer*. Ed. Ruth Leavitt. Morristown, New Jersey: Creative Computing Press, 1976.
- Moles, Abraham.** *Information Theory and Esthetic Perception*. 1958. Trans. Joel E. Cohen. Urbana, Illinois: University of Illinois Press, 1966.
- Molnár, Vera.** *Artist and Computer*. Ed. Ruth Leavitt. Morristown, New Jersey: Creative Computing Press, 1976.
- . "Artist Statement: Inconceivable Images". 2009. 29/4/2010. <[www.field.io/process/research/art/vera-molnar](http://www.field.io/process/research/art/vera-molnar)>.
- Montfort, Nick.** "Composition N° 1 by Marc Saporta: Reading notes by Nick Montfort". 2002. 15/2/2010. <[nickm.com/if/composition\\_no\\_1.html](http://nickm.com/if/composition_no_1.html)>.
- . "Introduction to the Cut-Up Method of Brion Gysin." *The New Media Reader*. Eds. Noah Wardrip-Fruin and Nick Montfort. Cambridge, Massachusetts: The MIT Press, 2003. 89.
- Moradi, Iman.** "Glitch Aesthetics." University of Huddersfield, 2004.
- Moradi, Iman, Ant Scott, Joe Gilmore, and Christopher Murphy,** eds. *Glitch: Design Imperfection*. New Jersey: Mark Batty Publisher, 2009.
- Morowitz, Harold J.** *The Emergence of Everything: How the World Became Complex*. New York: Oxford University Press, 2002.
- Morris, Desmond.** *The Biology of Art: A Study of the Picture-Making Behaviour of the Great Apes and its Relationship to Human Art*. London: Methuen & Co. Ltd., 1962.
- Morrison, Ewan.** "Ten Reasons Why the Art World Hates Digital Art." *Proud to Be Flesh: A Mute Magazine Anthology of Cultural Politics After the Net*. 1998. Eds. Josephine Berry Slater and Pauline van Mourik Broekman. London: Mute Publishing, 2009. 82-85.
- Morse, Margaret.** "Nature Morte: Landscape and Narrative in Virtual Environments." *Immersed in Technology*. Eds. Mary Anne Moser and Douglas MacLeod. Cambridge, Massachusetts: The MIT Press, 1996. 195-232.

- Moulthrop, Stuart.** "Rhizome and Resistance: Hypertext and the Dreams of a New Culture." *Hyper / Text / Theory*. Ed. George P. Landow. Baltimore, Maryland: The Johns Hopkins University Press, 1994. 299-319.
- Moura, Leonel.** *Formigas, Vagabundos e Anarquia: Ensaio Sobre Vida Artificial, Arte e Sociedade*. Lisboa: AAAL – Alife Art Architecture Lab, 2003.
- Müller, Boris.** "Poetry on the Road." 2006a. 6/5/2010. <www.esono.com/boris/projects/poetry06>.
- Muller, Nat, and Alessandro Ludovico,** eds. *The Mag.net Reader 3: Processual Publishing. Actual Gestures*. London: OpenMute, 2008.
- Mumford, Lewis.** *Technics and Civilization*. 1934. Orlando, Florida: Harcourt Brace & Company, 1963.
- Murray, Janet H.** *Hamlet on the Holodeck: The Future of Narrative in Cyberspace*. Cambridge, Massachusetts: The MIT Press, 1997.
- . "Inventing the Medium." *The New Media Reader*. Eds. Noah Wardrip-Fruin and Nick Montfort. Cambridge, Massachusetts: The MIT Press, 2003. 3-11.
- Murtaugh, Michael.** "Interaction." *Software Studies: A Lexicon*. Ed. Matthew Fuller. Cambridge, Massachusetts: The MIT Press, 2008. 143-149.
- Muxel, Andreas.** "Connect: Feed-Back Driven Sculpture." 2008b. 7/5/2010. <connect.andreamuxel.com>.
- Nake, Frieder, and Susanne Grabowski.** "The Interface as Sign and as Aesthetic Event." *Aesthetic Computing*. Ed. Paul A. Fishwick. Cambridge, Massachusetts: The MIT Press, 2006. 53-70.
- Negroponte, Nicholas.** *Being Digital*. New York: Vintage Books, 1995. 1996.
- Nelson, Theodor H.** "Computer Lib / Dream Machines." *The New Media Reader*. 1974. Eds. Noah Wardrip-Fruin and Nick Montfort. Cambridge, Massachusetts: The MIT Press, 2003a. 301-338.
- . "A File Structure for the Complex, the Changing and the Indeterminate." *The New Media Reader*. 1965. Eds. Noah Wardrip-Fruin and Nick Montfort. Cambridge, Massachusetts: The MIT Press, 2003b. 133-146.
- Nenadić, Oleg, and Michael Greenacre.** "Correspondence Analysis in R, with Two- and Three-dimensional Graphics: The ca Package." *Journal of Statistical Software* 20. 3 (2007).
- Nešetřil, Jaroslav.** "Aesthetics for Computers, or How to Measure Harmony." *The Visual Mind II*. Ed. Michele Emmer. Cambridge, Massachusetts: The MIT Press, 2005. 35-58.
- Nichols, Bill.** "The Work of Culture in the Age of Cybernetic Systems." *The New Media Reader*. 1988. Eds. Noah Wardrip-Fruin and Nick Montfort. Cambridge, Massachusetts: The MIT Press, 2003. 627-642.
- Nicolai, Carsten.** *Autopilot*. Chemnitz: Raster Noton, 2002.
- Nilson, Click.** "Live Coding Practice." *NIME*. New York, 2007.
- Nivasch, Gabriel.** "The 17c/45 Caterpillar Spaceship." 2005. 9/11/2009. <www.yucs.org/~gnivasch/life/article\_cat>.
- Noble, Jim.** "Fatal Attraction: Print Meets Computer." *Computers & Art*. Ed. Stuart Mealing. Exeter: Intellect Books, 1997. 77-95.
- Noguchi, Hideo.** "Mozart: Musical Game in C K. 516f." 1997. 8/9/2009. <www.asahi-net.or.jp/~rb5h-ngc/e/k516f.htm>.
- Norman, Donald A.** *Things That Make Us Smart: Defending Human Attributes in the Age of the Machine*. New York: Basic Books, 1993.
- . *The Design of Everyday Things*. 1988. Cambridge, Massachusetts: The MIT Press, 1998a.
- . *The Invisible Computer: Why Good Products Can Fail, the Personal Computer Is so Complex, and Information Appliances Are the Solution*. Cambridge, Massachusetts: The MIT Press, 1998b.
- . *Emotional Design: Why We Love (or Hate) Everyday Things*. New York: Basic Books, 2004.
- . *The Design of Future Things*. Philadelphia, Pennsylvania: Basic Books, 2007.
- Ong, Walter J.** *Orality and Literacy*. London: Routledge, 1982. 2007.
- Oxman, Neri.** "Digital Craft: Fabrication-Based Design in the Age of Digital Production." *Ubicomp 07*. Innsbruck, 2007.

- Page, Tim**, ed. *The Glenn Gould Reader*. New York: Vintage Books, 1984.
- Pajot, Dennis**. "kv.Anh C30.01 Musikalische Wurfespiel Dice Game." 2004. 8/9/2009. <www.mozartforum.com/Lore/article.php?id=044>.
- Palyka, Duane M.** "Computer Painting." *Artist and Computer*. Ed. Ruth Leavitt. Morristown, New Jersey: Creative Computing Press, 1976.
- Parikka, Jussi**. "Copy." *Software Studies: A Lexicon*. Ed. Matthew Fuller. Cambridge, Massachusetts: The MIT Press, 2008. 70-78.
- Parish, Yoav I. H., and Pascal Müller**. "Procedural Modeling of Cities." *Siggraph*, 2001.
- Paulus, Edo**. "The Use of Generative Music Systems for Interactive Media." 2001. Utrecht: Faculty of Art, Media and Technology, School of Art, Utrecht, 2002.
- Pearce, Marcus, and Geraint A. Wiggins**. "Towards a Framework for the Evaluation of Machine Compositions." *AISB'01 Symposium on AI and Creativity in Arts and Science*, 2001.
- Perret, Raphael**. "Between Man and Machine." *Total Interaction: Theory and Practice of a New Paradigm for the Design Disciplines*. Ed. Gerhard M. Buurman. Basel: Birkhäuser, 2005.
- Peterson, Ivars**. "Mozart's Melody Machine." 2001. 8/9/2009. <www.sciencenews.org/view/generic/id/1956/title/Mozarts\_Melody\_Machine>.
- Pinker, Steven**. *The Language Instinct: The New Science of Language and Mind*. London: Penguin Books, 1994.
- . *How the Mind Works*. 1997. London: Penguin Books, 1999.
- . *The Stuff of Thought: Language as a Window into Human Nature*. London: Penguin, 2007.
- Pold, Søren**. "Button." *Software Studies: A Lexicon*. Ed. Matthew Fuller. Cambridge, Massachusetts: The MIT Press, 2008a. 31-36.
- . "Preferences / Settings / Options / Control Panels." *Software Studies: A Lexicon*. Ed. Matthew Fuller. Cambridge, Massachusetts: The MIT Press, 2008b. 218-224.
- Pool, Ithiel de Sola**. *Technologies of Freedom*. Cambridge, Massachusetts: The Belknap Press, 1983.
- Popp, Markus**. "My Music is a Model for Music." 2004. 16/11/2009. <www.medienkunstnetz.de/themes/image-sound\_relations/music\_as\_a\_model/scroll>.
- Postman, Neil**. *Amusing Ourselves to Death: Public Discourse in the Age of Show Business*. 1985. London: Penguin Books, 2005.
- Poundstone, William**. *The Recursive Universe: Cosmic Complexity and the Limits of Scientific Knowledge*. Oxford: Oxford University Press, 1985.
- . *Prisoner's Dilemma*. New York: Anchor Books, 1992.
- Prendergast, Mark**. *The Ambient Century: From Mahler to Trance, the Evolution of Sound in the Electronic Age*. London: Bloomsbury Publishing, 2000.
- Prudence, Paul**. "Bridges 2009: Talysis II". 2009a. 6/5/2010. <www.paulprudence.com/?p=56>.
- Pruett, Melvin L.** *Art and the Computer*. New York: McGraw-Hill, 1984.
- Prusinkiewicz, Przemyslaw, and Aristid Lindenmayer**. *The Algorithmic Beauty of Plants*. Third ed. New York: Springer Verlag, 1990. 2004.
- Puig, Sergi Jordà**. "Digital Lutherie: Crafting Musical Computers for New Musics' Performance and Improvisation." Universitat Pompeu Fabra, 2005.
- Queneau, Raymond**. *Cent mille milliards de poèmes*. Paris: Gallimard, 1961.
- . "A Hundred Thousand Billion Poems." Trans. Stanley Chapman. *The New Media Reader*. 1961. Eds. Noah Wardrip-Fruin and Nick Montfort. Cambridge, Massachusetts: The MIT Press, 2003a. 149-169. 1983.
- . "Yours for the Telling." Trans. John Crombie. *The New Media Reader*. 1973. Eds. Noah Wardrip-Fruin and Nick Montfort. Cambridge, Massachusetts: The MIT Press, 2003b. 171-178. 1982.
- Qvortrup, Lars**. "Digital Art and Design Poetics: The Poetical Potentials of Projection and Interaction." *Digital Media Revisited: Theoretical and Conceptual Innovation in Digital Domains*. Eds. Gunnar Liestøl, Andrew Morrison and Terje Rasmussen. Cambridge, Massachusetts: The MIT Press, 2003. 239-262.

- Radical Software Group.** "How We Made Our Own 'Carnivore'". 2002. 5/5/2010. <r-s-g.org/carnivore/How\_We\_Made\_Our\_Own\_Carnivore.txt>.
- Raley, Rita.** *Tactical Media*. Minneapolis, Minnesota: University of Minnesota Press, 2009.
- Raskin, Jef.** "Down With GUIs!" *Wired* 1993.  
———. *The Humane Interface: New Directions for Designing Interactive Systems*. Reading, Massachusetts: ACM Press, 2000.
- Rau, Anja.** "Wreader's Digest: How to Appreciate Hyperfiction". 2000. 3/2/2010. <netzliteratur.net/rau/rau\_wreader.htm>.
- Ray, Tom S.** "Tierra." 1991. 17/08/2009. <life.ou.edu/tierra>.
- Reas, C. E. B.** "Process Compendium." 2008. 5/5/2010v. <reas.com/texts/processcompendium.html>.
- Reas, Casey, and Ben Fry.** *Processing: A Programming Handbook for Visual Designers and Artists*. Cambridge, Massachusetts: The MIT Press, 2007.
- Rees, A. L.** *A History of Experimental Film and Video* 1999. Londres: British Film Institute, 2003.
- Reichardt, Jasja.** *The Computer in Art*. London: Studio Vista, 1971.
- Renucci, Frank, and Hervé Zénouda.** "De l'Intelligence Artificielle à l'Inconscient Artificiel: l'Objet Petit A, Une Exposition d'Antoine Schmitt." *SIANA09*, 2009.
- Reville, Nicholas.** *International School on Digital Transformation*. Reitoria da Universidade do Porto, Porto, 2009.
- Ricoeur, Paul.** *The Rule of Metaphor: The Creation of Meaning in Language*. 1975. Trans. Robert Czerny, Kathleen McLaughlin and John Costello. London: Routledge, 1977.
- Riley, Howard.** "Generative Art: Multi-Modal Meanings." *Generative Art*. Milan, 2002.
- Roads, Curtis, ed.** *The Music Machine: Selected Readings from Computer Music Journal*. Cambridge, Massachusetts: The MIT Press, 1989.  
———. *The Computer Music Tutorial*. Cambridge, Massachusetts: The MIT Press, 1996.  
———. *Microsound*. Cambridge, Massachusetts: The MIT Press, 2001.
- Robbin, Tony.** *Shadows of Reality: The Fourth Dimension in Relativity, Cubism, and Modern Thought*. New Haven, Connecticut: Yale University Press, 2006.
- Robinson, Derek.** "Analog." *Software Studies: A Lexicon*. Ed. Matthew Fuller. Cambridge, Massachusetts: The MIT Press, 2008a. 21-31.  
———. "Function." *Software Studies: A Lexicon*. Ed. Matthew Fuller. Cambridge, Massachusetts: The MIT Press, 2008b. 101-110.
- Rokeby, David.** "Seen." 2002a. 3/4/2010. <homepage.mac.com/davidrokeby/seen.html>.  
———. "Taken." 2002c. 9/4/2010. <homepage.mac.com/davidrokeby/taken.html>.  
———. "Sorting Daemon." 2003a. 10/4/2010. <homepage.mac.com/davidrokeby/sorting.html>.  
———. "Gathering." 2004b. 10/4/2010. <homepage.mac.com/davidrokeby/gathering.html>.  
———. "San Marco Flow." 2005b. 3/4/2010. <homepage.mac.com/davidrokeby/smf.html>.
- Romero, Juan, and Penousal Machado.** "Preface." *The Art of Artificial Evolution: A Handbook on Evolutionary Art and Music*. Eds. Juan Romero and Machado Penousal. Berlin: Springer, 2008. vii-xii.
- Roncoroni, Umberto.** "Generative Art: A Question of Aesthetic, Knowledge and Interfaces." *Generative Art*. Milan, 2004.
- Rosenberg, Martin E.** "Physics and Hypertext: Liberation and Complicity in Art and Pedagogy." *Hyper / Text / Theory*. Ed. George P. Landow. Baltimore, Maryland: The Johns Hopkins University Press, 1994. 268-298.
- Roth, Evan, and Ben Engebretth.** "White Glove Tracking." 2007. 20/4/2010. <whiteglovetracking.com>.
- Roth, Evan, and James Powderly.** "Graffiti Research Lab." 2006. 2010/06/26. <graffitiresearchlab.com>.
- Rowe, Robert.** *Machine Musicianship*. Cambridge, Massachusetts: The MIT Press, 2001.
- Rucker, Rudy.** *Infinity and The Mind: The Science and Philosophy of the Infinite*. Cambridge, Massachusetts: Bantam Books, 1982. 1983.

- . *The Lifebox, the Seashell, and the Soul: What Gnarly Computation Taught Me About Ultimate Reality, the Meaning of Life, and How to Be Happy*. New York: Thunder's Mouth Press, 2005.
- Rushkoff, Douglas.** "NET EFFECT: It's Not Too Late for Humanity to Survive the Digital." *Arthur* 12/10/2009 2009.
- . "Program or be Programmed: Ten Commands for a Digital Age". 2010. <[www.youtube.com/watch?v=imV3pPIUy1k](http://www.youtube.com/watch?v=imV3pPIUy1k)>.
- Russ, Martin.** *Sound Synthesis and Sampling*. 1996. Third ed. Amsterdam: Elsevier, 2009.
- Russolo, Luigi.** *The Art of Noises*. 1913.
- Rutsky, R. L.** *High Technē: Art and Technology from the Machine*. Minneapolis, Minnesota: University of Minnesota Press.
- Ryan, Marie-Laure.** *Narrative as Virtual Reality: Immersion and Interactivity in Literature and Electronic Media*. Baltimore, Maryland: John Hopkins University Press, 2001.
- Sack, Warren.** "Painting Theory Machines." *Art and Design*. May (1996): 80-92.
- . "Artificial Dialectics." *Shaping the Network Society: Patterns for Participation, Action and Change: DIAC-02 Symposium*. Seattle, Washington, 2002.
- . "Memory." *Software Studies: A Lexicon*. Ed. Matthew Fuller. Cambridge, Massachusetts: The MIT Press, 2008. 184-193.
- . "Aesthetics of Information Visualization." Santa Cruz, California, 2009. University of California, Santa Cruz. <[hybrid.ucsc.edu/SocialComputingLab/Publications/wsack-infoaesthetics-illustrated.doc](http://hybrid.ucsc.edu/SocialComputingLab/Publications/wsack-infoaesthetics-illustrated.doc)>
- . "Network Aesthetics." Santa Cruz, California, 2009. University of California, Santa Cruz. <[hybrid.ucsc.edu/SocialComputingLab/Publications/wsack-network-aesthetics.doc](http://hybrid.ucsc.edu/SocialComputingLab/Publications/wsack-network-aesthetics.doc)>
- Sadi, Sajid.** "Metadesign. Design for Design: a Path Beyond Mass Customization." *Ubicomp 07*. Innsbruck, 2007.
- Sala, Nicoletta, and Gabriele Cappellato.** "The Generative Approach in the Botta's San Carlino." *Generative Art*. Milan, 2003.
- Salvaggio, Eryk.** "Duchamp's Ideal Children's Children: Net.Art's Brat Pack." 2003. turbulence.org. 07/11/2005. <[www.turbulence.org/curators/salvaggio/index.html](http://www.turbulence.org/curators/salvaggio/index.html)>
- Schell, Jesse.** *The Art of Game Design: A Book of Lenses*. Burlington, Massachusetts: Morgan Kaufmann, 2008. 2009.
- Schmidt, Karsten.** "Advanced Beauty: Enerugii, part II." 2008a. 6/5/2010. <[postspectacular.com/work/advancedbeauty/start](http://postspectacular.com/work/advancedbeauty/start)>.
- . "Faber Finds generative book covers." London, 2008c. 12/02/2010. <[postspectacular.com/process/20080711\\_faberfindslaunch](http://postspectacular.com/process/20080711_faberfindslaunch)>.
- . "Nokia Friends, Generative Characters." 2008d. 5/5/2010. <[postspectacular.com/process/20080810\\_nokiafriends](http://postspectacular.com/process/20080810_nokiafriends)>.
- Schubiger, Caroline.** "Interaction Design: Definition and Tasks." *Total Interaction: Theory and Practice of a New Paradigm for the Design Disciplines*. Ed. Gerhard M. Buurman. Basel: Birkhäuser, 2005. 341-351.
- Schwierin, Marcel, and Sandra Naumann.** "The Musicality of Abstract Film." *See This Sound. Audiovisuology. Compendium: An Interdisciplinary Survey of Audiovisual Culture*. Eds. Dieter Daniels, Sandra Naumann and Jan Thoben. Köln: Verlag der Buchhandlung Walther König, 2010. 19-23.
- Searle, John R.** "Minds, Brains, and Programs." *The Mind's I: Fantasies and Reflections on Self and Soul*. Eds. Douglas R. Hofstadter and Daniel C. Dennet. New York: Basic Books, 1981. 353-373. 2000.
- . *Mente, Cérebro e Ciência*. 1984. Trans. Artur Morão. Lisboa: Edições 70, 1997.
- Seife, Charles.** *Zero: Biografia de Uma Ideia Perigosa*. 2000. Trans. Raquel Paiva. Lisboa: Gradiva, 2001.
- . *Decoding the Universe: How the New Science of Information is Explaining Everything in the Cosmos, from Our Brains to Black Holes*. London: Viking Penguin, 2006.
- Selz, Peter,** ed. *Directions in Kinetic Sculpture*. Berkeley, California: University of California Press, 1966.

- Shanken, Edward A.** *Art and Electronic Media*. New York: Phaidon Press, 2009.
- Shannon, Claude E., and Warren Weaver.** *The Mathematical Theory of Communication*. Urbana, Illinois: University of Illinois Press, 1949. 1998.
- Shaviro, Steven.** *Without Criteria: Kant, Whitehead, Deleuze, and Aesthetics*. Cambridge, Massachusetts: The MIT Press, 2009.
- Shaw, Jeffrey.** "The Maturity of New Media." *Soft Cinema. Navigating the Database*. Ed. Lev Manovich. Cambridge, Massachusetts: The MIT Press, 2005.
- Shaw-Miller, Simon.** *Visible Deeds of Music: Art and Music from Wagner to Cage*. New Haven, Connecticut, 2002.
- Sherman, Tom.** "Cinematic Video: Film is Dying While 'Film' is Being Born..." 2006. 15/1/2007. <blog.wired.com/sterling/2007/01/dead\_media\_beat\_2.html>.
- Shlain, Leonard.** *Art & Physics: Parallel Visions in Space, Time, and Light*. New York: Harper Perennial, 1991. 2007.
- Silver, Stephen.** "Life Lexicon." 2006. 8/11/2009. <www.argentum.freereserve.co.uk/lex\_home.htm>.
- Simon, Herbert A.** *The Sciences of the Artificial*. Cambridge, Massachusetts: The MIT Press, 1969.
- Simon, John F., Jr.** "Every Icon." *Parachute* 1997b.
- Simondon, Gilbert.** *On the Mode of Existence of Technical Objects*. 1958. Trans. Ninian Mellamphy. London, Ontario: University of Western Ontario, 1980.
- Sims, Karl.** "Evolving Virtual Creatures." *Siggraph*. Orlando, Florida, 1994b. 15-22.
- . "Galápagos." 1997a. 21/9/2009. <www.karlsims.com/galapagos/index.html>.
- Slater, Josephine Berry, and Pauline van Mourik Broekman,** eds. *Proud to Be Flesh: A Mute Magazine Anthology of Cultural Politics After the Net*. London: Mute Publishing, 2009.
- Sneyd, Steve.** "Harry Matthew / Oulipo." 2005. 12/9/2009. <www.lacan.com/matthews.htm>.
- Solaas, Leonardo.** "Concept of the Project." 2005a. 5/5/2010. <solaas.com.ar/dreamlines/about.htm>.
- Spengler, Oswald.** *The Decline of the West*. An Abridged ed. by Helmut Werner. 1959. Trans. Charles Francis Atkinson. New York: Vintage Books, 1962. 2006.
- Spiller, Neil,** ed. *Cyber Reader: Critical Writings for the Digital Era*. London: Phaidon Press, 2002.
- Stallabrass, Julian.** *Internet Art: The Online Clash of Culture and Commerce*. London: Tate Publishing, 2003.
- Starr, Paul.** *The Creation of the Media: Political Origins of Modern Communications*. New York: Basic Books, 2004.
- Stebbing, Peter D.** "There is a Universal Grammar for Visual Communication." *Generative Art*. Milan, 1998.
- Steeb, Willi-Hans.** *The Nonlinear Workbook: Chaos, Fractals, Cellular Automata, Neural Networks, Genetic Algorithms, Fuzzy Logic with C++, Java Symbolic C++ and Reduce Programs*. 1999. Second ed. Singapore: World Scientific Publishing, 2001.
- Steiner, George.** *Grammars of Creation*. London: Faber and Faber, 2001.
- Sterling, Bruce.** *Tomorrow Now: Envisioning the Next Fifty Years*. New York: Random House, 2002.
- . "When Bobjects Rule the Earth." *SIGGRAPH*. Los Angeles, California, 2004.
- . *Shaping Things*. Cambridge, Massachusetts: The MIT Press, 2005.
- . "Designing Processes Rather Than Art." *Fabrica*, 2008.
- Sterne, Jonathan.** "The Death and Life of Digital Audio." *Interdisciplinary Science Reviews* 31. 4 (2006a): 338-348.
- . "The MP3 as Cultural Artifact." *New Media and Society* 8. 5 (2006b): 825-842.
- . "Media or Instruments? Yes." *Offscreen* 11. 8-9 (2007).
- Stewart, Ian.** *Does God Play Dice? The New Mathematics of Chaos*. 1989. Second ed. London: Penguin Books, 1997.
- . *Os Números da Natureza: A Realidade Irreal da Imaginação Matemática*. 1995. Trans. Jaime Sarmiento. Lisboa: Temas e Debates, 2003.
- . *Why Beauty Is Truth: A History of Symmetry*. New York: Basic Books, 2007.

- Stewart, Ian, and Martin Golubitsky.** *Fearful Symmetry: Is God a Geometer?* London: Penguin Books, 1992. 1993.
- Stiny, George, and James Gips.** *Algorithmic Aesthetics: Computer Models for Criticism and Design in the Arts.* Berkeley, California: University of California Press, 1978.
- Stockburger, Axel.** "The Rendered Arena: Modalities of Space in Video and Computer Games." University of the Arts, 2006.
- Stocker, Gerfried, and Christine Schöpf.** *Code: The Language of Our Time.* Osterfilden-Ruit: Hatje Cantz Verlag, 2003.
- Strickland, Stephanie.** "Quantum Poetics: Six Thoughts." *Media Poetry: An International Anthology.* Ed. Eduardo Kac. Bristol: Intellect, 2007. 25-44.
- Strogatz, Steven.** *Sync: The Emerging Science of Spontaneous Order.* London: Penguin Books, 2003. 2004.
- Strosberg, Eliane.** *Art and Science.* 1999. New York: Abbeville Press, 2001.
- Struycken, Peter.** "SPLASH 1972/1974." *Artist and Computer.* Ed. Ruth Leavitt. Morristown, New Jersey: Creative Computing Press, 1976.
- Suchman, Lucy A.** "From Plans and Situated Actions. Preface: Navigation." *The New Media Reader.* 1987. Eds. Noah Wardrip-Fruin and Nick Montfort. Cambridge, Massachusetts: The MIT Press, 2003. 600-612.
- Sutherland, Ivan E.** "Sketchpad: A Man-Machine Graphical Communication System." *The New Media Reader.* 1963. Eds. Noah Wardrip-Fruin and Nick Montfort. Cambridge, Massachusetts: The MIT Press, 2003. 111-126.
- Svanæs, Dag.** "Understanding Interactivity: Steps to a Phenomenology of Human-Computer Interaction." *NTNU*, 2000.
- Taylor, Gregory.** "Introduction to Oblique Strategies." 1997. 27/4/2010. <[www.rtqe.net/ObliqueStrategies/OSintro.html](http://www.rtqe.net/ObliqueStrategies/OSintro.html)>.
- Tenhaaf, Nell.** "Mysteries of the Bioapparatus." *Immersed in Technology.* Eds. Mary Anne Moser and Douglas MacLeod. Cambridge, Massachusetts: The MIT Press, 1996. 51-71.
- Terzidis, Kostas.** "The Etymology of Design: Pre-Socratic Perspective." *Design Issues* 23. 4 (2007): 69-78. ———. *Algorithms for Visual Design Using the Processing Language.* Indianapolis, Indiana: Wiley Publishing, 2009.
- Thackara, John.** *In The Bubble: Designing in a Complex World.* Cambridge, Massachusetts: The MIT Press, 2005.
- Thacker, Eugene,** ed. *Hard\_Code: Narrating the Network Society.* Boulder, Colorado: Alt-X Digital Arts Foundation, 2001.
- Thayer, Pall.** "On Artists That Write Code and Artists That Do Not". 2008. 3/1/2010. <[pallit.lhi.is/microcodes/artists\\_that\\_write\\_code.pdf](http://pallit.lhi.is/microcodes/artists_that_write_code.pdf)>.
- . "The Microcode Primer: A Guide for Non-Coders Towards a Conceptual Appreciation of Code". Reykjavik, 2009a. 3/1/2010. <[pallit.lhi.is/microcodes/MCprimer.pdf](http://pallit.lhi.is/microcodes/MCprimer.pdf)>.
- Thompson, D'Arcy Wentworth.** *On Growth and Form.* 1917. Revised and enlarged ed. Cambridge: Cambridge University Press, 1942.
- Thomson, Phil.** "Atoms and Errors: Towards a History and Aesthetics of Microsound." *Organised Sound* 9. 2 (2004): 207-218.
- Tisseau, Jacques.** "Virtual Reality: In Virtuo Autonomy." University of Rennes 1, 2001.
- . "Virtual reality and complexity". Brest, 2004. 12/7/2010. <[www.enib.fr/~tisseau/pdf/paper/manifeste.uk.pdf](http://www.enib.fr/~tisseau/pdf/paper/manifeste.uk.pdf)>.
- Toffler, Alvin.** *The Third Wave.* New York: Bantam Books, 1980. 1990.
- Tomas, David.** *Beyond the Image Machine: A History of Visual Technologies.* London: Continuum, 2004.
- Toop, David.** *Ocean of Sound: Aether Talk, Ambient Sound and Imaginary Worlds.* London: Serpent's Tail, 1995.
- . *Haunted Weather: Music, Silence and Memory.* London: Serpent's Tail, 2004.

- Toulis, Tadeo.** "UGLY: How Unorthodox Thinking Will Save Design." 2008. Core77. <[www.core77.com/blog/featured\\_items/ugly\\_how\\_unorthodox\\_thinking\\_will\\_save\\_design\\_by\\_tad\\_toulis\\_11563.asp](http://www.core77.com/blog/featured_items/ugly_how_unorthodox_thinking_will_save_design_by_tad_toulis_11563.asp)>.
- Transcriptions Project.** "The Agrippa Files." Santa Barbara, California. University of California, Santa Barbara. 16/12/2009. <[agrippa.english.ucsb.edu](http://agrippa.english.ucsb.edu)>.
- Tronstad, Ragnhild.** "Semiotic and Nonsemiotic MUD Performance." *COSIGN*. Amsterdam, 2001.
- Tryfonidou, Katerina, and Dimitris Gourdoukis.** "What Comes First: The Chicken or The Egg? Pattern Formation Models in Biology, Music and Design." 2008. 30/12/2009. <[the-t-machine.blogspot.com/2008/06/what-comes-first-chicken-or-egg-pattern.html](http://the-t-machine.blogspot.com/2008/06/what-comes-first-chicken-or-egg-pattern.html)>.
- Tufte, Edward R.** *Envisioning Information*. 1990. Cheshire, Connecticut: Graphic Press, 2003.
- . *Visual Explanations: Images and Quantities, Evidence and Narrative*. 1997. Cheshire, Connecticut: Graphics Press LLC, 2005.
- . *Beautiful Evidence*. Cheshire, Connecticut: Graphics Press LLC, 2006a.
- . *The Cognitive Style of PowerPoint: Pitching Out Corrupts Within*. Second ed. Cheshire, Connecticut: Graphics Press LLC, 2006b.
- . *The Visual Display of Quantitative Information*. 2001. Second ed. Cheshire, Connecticut: Graphic Press, 2006c.
- Turing, Alan Mathison.** "On Computable Numbers, With an Application to the Entscheidungs Problem." *Proceedings of the London Mathematical Society* 2. 43 (1936): 544-546.
- . "Computing Machinery and Intelligence." *Mind* 59. (1950): 433-460.
- . "Solvable and Unsolvable Problems." *Mechanical Intelligence*. 1954. Ed. D.C. Ince. Amsterdam: Elsevier Science Publishers B. V., 1992. 187-203.
- Turkle, Sherry.** "Constructions and Reconstructions of the Self in Virtual Reality." *Cyber Reader: Critical Writings for the Digital Era*. Ed. Neil Spiller. London: Phaidon Press, 1994. 208-215. 2002.
- . *The Second Self: Computers and the Human Spirit*. 1984. Twentieth Anniversary ed. Cambridge, Massachusetts: The MIT Press, 2004.
- Turner, Alasdair.** "A Simple Model of the Belousov-Zhabotinsky Reaction from First Principles." London: Bartlett School of Graduate Studies, University College, London, 2009.
- Tyler, Christopher William.** *Artist and Computer*. Ed. Ruth Leavitt. Morristown, New Jersey: Creative Computing Press, 1976.
- Tzara, Tristan.** *Sete Manifestos Dada*. 1924. Trans. José Miranda Justo. Lisboa: Hiena, 1987.
- Ullman, Ellen.** *Close to the Machine: Technophilia and Its Discontents*. San Francisco, California: City Lights Books, 1997.
- Universal Everything.** "V&A Museum Video Art." 2008. 8/5/2010. <[www.universaleverything.com/276](http://www.universaleverything.com/276)>.
- Ventrella, J. J.** "Evolving Structure in Liquid Music." *The Art of Artificial Evolution: A Handbook on Evolutionary Art and Music*. Eds. Juan Romero and Penousal Machado. Berlin: Springer, 2008. 269-288.
- Verostko, Roman.** "Epigenetic Painting: Software As Genotype, a New Dimension of Art." *First International Symposium on Electronic Art*. Utrecht, 1988.
- . "verostko.com" 1995. 16/08/2009. <[verostko.com](http://verostko.com)>.
- . "The 'Cloud of Unknowing' Revisited." Minneapolis, Minnesota, 1998a. 16/08/2009. <[verostko.com/archive/writings/utm-notes.htm](http://verostko.com/archive/writings/utm-notes.htm)>.
- . "Seven Sisters: the Pleiades." 1998c. 18/1/2010. <[www.verostko.com/gladbeck/pleiades.html](http://www.verostko.com/gladbeck/pleiades.html)>.
- . "Epigenetic Art Revisited: Software as Genotype." *Code: The Language of Our Time*. Eds. Gerfried Stocker and Christine Schöpf. Osterfilden-Ruit: Hatje Cantz Verlag, 2003. 156-167.
- Viégas, Fernanda B., and Martin Wattenberg.** "Artistic Data Visualization: Beyond Visual Analytics." *HCI*, 2007.
- Virilio, Paul.** "The Aesthetics of Disappearance." *Cyber Reader: Critical Writings for the Digital Era*. Ed. Neil Spiller. London: Phaidon Press, 1980. 90-95. 2002.

- . *The Art of the Motor*. Trans. Julie Rose. Minneapolis, Minnesota: University of Minnesota Press, 1995.
- . *A Velocidade de Liberdade*. 1995. Trans. Edmundo Cordeiro. Lisboa: Relógio d'Água, 2000.
- . *Art and Fear*. 2000. Trans. Julie Rose. London: Continuum, 2003. 2004.
- . *Negative Horizon: An Essay in Dromoscopy*. 1984. Trans. Michael Degener. London: Continuum, 2005. 2007.
- Voegelin, Salomé**. *Listening to Noise and Silence: Towards a Philosophy of Sound Art*. New York: Continuum, 2010.
- von Baeyer, Hans Christian**. *Information: The New Language of Science*. 2003. London: Phoenix, 2004.
- von Neumann, John**. *The Computer and the Brain*. New Haven, Connecticut: Yale University Press, 1958. 1979.
- Wager, Willis**. "Composers and Crapshooters." New York, 2000. Carousel Publications. 8/9/2009. <[www.carousel-music.com/shooters.html](http://www.carousel-music.com/shooters.html)>.
- Walker, Jill**. "Piecing Together and Tearing Apart: Finding the Story in Afternoon." *ACM Hypertext*. Darmstadt, 1999.
- Walters, John L.** "Reputations: Karsten Schmidt." *Eye* 2009: 18-25.
- Wardrip-Fruin, Noah, and Nick Montfort**, eds. *The New Media Reader*. Cambridge, Massachusetts: The MIT Press, 2003.
- Ware, Colin**. *Information Visualization: Perception for Design*. Second ed. San Francisco, California: Morgan Kaufmann, 2004.
- Wark, McKenzie**. *A Hacker Manifesto*. Cambridge, Massachusetts: Harvard University Press, 2004.
- . "Post Human? All Too Human." 2005. 14/1/2008. <[neme.org/main/290/post-human](http://neme.org/main/290/post-human)>.
- . *Gamer Theory*. Cambridge, Massachusetts: Harvard University Press, 2007.
- Watz, Marius**. "Abstracts 1-3." 2004. 7/5/2010. <[www.unlekker.net/proj/abstracts/index.html](http://www.unlekker.net/proj/abstracts/index.html)>.
- . "It's All About the Software, Baby. Why Designers Should Code. Software Literacy, Generative Systems, Computational Design. What Happens When Media Becomes Software, and How Algorithms Are Materials Too. Soft & Intelligent Media, Open Source Thinking. It's a Plugin World Out There." 2006. 10/3/2007. <[workshop.evolutionzone.com/workshops/061211\\_hyperwerk/code/20061211\\_watz\\_Hyperwerk\\_Software\\_baby.pdf](http://workshop.evolutionzone.com/workshops/061211_hyperwerk/code/20061211_watz_Hyperwerk_Software_baby.pdf)>.
- . "Moving Towards the Inevitable: Brandon Morse." 2008b. 6/5/2010. <[www.generatorx.no/20080409/structural-tension-brandom-morse](http://www.generatorx.no/20080409/structural-tension-brandom-morse)>.
- Weizenbaum, Joseph**. *Computer Power and Human Reason: From Judgment to Calculation*. San Francisco: W. H. Freeman and Company, 1976.
- . "ELIZA: A Computer Program for the Study of Natural Language Communication Between Man and Machine." *Communications of the ACM* 26. 1 (1983): 23-28.
- Whitelaw, Mitchell**. *Metacreation: Art and Artificial Life*. Cambridge, Massachusetts: The MIT Press, 2004.
- . "More is More: Multiplicity and Generative Art." 2007. 15/01/2008. <[teemingvoid.blogspot.com/2007/10/more-is-more-multiplicity-and.html](http://teemingvoid.blogspot.com/2007/10/more-is-more-multiplicity-and.html)>.
- . "Synesthesia and Cross-Modality in Contemporary Audiovisuals." *Senses & Society* 3. 3 (2008): 259-276.
- Whitney, John**. "Computational Periodics." *Artist and Computer*. Ed. Ruth Leavitt. Morristown, New Jersey: Creative Computing Press, 1976.
- Wiener, Norbert**. *Cybernetics: or Control and Communication in the Animal and the Machine*. Second ed. Cambridge, Massachusetts: The MIT Press, 1948. 1965.
- . *The Human Use of Human Beings*. Boston, Massachusetts: Da Capo Press, 1954. 1988.
- . "Man, Machines, and the World About." *The New Media Reader*. 1954. Eds. Noah Wardrip-Fruin and Nick Montfort. Cambridge, Massachusetts: The MIT Press, 2003. 65-72.
- Wiggins, Geraint A.** "Music, Syntax, and the Meaning of 'Meaning'." *Symposium on Music and Computers*. Corfu, Greece, 1998.

- . “Towards a More Precise Characterisation of Creativity in AI.” *ICCBR*. Vancouver, British Columbia, 2001.
- . “Categorising Creative Systems.” *IJCAI*, 2003.
- Wilden, Anthony.** *The Rules Are No Game: The Strategy of Communication*. London: Routledge & Kegan Paul, 1987.
- Wilson, Stephen.** *Information Arts: Intersections of Art, Science, and Technology*. Cambridge, Massachusetts: The MIT Press, 2002.
- . *Art + Science Now: How Scientific Research and Technological Innovation Are Becoming Key to 21st-Century Aesthetics*. London: Thames & Hudson, 2010.
- Winograd, Terry, and Fernando Flores.** *Understanding Computers and Cognition: A New Foundation for Design*. 1986. Fifth ed. Norwood, New Jersey: Ablex Publishing Corporation, 1990.
- Wolfram, Stephen.** *A New Kind of Science*. Champaign, Illinois: Wolfram Media, 2002.
- Wollen, Peter.** “24 Mismatches of Sound and Image.” *Soundscape: The School of Sound Lectures 1998-2001*. Eds. Larry Sider, Diane Freeman and Jerry Sider. London: Wallflower Press, 2003. 221-230.
- Wright, Alex.** *Glut: Mastering Information Through the Ages*. Washington, DC: Joseph Henry Press, 2007.
- Wright, Alyssa.** “Building Process. A Framework for Fluid Construction.” *Ubicomp 07*. Innsbruck, 2007.
- Wright, Richard.** “Visual Technology and the Poetics of Knowledge.” *Computers & Art*. Ed. Stuart Mealing. Exeter: Intellect Books, 1997. 23-32.
- . “From System to Software: Computer Programming and the Death of Constructivist Art.” *White Heat, Cold Logic. British Computer Art 1960-1980*. Eds. Charlie Gere, Nicholas Lambert and Catherine Mason. Cambridge, Massachusetts: The MIT Press, 2006.
- . “Data Visualization.” *Software Studies: A Lexicon*. Ed. Matthew Fuller. Cambridge, Massachusetts: The MIT Press, 2008. 78-87.
- Xenakis, Iannis.** *Formalized Music: Thought and Mathematics in Composition*. New expanded ed. New York: Pendragon Press, 1992.
- . *Musica. Architettura*. 1976. Trans. Letizia Lionello, Giancarlo Secco and Angelo Varese. Ed. Roberto Sudasassi. Milano: Spirali, 2003.
- Young, La Monte.** “Notes to Compositions 1960”. 2001. 13/9/2009. <[www.diapasongallery.org/archive/01\\_06\\_20.html](http://www.diapasongallery.org/archive/01_06_20.html)>.
- Yuill, Simon.** “All Problems of Notation Will Be Solved by the Masses: Free Open Form Performance, Free/Libre Open Source Software, and Distributive Practice.” *FLOSS + Art*. Eds. Aymeric Mansoux and Marloes de Valk. Poitiers: GOTO10, 2008. 64-91.
- Zajec, Edward.** *Artist and Computer*. Ed. Ruth Leavitt. Morristown, New Jersey: Creative Computing Press, 1976.
- Zénouda, Hervé.** “Images et Sons dans les Hypermédias. De la Correspondance à la Fusion.” *H2PTM05*. Paris, 2005a.
- . “La ‘Forme Réseau’ Dans la Musique Écrite (Ouverture et Indétermination Dans la Composition Musicale des Années 1950/1960).” 2005b. 6/7/2010. <[zenouda.free.fr/texts/Indetermination.pdf](http://zenouda.free.fr/texts/Indetermination.pdf)>.
- . “Images et Sons Dans les Hypermédias. De la Correspondance à la Fusion.” Université Paris 13, 2006a.
- . “Relation Image/Son: de l’Illustration Sonore à la Fusion Multi-Modale.” *Colloque Illustration*. Bobigny, 2006b.
- Ziegfeld, Richard.** “Interactive Fiction: A New Literary Genre?” *New Literary History* 20. (1989): 341-372.
- Zielinski, Siegfried.** *Deep Time of The Media: Toward an Archaeology of Hearing and Seeing by Technical Means*. 2002. Trans. Gloria Custance. Cambridge, Massachusetts: The MIT Press, 2006.



## WORKS CITED

- Andre, Carl.** *Alloy Square*. 1970.
- Aranda/Lasch, and Terrol Dew Johnson.** *Baskets*. 2006.  
@c. 30×1.3. Alg-a, 2010.
- Bach, Johann Sebastian.** *Das Wohltemperierte Klavier*. 1722.
- Basinski, William.** *The Disintegration Loops*. 2062, 2002.  
———. *The Disintegration Loops II*. 2062, 2003a.  
———. *The Disintegration Loops III*. 2062, 2003b.  
———. *The Disintegration Loops IV*. 2062, 2003c.
- Becher, Bernd, and Hilla Becher.** *Cylindrical Gas Tanks*. 1984.
- Bodin, Magnus.** “Cent mille milliards de poèmes.” 1997. 9/5/2010. <x42.com/active/queneau.html>.
- Borges, Jorge Luis.** “A Biblioteca de Babel.” *Ficções*. 1989. Lisboa: Teorema, 1998a. 67-78.  
———. “O Jardim dos Caminhos que se Bifurcam.” *Ficções*. 1989. Lisboa: Teorema, 1998b. 79-96.  
———. “Pierre Menard, Autor do Quixote.” *Ficções*. 1989. Lisboa: Teorema, 1998c. 31-42.
- Brown, Adam, and Andrew Fagg.** *Bion*. 2006.
- Brown, Earle.** *December 1952*. 1952.
- Cage, John.** *Imaginary Landscape N° 1*. 1939.  
———. *Imaginary Landscape N° 4*. 1951.  
———. *Music of Changes*. 1951.  
———. “4'33””. 1952.  
———. *Cartridge Music*. 1960.
- Cardew, Cornelius.** *Treatise*. 1967.
- Carvalhais, Miguel, and Lia.** *Ozy, Tokei*. 2002. Force-Inc, Frankfurt.  
———. *Aus Lage [in Arbeit]*. 2003.
- Carvalhais, Miguel, Pedro Tudela, and Lia.** 30×1. 2005a. Solar, Galeria de Arte Cinemática, Vila do Conde.  
———. 30×1.01. Porto, 2005b.  
———. 30×1.2. 2007. Casa da Música, Porto.
- Cayley, John.** *Book Unbound*. London: Wellsweep, 1995.
- Close, Chuck.** *Robert / 104,072*. 1974.
- Cohen, Harold.** *AARON*. 1973a.
- Condon, Brody.** *Adam Killer*. 1999.
- Cortázar, Julio.** *Hopscotch*. 1963. Trans. Gregory Rabassa. New York: Pantheon, 1966.

- Crowther, William.** *Colossal Cave Adventure*. 1976.
- Csuri, Charles, and James Schaffer.** *Hummingbird*. 1967.
- Deutsch, Gustav.** *Film Ist. (1-6)*. 1998.
- Dockstader, Tod.** *Aerial #1*. Sub Rosa, 2005a.  
 ———. *Aerial #2*. Sub Rosa, 2005b.  
 ———. *Aerial #3*. Sub Rosa, 2006.
- Dragulescu, Alex.** *Extrusions in C Major*. 2006.
- Eno, Brian, and Peter Schmidt.** *Oblique Strategies*. 1975.
- Fake, Caterina.** *Mount Fuji*. 2000.
- Farmers Manual.** *Explorers\_We*. OR, 1998.
- FIELD.** *Animations for Aol. Rebrand*. 2009.
- Fischer, Andreas Nicolas.** *A Week in the Life*. 2008.
- Frank, Tina.** *Pita, Get Out*. 1999. Mego, Vienna.
- Frere-Jones, Tobias.** *F-Hz (#190736, 1996)*. Touch, 2000.
- Friedman, Tom.** *Untitled*. 2000.  
 ———. *Untitled*. 2004.
- Fry, Ben.** *All Streets*. 2008a.
- Fuchs, Martin, ed.** *Written Images*. Basel, in preparation.
- Gage, Zach.** *temporary.cc*. 2009b.
- Gescom.** *Minidisc*. OR, 1998.
- Gibson, William.** *Neuromancer*. Voyager Classics, 1984. 2001.  
 ———. *Agrippa (a Book of the Dead)*. Kevin Begos Jr., 1992.
- Gonzalez-Torres, Felix.** “Untitled” (*Public Opinion*). 1991.
- Granular Synthesis.** *Modell 3*. 1992.  
 ———. *Modell 5*. 1994.
- Harris, Jonathan, and Sep Kamvar.** *We Feel Fine*. 2006a. <www.wefeelfine.org>.
- Harvey, Auriea, and Michaël Samyn.** *The Graveyard*. 2008. Tale of Tales.  
 ———. *Vanitas*. 2010. Tale of Tales.
- Haydn, Joseph.** *Gioco Filarmonico*. 1790.
- Henze, Eno.** *Der Wirklichkeitsschaum*. 2007.
- Hoogerbrugge, Hans.** *The Inability To Solve a War at a Cocktail Party (an Awkward Dance with Mr. Henri van Zanten)*. 2010.
- Huntington, Andy, and Drew Allan.** *Cylinder*. 2003.
- Ikeda, Ryoji.** *Datamatic [prototype-ver.2.0]*. 2006.
- Jackson, Shelley.** *Patchwork Girl*. Cambridge, Massachusetts: The Eastgate Press, 1995.
- JODI.** *SOD*. 1999.  
 ———. *Untitled Game*. 2001.
- Joyce, Michael.** *Afternoon, a Story*. Cambridge, Massachusetts: The Eastgate Press, 1990.
- Judd, Donald.** *Untitled*. 1989.
- Kawara, On.** *June 19, 1967*. 1967.  
 ———. *Oct.31,1978*. 1978.  
 ———. *2 Juin 2000*. 2000.  
 ———. *Sept.25,2002*. 2002.
- Kirnberger, Johann Philipp.** *Der allezeit fertige Polonaisen und Menuetten Komponist*. 1757.
- Klingemann, Mario.** *Ornamism*. 2005.
- Knižák, Milan.** *Broken Music*. Multiplha Records, 1979.
- Kontopoulos, Michael.** *Inner Forests*. 2007.
- Kratky, Andreas.** *Absences*. 2004.
- Kubelka, Peter.** *Arnulf Rainer*. 1960.
- Kurbak, Ebru, and Mahir M. Yavuz.** *News Knitter*. 2007.

- Lab[au].** *Pixflow #2*. 2007a.
- Laric, Oliver.** *Moving Pixel Portraits*. 2006. <oliverlaric.com/pixel.htm>.
- Leandre, Joan.** *nostal(G) \_ PHOENIX WEST*. 2003.
- Leege, Jan Robert.** *Three Buttons*. 2005. <www.leege.org/works/online/threebuttons>.
- Levin, Golan.** *Yellowtail*. 2000c.
- . *Merce's Isosurface*. 2009.
- Levin, Golan, and Zach Lieberman.** *Reface [Portrait Sequencer]*. 2007.
- Levin, Golan, Gregory Shakar, and Scott Gibbons.** *Scribble*. 2000.
- Lewis, Matthew.** *Sketch*. 1998.
- LeWitt, Sol.** *Cubic Modular Piece N° 3*. 1968.
- . *All Single, Double, Triple, and Quadruple Combinations of Lines in Four Directions One-, Two-, Three- and Four-Part Combinations*. 1969a.
- . *Incomplete Open Cube*. 1974a.
- . *Variations of Incomplete Open Cubes*. 1974b.
- Lia.** "re-move.org". 1999-2003. <www.re-move.org>.
- . *int.16/54//son01/30x1*. 2005.
- . *Construction 76*. 2008a.
- . *Maxalot: Processing Light @ TodaysArt 2008*. 2008b.
- . *phiLia 01*. 2009.
- . *Visuals for the Hugo Wolf Festival*. 2010.
- Lia, and Dextro.** "turux.org". 1997-2001. <www.turux.org>.
- Lialina, Olia.** "My Boyfriend Came Back From the War". 1996. <myboyfriendcamebackfromth.ewar.ru>.
- Lu, David.** *Droom Zaacht*. 2004.
- Maeda, John.** *Amber Waves*. 2003.
- Manovich, Lev.** *Mission to Earth*. 2004b.
- . *Texas*. 2004c.
- Marclay, Christian.** *Record Without a Cover*. Recycled Records, 1985.
- . *Untitled (Record Without a Groove)*. Ecart Editions, 1987.
- . *Footsteps*. RecRec Music, 1989.
- . *Shuffle*. New York: Aperture, 2007.
- Mathieu, Stephan.** *FrequencyLib*. Ritornell, 2001.
- . *The Sad Mac*. Vectors, 2004.
- . *Radioland*. Die Schachtel, 2008.
- Mathieu, Stephan, and Taylor Deupree.** *Transcriptions*. Spekk, 2009.
- McDonald, Kyle.** *Only Everything Lasts Forever*. 2010a.
- Meier, Sid.** *Civilization*. 1991.
- Meta.** *Emeral*. 2004. <meta.am/image/emeral>.
- . *Folia*. 2007. <meta.am/image/fovia>.
- Molnár, Vera.** *Interruptions*. 1969.
- . *Sorties du rang*. 2003.
- . *L'ombre prend le dessus*. 2005.
- Morse, Brandon.** *A Confidence of Vertices*. 2008.
- Moulthrop, Stuart.** *Victory Garden*. Cambridge, Massachusetts: The Eastgate Press, 1992.
- Moura, Leonel.** *Robotic Action Painter*. 2006.
- Mozart, Wolfgang Amadeus.** *Musikalisches Würfelspiel im C K516f*. 1787.
- Müller, Andreas.** *For All Seasons*. 2004.
- Müller, Boris.** *Poetry on the Road*. 2006b.
- Muxel, Andreas.** *Connect*. 2008a.
- Nake, Frieder.** *Hommage à Paul Klee 13/9/65 Nr.2*. 1965.

- Napier, Mark.** *Black & White*. 2003. <potatoland.org/blackwhite>.
- Natzke, Erik.** *Crimson*. 2009a.  
 ———. *Found*. 2009b.  
 ———. *Rouge*. 2009c.  
 ———. *Shine*. 2009d.
- Nicolai, Carsten.** *Telefunken*. 2000.
- Noto.** *Telefunken*. Raster-Noton, 2000.
- NR2154, and Shiftcontrol.** *Identity Program for COP15 Copenhagen / United Nations Climate Change Conference 2009*. 2009.
- Onda, Aki.** *Ancient & Modern: Cassette Memories Vol. 1*. Phonomena Audio Arts & Multiples, 2003.
- Oswald, John.** *Plunderphonics*. Mystery Tape Laboratory, 1988.
- Oval.** *Systemisch*. Mille Plateaux, 1994.  
 ———. *.94diskont*. Mille Plateaux, 1995.  
 ———. *Dok*. Thrill Jockey, 1998.  
 ———. *Oval Process Public Beta*. 2000a.  
 ———. *Ovalprocess*. Thrill Jockey, 2000b.  
 ———. *Ovalprocess Terminals*. 2000c.  
 ———. *Ovalcommers*. Thrill Jockey, 2001.
- Paik, Nam June.** *Zen for Film*. 1964.
- Paterson, James.** *Page 0*. 2004. <www.presstube.com/project.php?id=217>.
- Pavić, Milorad.** *Damascene. A Tale for Computer and Compasses*. Trans. Ian Campbell: Enterzone, 1998.  
 <ezone.org/damaskin>
- Prudence, Paul.** *Talysis II*. 2009b.
- Pullinger, Kate, and Talan Memmott.** *Branded*. 2003. <tracearchive.ntu.ac.uk/frame/branded/index.html>.
- Quan, Tony, Evan Roth, Chris Sugrue, Zach Lieberman, Theo Watson, and James Powderly.** *EyeWriter Initiative*. 2009.
- Queneau, Raymond.** *Cent mille milliards de poèmes*. Paris: Gallimard, 1961.
- Rauschenberg, Robert.** *Oracle*. 1962-65.
- Reas, C.E.B.** *Process 11*. 2006a.  
 ———. *Process 12*. 2006b.  
 ———. *Process 13*. 2006c.  
 ———. *Process 14*. 2006d.  
 ———. *Process 15*. 2006e.  
 ———. *Process 16*. 2006f.  
 ———. *Process 18*. 2007.
- Reas, C.E.B., and Cait Reas.** *Tissue Collection*. 2008.
- Rohrer, Jason.** *Sleep is Death (Geisterfahrer)*. 2010.
- Reinhardt, Ad.** *Abstract Painting, Blue*. 1952.
- Rokeby, David.** *Watch*. 1995.  
 ———. *Seen*. 2002b.  
 ———. *Taken*. 2002d.  
 ———. *Sorting Daemon*. 2003b.  
 ———. *Gathering*. 2004a.  
 ———. *San Marco Flow*. 2005a.
- Rooster Teeth Productions.** *Red vs. Blue*. 2003-2010. <redvsblue.com>.
- Roth, Evan.** *White Glove MHI*. 2007.
- Roth, Evan, and James Powderly.** *GRL in Barcelona*. 2007.
- Ruscha, Ed.** *Various Small Fires and Milk*. Los Angeles, California, 1964.  
 ———. *Every Building on the Sunset Strip*. Los Angeles, California, 1966.

- . *Nine Swimming Pools*. Los Angeles, California, 1968.
- Russel, Steve, Martin Graetz, and Wayne Witaenem.** *Spacewar!* 1962.
- Saporta, Marc.** *Composition N° 1*. Paris: Éditions du Seuil, 1961.
- Schindling, Eva.** *BZ\_11295\_mode1\_A1.2\_B1.0\_C1.0*. 2009a.
- . *BZ\_112853\_mode1\_A1.2\_B1.0\_C1.0*. 2009b.
- Schmidt, Karsten.** *Enerugii*. 2008b.
- . *Print magazine August 2008 cover design*. 2008e.
- Schwartz, Lillian, and Kenneth Knowlton.** *Pixilation*. 1970.
- Seo, James Jung-Hoon.** *Slinky*. 2007.
- Siena, James.** *Enter the Faces*. 1996.
- . *Global Key, second version*. 2000.
- . *Multi-Colored Nesting Unknots*. 2004.
- Simon, John F., Jr.** *Every Icon*. 1997a.
- . *CodedocII*. 2003.
- Sims, Karl.** *Evolved Virtual Creatures*. 1994a.
- . *Galápagos*. 1997b.
- Soda.** *Soda Constructor*. 2000. <sodaplay.com/creators/soda/items/constructor>.
- Solaas, Leonardo.** *Dreamlines*. 2005b. <solaas.com.ar/dreamlines>
- Sommerer, Christa, and Laurent Mignonneau.** *A-Volve*. 1994.
- Stadler, Maximilian.** *Tables from which one can toss off countless Menuets and Trios for the Klavier*. 1781.
- Tarbell, Jared.** *Substrate*. 2003. <www.complexification.net/gallery/machines/substrate>
- . *Happy Place*. 2004. <www.complexification.net/gallery/machines/happyPlace>
- Thayer, Pall.** “Microcodes”. 2009b. 19/01/2010. <pallit.lhi.is/microcodes>.
- . *Sleep*. 2009c.
- Thompson, Jon, and Alison Craighead.** *Triggerhappy*. 1998.
- Tietchens, Asmus.** *Daseinsverfehlung*. Stille Andacht, 1993.
- Tmema, Jaap Blonk, and Joan La Barbara.** *Messa di Voce*. 2003.
- Tone, Yasunao.** *Solo for Wounded* CD. Tzadik, 1997.
- . *Wounded Man’Yo #38-9/2001*. Alku, 2002.
- Tudela, Pedro.** Stage design for *Rua! Cenas de Música para Teatro*. 2003. TeCA, Teatro Carlos Alberto. Porto.
- UBERMORGEN.COM, and Stefan Nussbaumer.** “The Sound of eBay.” 2008. 30/4/2010. <www.sound-of-ebay.com>.
- . *1001 Songs of eBay*. Crónica, 2009.
- Universal Everything.** *Lovebytes 2007 Identity*. 2007.
- . *Advanced Beauty: 18 Sound Sculptures*. 2009.
- Universal Everything, and Karsten Schmidt.** *Forever*. 2008a.
- . *Nokia Friends*. 2008b.
- Utterback, Camille, and Romy Achituv.** *Text Rain*. 1999.
- Verostko, Roman.** *Seven Sisters: The Pleiades*. 1998b.
- von Bismarck, Julius, and Benjamin Maus.** *Perpetual Storytelling Apparatus*. 2009.
- Wall, Darren, and Karsten Schmidt.** *Faber Finds book covers*. 2008.
- Warhol, Andy.** *Troy Diptych*. 1962.
- . *Oxidation Painting*. 1978.
- Watz, Marius.** *Amoebaabstract 01*. 2002a.
- . *Amoebaabstract 02*. 2002b.
- . *Amoebaabstract 03*. 2002c.
- . *Maxalot: Processing Light @ TodaysArt 2008*. 2008a.
- . *Conical*. 2009.
- Weisbeck, Markus, and Frank Hauschild.** *Rhizome Logo*. 2001.

- Whitelaw, Mitchell.** *Weather Bracelet*. 2009.
- Wicks, David.** *Flocking Gloves*. 2008.
- Wieden + Kennedy London, and Karsten Schmidt.** *onedotzero festival identity*. 2009.
- Wright, Will.** *The Sims*. 2000.
- Xenakis, Iannis.** *Duel*. 1958.
- . *ST/10-1, 080262*. 1956-62.
- . *Persepolis*. Editions RZ, 1971.
- . *Mycenae Alpha*. Neuma, 1978.
- Young, La Monte.** *Composition 1960 #7*. 1960a.
- . *Composition 1960 #9*. 1960b.
- . *Composition 1960 #10*. 1960c.