

Computational Mind Models for Emotional Behavioral Multi-Agent Systems

Daria Alexandrovna Barteneva

A Thesis presented for the degree of
Master in Artificial Intelligence and Intelligent Systems

Supervisor: Prof. Luís Paulo Reis
Co-Supervisor: Prof. Nuno Lau



Universidade do Porto
Faculdade de Engenharia

FEUP

December 2006

Dedicated to

My Parents and my Brother for the support and caring

Agradecimentos

A execução deste trabalho nunca seria possível sem o auxílio e colaboração das pessoas que me rodeiam. Pessoas que, numa dimensão relacional de índole mais profissional contribuíram para a construção da tese e, numa mais íntima, para a construção do meu “eu”. Pessoas que não conseguirei nomear na totalidade, mas às quais o “obrigada” não escapa.

Gostaria de agradecer, em primeiro lugar, ao Professor Luís Paulo Reis e ao Professor Nuno Lau por terem mantido a confiança e a paciência ao longo de todo este tempo, pela ajuda e motivação transmitida, pelo encorajamento, bom humor e disponibilidade constante. Agradeço as experiências partilhadas, o desafio constante na procura de respostas e ainda as soluções apresentadas, mesmo quando parecia que não existiam. Obrigada pela amizade, pelas muitas horas nocturnas, pela estratégia de trabalho que me ajudou a avançar, pelas muitas outras pequenas (grandes) coisas que nunca me seria possível descrever aqui.

Agradeço também aos meus pais e ao meu irmão, pelo apoio, paciência, compreensão e aconselhamento sábio. Um carinho especial para o meu pai, pela sabedoria e experiência que partilhou comigo e pelo questionamento constante de todos os meus passos, fazendo-me lutar e procurar as melhores resoluções.

Gostaria de agradecer em especial ao José Carlos Miranda, essencialmente pelas inúmeras discussões e trocas de ideias sobre programação de emoções, pelas horas de correcção dos meus erros e pelo debug da aplicação, além da amizade incrível que se estabeleceu entre nós.

Quero ainda agradecer à Dorabella Silva Santos pela disponibilidade e infindável paciência para a correcção do meu Inglês, pelas sugestões valiosas e pelo suporte dado.

Aos colegas e amigos que tornaram isto possível: um abraço especial.

*If you can keep your head when all about you
Are losing theirs and blaming it on you,
If you can trust yourself when all men doubt you,
But make allowance for their doubting too;
If you can wait and not be tired by waiting,
Or being lied about, don't deal in lies,
Or being hated, don't give way to hating,
And yet don't look too good, nor talk too wise:*

*If you can dream - and not make dreams your master;
If you can think - and not make thoughts your aim;
If you can meet with Triumph and Disaster
And treat those two impostors just the same;
If you can bear to hear the truth you've spoken
Twisted by knaves to make a trap for fools,
Or watch the things you gave your life to, broken,
And stoop and build 'em up with worn-out tools:*

*If you can make one heap of all your winnings
And risk it on one turn of pitch-and-toss,
And lose, and start again at your beginnings
And never breathe a word about your loss;
If you can force your heart and nerve and sinew
To serve your turn long after they are gone,
And so hold on when there is nothing in you
Except the Will which says to them: 'Hold on!'*

*If you can talk with crowds and keep your virtue,
Or walk with Kings - nor lose the common touch,
if neither foes nor loving friends can hurt you,
If all men count with you, but none too much;
If you can fill the unforgiving minute
With sixty seconds' worth of distance run,
Yours is the Earth and everything that's in it,
And - which is more - you'll be a Man, my son!
Rudyard Kipling*

Resumo

Os avanços recentes nas áreas das neurociências e da psicologia apontam para a evidência de que os fenómenos afectivos influenciam a inteligência a vários níveis, sendo inseparáveis dos conceitos que ligam a cognição e a acção. A percepção, a atenção, a memória, a aprendizagem, a tomada de decisão, a adaptação, a comunicação e a interacção social são alguns dos aspectos influenciados por eles. Este trabalho está inspirado na neurobiologia, psicofísica e sociologia e tem por objectivo a resolução do problema de construção de robôs autónomos capazes de interagir entre si e de construir estratégias baseadas no mecanismo de decisão temperamental. A modelação de emoções é uma área relativamente recente na Inteligência Artificial. Tais modelos podem idealmente fornecer-nos informações precisas sobre o comportamento humano. O desenvolvimento de modelos computacionais da emoção está focado na construção de sistemas que modelam, interpretam ou influenciam o comportamento humano.

Este trabalho apresenta um modelo computacional da mente baseado em algoritmos de decisão temperamentais e na implementação de um sistema Multi-Agente, comportamental e emocional com o objectivo de efectuar a análise e a avaliação das estratégias baseadas em comportamentos temperamentais. O nosso modelo computacional da emoção é inspirado na teoria de Avaliação (Appraisal) e em características do sistema nervoso. A maioria das teorias de Avaliação (Appraisal) define como a base do raciocínio as crenças, os desejos e as intenções, procedendo assim a avaliação emocional da situação dos agentes. A fim de criar um sistema comportamental emocional mais flexível e mais eficiente, o modelo de avaliação que implementamos é executado em simultâneo com a teoria temperamental de Pavlov, que estuda as características fundamentais de comportamento temperamental. O modelo emocional propoisto é escalável, flexível e modular, permitindo a avaliação em tempo real entre a qualidade e o desempenho do sistema. Foi utilizado um ambiente da simulação baseado no

simulador da competição Ciber-Rato para testar e avaliar as estratégias implementadas. Utilizando este simulador, foi realizado um conjunto de experiências a fim de testar o desempenho do sistema. Os resultados mostram que as estratégias baseadas em mecanismos da decisão temperamentais influenciam significativamente o desempenho do sistema e há uma dependência evidente entre o estado emocional dos agentes e a sua configuração temperamental. Mostram também a dependência entre o desempenho da equipa e a configuração temperamental dos membros da mesma. Estes resultados permitem-nos concluir que a arquitectura modular para a programação de emoções baseada na teoria temperamental é uma boa escolha para o desenvolvimento de modelos computacionais da mente para os sistemas comportamentais Multi-Agente, baseadas em emoções.

Abstract

Recent advances in neurosciences and psychology have provided evidence that affective phenomena pervade intelligence at many levels, being inseparable from the cognition-action loop: Perception, attention, memory, learning, decision-making, adaptation, communication and social interaction are some of the aspects influenced by them. This work draws its inspirations from neurobiology, psychophysics and sociology to approach the problem of building autonomous robots capable of interacting with each other and building strategies based on temperamental decision mechanism. Modelling emotions is a relatively recent focus in artificial intelligence and cognitive modelling. Such models can ideally inform our understanding of human behavior. We may see the development of computational models of emotion as a core research focus that will facilitate advances in the large array of computational systems that model, interpret or influence human behavior.

This work presents a computational mind model based on temperamental decision algorithms and an implementation of an emotional-behavioral multi-agent system for analysis and evaluation of different strategies based on temperamental behaviors. Our computational model of emotion is inspired on appraisal theory and on superior nervous system characteristics. Most appraisal theories assume that beliefs, desires and intentions are the basis of reasoning and thus of emotional evaluation of the agents situation. In order to create a more flexible and efficient emotion-based behavior system, the appraisal model is implemented in mixture with Pavlov's temperamental theory which studies the basic reasons for different temperamental behaviors. We propose a model based on a scalable, flexible and modular approach to emotion which allows runtime evaluation between emotional quality and performance. A simulation environment based on a Cyber-Mouse competition simulator was used to test and evaluate the strategies used on the work. A set of robotic experiments was conducted in order to test the performance of the system. Results achieved showed that the

strategies based on temperamental decision mechanism strongly influence the system performance and there are evident dependency between emotional state of the agents and their temperamental type, as well as the dependency between the team performance and the temperamental configuration of the team members, and this enable us to conclude that the modular approach to emotional programming based on temperamental theory is the good choice to develop computational mind models for emotional behavioral Multi-Agent systems.

Table of Contents

Chapter 1 Introduction.....	15
1.1 Introduction.....	15
1.2 Motivation.....	17
1.3 Some Considerations About Emotions.....	20
1.4 Thesis Structure.....	22
Chapter 2 Emotions.....	24
2.1 Introduction.....	24
2.2 Emotions and Feelings.....	26
2.3 Biological Basis of Emotion.....	30
2.4 Physiological Basis of emotions.....	32
2.5 Emotional Expressiveness.....	34
2.6 Emotional life of personality.....	36
2.7 Influence of emotions on the behavior of man.....	37
2.8 Basic classifications of emotions.....	39
2.9 Forms of emotional states.....	41
2.10 Temporary Insanity and Passions	42
2.11 Conclusion.....	43
Chapter 3 Temperament – Typologies of Personality.....	45
3.1 Introduction.....	45
3.2 A General Framework for Describing the Central Nervous System and Pavlov's Theory	50
3.2.1 Eysenck Methodology.....	59
3.2.2 Influence of the type of temperament on the activity	61
3.3 Temperamental Scale - Pleasure Arousal and Dominance (PAD).....	63
3.4 Analysis of Personality Factors in Terms of the Big-Five Temperamental Model.....	65

3.5 Conclusions.....	68
Chapter 4 Emotional Agents – State-of-the Art.....	70
4.1 Introduction.....	70
4.2 Broekens and DeGroot.....	71
4.3 Aaron Sloman.....	73
4.4 Velásquez.....	76
4.5 Lola Cañamero.....	80
4.6 Sandra Clara Gadanho.....	83
4.7 Andrew Ortony, Gerald L. Clore, and Allan Collins.....	86
4.8 Paolo Petta.....	87
4.9 Nico H. Frijda.....	88
4.10 Rosalind W. Picard.....	89
4.11 Rolf Pfeifer.....	89
4.12 Ana Paiva.....	90
4.13 Eugénio Oliveira and Luís Sarmiento.....	91
4.14 Summary and Conclusions.....	93
Chapter 5 Computational Approach to Emotional Agents.....	94
5.1 Introduction.....	94
5.2 Previous Assumptions.....	97
5.2.1 Software Agent.....	98
5.2.2 Emotional State.....	98
5.2.3 Emotional Agent.....	98
5.2.4 Temperament.....	98
5.2.5 Motivation.....	99
5.3 Appraisal Theory.....	99
5.4 Agents Behaviors.....	102
5.5 Implementation of Pavlov's Theory.....	105

5.5.1 Fuzzy Logic Application.....	106
5.5.1.1 Force.....	106
5.5.1.2 Mobility.....	107
5.5.1.3 Steadiness.....	107
5.5.1.4 Emotional Receptivity.....	108
5.6 Implementation of the PAD Model.....	109
5.6.1 Appraisal Bank.....	111
5.6.2 Coding Emotion-Related States.....	118
5.7 Integration of the Pavlov's Theory and PAD Model.....	119
5.8 Conclusions.....	120
Chapter 6 Simulation Environment.....	122
6.1 Introduction.....	122
6.2 Ciber-Mouse as an Experimental Platform.....	122
6.3 Cyber Mouse Modifications.....	128
6.4 Conclusions.....	130
Chapter 7 Experimental Results.....	131
7.1 General Description of Evaluations.....	131
7.2 Example of Evaluation of the Homogeneous Temperamental Team.....	133
7.2.1 Choleric Team.....	133
7.2.1.1 Simple Small Arena.....	134
7.3 Non-Homogeneous Multi-Temperamental Team.....	136
7.4 Evaluation Results.....	136
Chapter 8 Conclusions.....	142
Chapter 9 References.....	144
Appendix A – Psychology Glossary.....	154

List of Figures

Schema of the Emotional Process.....	27
Example of James-Lange theory.....	33
Emotional process by James-Lange.....	33
Central Nervous System Diagram.....	53
Image of woodcut from 18th century text by Johann Kaspar Lavater: Four Temperamental Types.....	56
Scale of temperamental classification by Eysenck.....	60
Mehrabian Temperamental Scale.....	64
Overview of the components of the FeelMe framework.....	72
Emotional Process.....	88
Temperamental Architecture.....	97
Schacter-Singer Appraisal Theory.....	101
BDI Based Agent Architecture.....	102
Graphical definition of a behavior.....	102
Motor and Sensor Strength.....	107
Anxiety Scale.....	108
Emotional Receptivity Scale.....	109
Central Nervous System vs PAD Model.....	115
PAD vs Four Temperaments (Sanguine, Choleric, Phlegmatic and Melancholic).....	116
Multi Agent Architecture.....	120
Ciber Mouse Simulation Model.....	123
Body of the Virtual Robot (Ciber-Mouse: Rules and Technical Specifications).....	124
Sensor Characterization.....	126
Actuator Characterization.....	126

Ciber-Mouse Maze.....	127
Screenshot of the Agent Control and Configuration Panel.....	129
Example of the 1st scenario.....	132
Example of complex scenario with large arena.....	132
Example of the complex scenario with the small arena.....	133
Emotional Valence (Choleric Homogeneous Team).....	134
PAD Values (Choleric Homogeneous Team).....	135
Team performance vs Appraisal Emotional State.....	139
Team Performance vs PAD, Motor, Sensor and Anxiety values.....	140
Team Performance and Emotional State by different scenarios.....	141

List of Tables

Table 1: Mapping OCC into PAD Space [106].....	110
Table 2. Appraisal Survival Bank.....	113
Table 3. Appraisal Temperamental Bank.....	113
Table 4. Appraisal Goals Bank.....	117
Table 5: Emotion Related States.....	119
Table 6: Average Values of the Temperamental Configuration.....	134
Table 7: Appraisal Results (Choleric Homogeneous Team).....	135
Table 8: Maximum and Minimum of the Appraisal Values (Choleric Homogeneous Team)	135
Table 9: Labels for the Table 11.....	136
Table 10: Scenario Descriptions.....	137
Table 11: Final Results.....	138

Chapter 1 Introduction

“What most experimenters take for granted before they begin their experiments is infinitely more interesting than any results to which their experiments lead.”

Norbert Wiener

1.1 Introduction

With this inspiring quote, of the famous mathematician Norbert Wiener, we started exploring new ways of including emotions in robotic environments.

Emotions are part of our every day lives. They help us focus attention, remember, prioritize, understand and communicate. Emotions are the chemical that integrates our minds and bodies, literally. The possibility of computation of emotions has interested researchers for many years. Emotions influence decision-making processes, socialization, communication, learning and many other important issues of our life. Implementation of emotions in an artificial organism is an important step for different areas of intervention, like academical inquiry, education, communication, entertainment and others [9], [15], [18], [21]. Among the models of emotions that are described through the computational process different approaches

exist to the proper concept of emotion. Each model results from the definition that is given to the emotional process, since analysis of needs/satisfactions of the human being, passing through the analysis of the characteristics of the superior nervous system and analysis of the psychology of individual personality [1], [3], [7], [8], [16], [17].

The most important questions in this area are: What is emotion? How can we represent emotions through computational models? As Marvin Minsky said [3] our culture sees emotions as a deep and ancient mystery. He also reinforced that psychology has not even reached a consensus on which emotions exist. He describes emotions as a complex rule of schemes which we develop during our mental growth submitted to external influences like learning. A more detailed approach was made by António Damásio [17] who studied emotions from a neurobiological perspective. He divided emotions into two groups: primary and secondary. In the first group he included the emotions which depend on our limbic system and these are innate reactions. For instance, young birds do not know what “eagle” is, but they hide when an object with large wings and high speed comes close. In the second group Damásio included emotions we develop during our life based on our experience. Finally he defined emotions as a process of mental evaluation, simple or complex, with disposal responses directed to the body and the brain resulting in additional brain alterations.

In the context of this work emotions are defined as a set of external and internal responses which depends on a set of rules based on agent beliefs, desires and intentions. The other research questions we are trying to answer are: How can we define these rules? To proceed with the development of our emotional model we need to use some kind of quantitative measure to evaluate emotional state. But what is this “emotional state”? An interesting definition for this concept was given by Mehrabian [1]. He defined it as transitory conditions of the organism – conditions that can vary substantially, and even rapidly, over the course of a day. He also defined “emotional traits” (i.e. temperament) as conditions that are stable over periods of a year or even a lifetime. The classical definition for “Temperament” follows: it is a

specific feature of Man, which determines the dynamics of his mental activity and behavior. Two basic indexes of the dynamics of mental processes and behaviors at present are distinguishable: activity and emotionality. In this project we will analyse and develop an emotional model for the agents with temperament. We will use a full approach to emotion/temperament concepts: based on nervous system characteristics and based on psychological characteristics of the agents.

Useful as a historical foundation for the persistent questions about the nature of emotion is the work of William James [37]. James identifies the contradictions inherent in understanding emotion from either a purely cognitive or purely physiological perspective. In doing so, he elucidates one of the major hurdles to modelling emotion in computation: what is left of emotion if there is no physiological response? His physiological analysis of emotion does not, of course, take into account the knowledge of the last 100 intervening years. That limitation aside, his analysis is a helpful framework for integrating the various components into an understanding of emotion that takes into account mind and the subjective self.

1.2 Motivation

Many studies have been performed to integrate emotions into machines. Researchers have focused on the functions of emotion for computational models trying to describe some of the behavioral responses to reinforcing signals, communications which transmit the internal states or social bonding between individuals, which could increase fitness in the context of evolution [23]. There are several arguments suggesting that emotion affects decision-making in humans [17]. In the least, it is universally recognized that the benefits of humans having emotions encompass more flexible decision-making, as well as relativity [24].

This work draws its inspirations from neurobiology, psychophysics and sociology to approach the problem of building autonomous robots capable of interacting with each other

and able to build strategies based on temperamental decision mechanism. Several researchers have acknowledged the importance of emotions in human thinking and behavior, and neurological evidence support this idea. As described in Pavlov's theory [16], all human and animal behaviors are coordinated by the Central Nervous System (CNS). Therefore we can not study emotional agents without considering the particularities of the CNS and, consequently, the particularities of temperamental theory.

The study of emotions on a computational perspective has called the attention of the researcher for some years. Different projects are conducted in order to create an agent whose internal structure and behavior is inspired by ideas of emotions. There are many applications for emotional machines: education, health care, rescue, entertainment and other areas.

In psychology, emotion is often defined as a psychological state or process that functions in the management of goals and needs of an individual [4]. Each emotional behavior can be described by the different states of physiological changes, feelings, expressive behavior and inclinations to act. Psychologists describe emotion as a result of the evaluation of each event as positive or negative for the accomplishment of the goals. As argued by Sloman and Croucher, emotional robots can prioritise their decision making process [27]. They claim that humans use emotions to give priority to life-goals. For instance, humans often give higher precedence to goals that make them feel happy or fulfilled [6]. Similarly, intelligent robots performing complex tasks must prioritise their activities in some manner. Emotional decision mechanisms can work in order to prioritise actions and determine which task an agent should perform.

In this work we approach the problem of building autonomous robots capable of interacting with each other and able to build strategies based on a temperamental decision system. For defining our temperamental model we use Fuzzy Logic, since the subject of our study is the emotion and the temperament which are very uncertain concepts and difficultly measurable and there are no pure temperaments in nature, but mixtures of different

characteristics.

We will focus our work on temperament-based agents and in order to categorize the emotional feedback the Mehrabian PAD model [1] will be used.

On this work temperament is viewed as the many mental differences between people - difference in the depth, intensities, stability of emotions, emotional sensitiveness, rate of processes, the energy of actions and other dynamic, individual steady special features of mental life, behavior and activity. Nevertheless, the definition of temperament, today, remains in many aspects a questionable and unresolved problem. However, with an entire variety of approaches to the problem, scientists and practice recognize that temperament is a biological foundation, on which personality is formed as a social essence. Temperament has a strong effect on man's nature, on his behavior, and also on the general fitness for work.

So, what is temperament? Temperament¹ is the characteristic of individual from the side of the dynamic special features of his mental activity, i.e., rate, rapidity, rhythm, intensity, that compose this activity of mental processes and states. Temperament - quality of personality, which was formed in the personal experience of man on the basis of a genetic conditionality of his type of nervous system and which to a considerable extent, determines the style of his activity. Temperament relates to the biologically caused substructures of personality [47, 49, 50].

Four basic types of temperament may be distinguished: sanguine person, choleric, phlegmatic person and melancholic [16, 22, 33-35, 46-50]. The temperament reflects the dynamic aspects of behavior, predominantly innate nature; therefore the properties of temperament are most steady and constant in comparison with other mental special features of man [16]. The most specific special feature of temperament consists in the fact that different properties of the temperament of a person are not randomly combined with each other, but it is regularly connected together, forming a specific organization and structure. Thus,

¹ From the Latin: Temperament - proper relationship of features from temper - mixed up in the proper state

temperament should be understood as the individually unique properties of psyche, which determine the dynamics of mental human activity and which, being equally manifested in the diverse activity independent of its content of purposes and motives, remains constant at ripe age and the interrelation characterizes the type of temperament.

We considered also the Damásio Theory [17] which distinguishes between primary (innate) and secondary emotions those arising later in development of an individual as systematic connections are identified between primary emotions and categories of objects and situations [21], [30].

Another theory very interesting and useful in this project was developed by Izard [26, 32]. Izard is a well-known clinical psychologist at the University of Delaware whose primary area of study is emotion. In his work he makes a thorough examination of the role of emotion in interaction with the environment and with other humans; and of various theories of emotion. Of particular notice is the Cognitive-Affective approach, which examines—primarily from a developmental perspective—the role of emotion in making sense of the environment; and ”Emotion as the Interaction of Need and the Probability of Goal Achievement” which we find very interesting since it supports the idea of emotion as the intersection of intention with context. Izard examines the principal methods used in the study of psychology of emotion. In his work [32] he discusses the relationship between emotion and consciousness, particularly how emotion influences perception and facilitates the experience of consciousness. The balance of his work studies individual emotions in depth.

1.3 Some Considerations About Emotions

Emotions play a crucial role in mediating human social relationships [54, 55]. Emotion can also act as a mental process, altering how people see the world, how they form decisions, and how they respond to the environment. In the next chapter, we focus on emotions that have

a social component: the rage arising from a perceived offence, the guilt we feel after harming another. Such emotions arise from social explanations involving judgements not only of causality but intention and free will [68]. These explanations underlie how we act on and make sense of the social world. In short, they lie at the heart of social intelligence. With the advance of multi-agent systems, user interfaces, and human-like agents, it is increasingly important to reason about this uniquely human-centric form of social inference. Here we relate recent progress in modelling such as socio-emotional judgements.

On the one hand, modelling applications must account for how people behave when experiencing intense emotion including disaster preparedness (e.g., when modelling how crowds react in a disaster [56], training (e.g., when modelling how military units respond in a battle [57], and even macro-economic models (e.g., when modelling the economic impact of traumatic events such as 9/11 or the SARS epidemic). On the other hand, many applications presume the ability to correctly interpret the beliefs, motives and intentions underlying human behavior (such as tutoring systems, dialogue systems, mixed-initiative planning systems, or systems that learn from observation) and could benefit from a model of how emotion motivates action, distorts perception and inference, and communicates information about mental state. Emotions play a powerful role in social influence, a better understanding of which would benefit applications that attempt to shape human behavior, such as psychotherapy applications [58, 59], tutoring systems [60-62], and marketing applications [63, 64]. Lastly, models of emotion may give insight into building models of intelligent behavior in general. Several authors have argued that emotional influences that seem irrational on the surface have important social and cognitive functions that would be required by any intelligent system [3, 17, 18, 65, 66]. For example, social emotions such as anger and guilt may reflect a mechanism that improves group utility by minimizing social conflicts, and thereby explains people's "irrational" choices in social games such as prisoner's dilemma [67].

1.4 Thesis Structure

The remainder of this dissertation will be organized as follows:

Chapter 2: Emotions. This chapter contains a revision about the most important aspects of Human Emotion especially those concerning the functionalities of Emotion. It is focussed on discussing the emotional basis, states and behaviors that can be usefully applied or transposed to the development of Emotional Multi-Agent System. Although this section may be considered rather dense, the concepts discussed therein are essential for subsequent formalizations developed in the following chapters.

Chapter 3: Temperament – Typologies of Personality. This chapter makes a revision about the most important temperamental studies and presents the fundamental theories used in this work: Pavlov's theory about the superior nervous system and Mehrabian's models for temperamental classification.

Chapter 4: Emotional Agents: State-of-the-Art. Contains a review of related work developed with similar goals and makes some observations about what we consider more interesting and more relevant for work development.

Chapter 5: Computational Approach to Emotional Agents. Introducing the proposed model of Temperamental Mechanisms and explaining how it can be integrated in a general Multi-Agent System. We will present the modular architecture for implementation of a multi-agent system with Personality characteristics. Specifically, we will try to demonstrate how such Emotional Mechanisms can be used to transpose functional Human Emotion interactions to Synthetic Agents. We will also try to show how this can be advantageous for Agents in general, and especially for robotic agents with physical characteristics. We will also explain how Emotional-mechanisms may be configured to alter the global behavior of the Agent, enabling the development of Agents with different Temperaments.

Presenting the prototype of the Emotion-based Multi-Agent System with temperamental

characteristics that we have developed, instantiated for the Cyber-Mouse environment. Present each of the functional modules that compose the Architecture and explain how they are organized in two different processing layers. We will explain how Temperamental Mechanisms are used in the Architecture to dynamically influence several of the internal parameters available. We will also explain the influence of Emotional Mechanisms on perception, on decision-making, on goal selection and also on the Agent's global attitude towards the environment. We will explain how all these interactions are advantageous for the Agent and how they may even be considered as a requirement for intelligent behavior under resource constraints.

Chapter 6: Simulation Environment. This chapter presents in detail the Cyber-Mouse Simulation Platform, and individually describes each of its composing elements. We will thoroughly describe the simulated environment and discuss its most relevant properties for Agent development. We will present the implementation we made in order to adapt the simulation system to our needs.

Chapter 7: Experimental Results. A set of experiments conducted in order to evaluate our Temperamental multi-agent system and prove the consistency of our theory is described in detail.

Chapter 8: Conclusion. Presenting the summary of the most relevant points of our Emotion-based Multi-Agent System and analysing the most important aspects and limitations of Emotional Mechanisms. We will also point out possible lines for future work, namely: including additional Emotional Mechanisms in the current Agent Architecture, exploring the implementation of different search strategies for emotional multi-agent systems.

The reader can also find some additional information about the psychology glossary in Appendix A.

Chapter 2 Emotions

2.1 Introduction

Emotions are the experiences of man, accompanied by feelings of pleasant and unpleasant, pleasure and displeasure, and also by their diverse nuances and by combinations. *Pleasure* and *displeasure* - these are the simplest emotions. Their more complex versions are such feelings as *happiness*, *grief*, *melancholy*, *fear*, *anger*.

The difference between emotions and sensations is defined in terms of the fact that sensations are usually accompanied by no specific subjective experiences of the type of pleasure or displeasure, pleasant or unpleasant. They give to man objective information about that which occurs in it and out of it. However, emotions express the subjective states of man, connected with his needs and motives, by themselves.

Practically is not easy to separate emotions from sensations, since they merge in the unified experience of man. For example, the perception of the works of skill in the means is always accompanied by these or other emotional experiences, which express the attitude of man toward the fact that he sees and feels. Interesting, successful thought, creative activity is accompanied by emotions. Different kinds of recollections are also connected with the means and contain not only information, but also feeling. The simplest gustatory senses, such as acid,

sweet, bitter and salt, also are so poured with the emotions that, without them, are not encountered in life.

Physical and psychological states of man and his organism are reflected in the emotions. A healthy person, in which all basic vital needs are satisfied, feels satisfactoriness; a person whose needs are not satisfied chronically, experiences dissatisfaction.

The successfully executed action, the well made matter generate pleasant emotions, and failures are accompanied by unpleasant emotional experiences. Whatever mental or organic processes, such as the behavioral report we examined, everywhere it is possible to reveal their close connection with emotions. Consequently, emotion is a necessary attribute of any manifestation of life.

What is the role of emotions? In first place, they reflect, in their quality, the nature of the flow of different vital processes. In second place, they govern these processes, activating or preventing them depending on needs. By vital processes we understand that every process is meaningful to satisfaction of the needs of the person.

Although there are emotions in all living beings, the emotional life of man is nevertheless the richest. Besides the simplest emotions, characteristic of all highest living beings: *pleasant* and *unpleasant*, *fear*, *fury*, etc., in man there are more complex emotions, connected with the knowledge he acquires in life, like: *moods*, *temporary insanity*, *feelings*, *passions* and *stresses* [33]:

Moods - these are the weakly grown, long time and the preservable emotional state, connected either with the general physical or with the psychological health of man in this period of time.

Temporary insanity (Affect) is the short-term and strong emotional experience, stormily elapsing, affecting basic physiological processes in the organism and connected with the outstanding events in the life of man, the achievements and the omissions, the successes and

the failures. Examples of temporary insanity: *happiness, anger, grief, fear*.

Feelings - these are the complex connections of diverse moods and passions, related in the person with different, personally essential events of life, with the people around him, and the objects or with the forms of activity that surround him.

Sometimes the word "feeling" is used in the wider value, using it as a synonym of concept "emotion". But in a stricter, more scientific sense this word designates the set of the specific emotions, which are caused in a person by significant people, events or objects from the surrounding reality, and also by forms of occupations. This is, those emotions which are usually accompanied by means, ideas and thoughts of people about objects which surround them, and which occur with them.

Passion is the excessively strong, entirely suppressing feeling, which subordinates to itself all the remaining emotions and desires, that impels man besides his will to specific actions related to the object of passion. These emotions are governed with difficulty by consciousness and by the thinking man, and what is more - they frequently subordinate them to themselves, making behavior unreasonable and actually weakly willed. The object of the passion of man can be any another person, such as specific kinds or forms of occupations, any vital purpose, the tendency toward which man devotes his entire life.

Stress is the emotional experience, which reached such force, that it begins to negatively affect the general physical state, psychological processes and behavior.

2.2 Emotions and Feelings

We will begin the discussion about the emotions and feelings from the question, which seems strange and unexpected at first glance: *why are feelings necessary, why are emotions necessary?*

We already know that the reflection of the surrounding reality is accomplished because of the cognitive processes. In this case each of the studied processes introduces their contribution [36]:

1. **sensations** provide information about the separate properties and the signs of objects and phenomena;
2. **perception** give the integral means;
3. **memory** stores which is perceived;
4. **thinking** and fantasy process this material in the thought and new means.

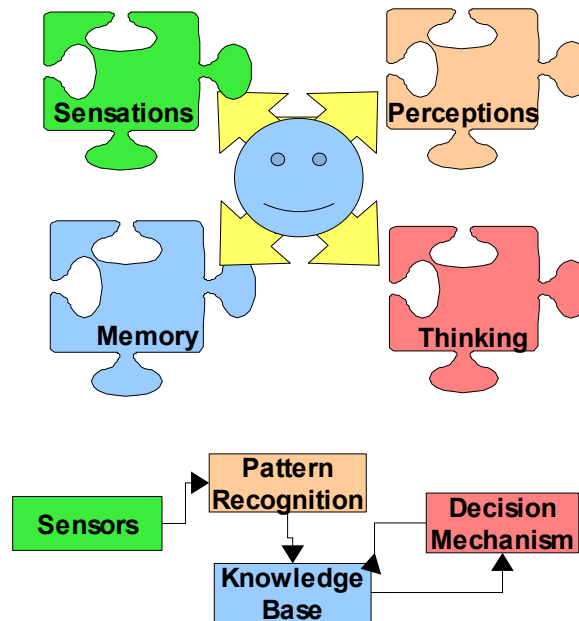


Figure 1: Schema of the Emotional Process

On Figure 1 we can observe the relationship between different components of the emotional process and its schematic representation.

Man achieves his plans mainly because of will and dynamism. Would it be easy to

manage without happiness and suffering, pleasure and vexation and finally without love and hate?

At the same time we know from our personal experience that the entire cognitive activity and even our entire life are unthinkable without emotions and feelings.

Since remote antiquity arose the idea about the trinomial structure of mental life: **mind**, **will** and **feeling**. At the same time, as the historians of psychology noted, the greatest attention was always paid to the study of cognitive and volitional processes, whereas a study of emotional life remained in the domain of poetry and music. However, nowadays many scientists and entire scientific associations deal with the problem of emotions and feelings. And one of the chief problems remains, from which we began our discussion: *why are feelings necessary?* In other words, such as their functions, what role do they play in the mental life of man?

There is no short answer to this question. The fact is that emotions and feelings do not have one specific function, but several. First of all, emotions and feelings, as all the remaining mental processes, are the reflection of genuine reality, but only in the form of experience. In this case the concepts of "emotion" and "feelings", which we, until now, used as equivalent, in reality designate different mental phenomena, which, of course, are intimately connected together. In the emotions and feelings are reflected the needs of man, and the way these needs are satisfied.

In the emotional experiences it is reflected the vital significance of this phenomena and situations and their influence on the person. In other words, emotion is a reflection of phenomena and situations in the form of partial experience of the vital sense [32]. In conclusion, we can say that **all which facilitate satisfaction of needs causes positive emotional experiences, and, on the contrary, everything which prevents this, causes negative emotional experiences.**

An important difference between feelings and emotions is the fact that feelings possess

relative stability and constancy, and emotions appear in response to concrete situations. The deep connection of a feeling with emotions is manifested, first of all, in the fact that a feeling survives and is revealed precisely in the concrete emotions. So, a feeling of love for other person can survive depending on situation, for instance it depends on the emotion of happiness, pleasures from the contact, anxieties if anything is threatened, vexation, if it did not justify our hopes, pride for its successes, shame if it completed anything unworthy and, etc. Into the structure of a feeling enters not only the emotion, the direct experience, but also the more generalized relation, connected with knowledge, with understanding, with concept.

One of the main functions of emotions lies in the fact that they help us on orientation in the surrounding reality, to estimate objects and phenomena from the point of view of their desirability or undesirability, usefulness or harmfulness. In the opinion of Russian psychophysiology Simonov [34], emotion appears when there is disagreement between what is necessary to be known in order to satisfy need (necessary information) and what it is known in reality. The formula of emotions is created on this basis:

$E=N (UI-KI)$ where E - emotion,

N - the need (for the formula it is taken with the negative sign "-");

UI - information, necessary for the satisfaction of need;

KI - information, which can be used, that is already known.

Four consequences follow from this formula:

1. if $N = 0$, i.e. if there are no needs, E is also equal to 0.
2. $E = 0$, i.e. emotion does not even appear when $UI=KI$. This is the case, when a person who experiences need, possesses complete possibility for its realization.
3. E is maximum, if $KI= 0$. This means that the emotion reaches its greatest force when need exists, but there is no information about how to satisfy it. Here emotion

seemingly compensates information scarcity. There are reasons to indicate that it is uncertainty that frightens and not the event itself.

4. finally, according to the formula, in the case, when $KI > UI$, a positive emotion must arise.

According to the theory of Simonov, the appearance of emotion is caused by the scarcity of pragmatic information (when UI is greater than KI); more precisely, this causes the emotions of the negative nature: aversion, fear, anger and so on. Positive emotions, such, as happiness and interest, appear in the situation, when the obtained information increases the probability of satisfaction of the need in comparison with the already existing forecast; in other words - when KI is greater than UI .

Many phenomena of emotional life can not be plotted by the formula. And this is not surprising: life is always richer than formulas.

Emotions are also of great value for the regulation of behavior when the instantaneous mobilization of all forces and possibilities of the organism is required. Is it not here that we should search the reason for the surprising phenomenon, at first glance, that under the effect of strong emotions man can accomplish the impossible?

2.3 Biological Basis of Emotion

The close connection of emotions with the vital processes indicates a natural origin, at least for the primary emotions. In all those cases, when life of the living being stops, partially or completely, we, first of all, reveal that its external, emotional manifestations disappeared. The section of the skin, temporarily deprived of blood supply, ceases to be sensitive; a physically sick person becomes apathetic, indifferent to the facts that occur around him, i.e. insensible. He loses the ability to emotionally respond to external actions in the same manner that with the normal flow of life.

All the highest animals and man have structures in the brain which are closely related to the emotional life. This is the so-called limbic system, where the accumulations of nerve cells enter, located under the cerebral cortex, in immediate proximity to its centre, which manage the basic organic processes: blood circulation, digestion, the glands of internal secretion. Hence close connection of emotions exists both with the consciousness of man and with the states of his organism.

Keeping in mind the great vital value of emotions, Charles Darwin [44] proposed a theory, which explains origin and designation of those organic changes and motions, which usually accompany the clearly expressed emotions. This theory was called *evolutionary* and focused attention on the fact that pleasure and displeasure, happiness, fear, anger, grief are manifested approximately in an identical way both in man and in anthropomorphous monkeys.

Darwin become interested in the vital sense of those changes in the organism, which accompany the appropriate emotions. After comparing facts, Darwin arrived at the following conclusions about the nature and the role of emotions in life:

1. Internal (organic) and external (engine) manifestations of emotions perform in the life of man an important adaptive role. They tune it to defined actions and, furthermore, they are the signal about how it is disposed and which is intended to undertake another living being.
2. Once in the process of the evolution of the living beings those organic and engine reactions, which they have at present, were the components of the valuable, expanded practical adaptive actions. Subsequently their external components were reduced, but vital function remained. For example, a man or animal in anger sneer teeth, strain muscles, and if being prepared for the attack, the respiration and pulse are accelerated. This is the signal: the living being to be prepared for a complete act of aggression.

2.4 Physiological Basis of emotions

Nowhere, perhaps, is revealed so vividly the interrelation of physiological and mental phenomena, of body and soul, as in psychology of emotions. Emotional experiences are always accompanied by more or less profound alterations in the activity of the nervous system, heart, respiration, glands of internal secretion, muscular system and so on. Under the effect of emotions, voice, the expression of the eyes, the blush of the skin are changes. Emotions are capable of covering by their influence the entire human organism, of disorganizing or, on the contrary, of improving its activity.

But how are psychological emotional states and corresponding physiological changes connected together? What does it depend on? At first glance, everything is clear: when man is under the effect of any external action a specific emotion appears, which produces these or other physiological changes. However, this is not so simple. At the end of the XIX century American psychologist William James [37] and, independently, Danish physiologist Carl Lange [94] advanced the theory of emotions, which was called theory James - Lange. *"My theory ... is that the bodily changes follow directly the perception of the exciting fact, and that our feeling of the same changes as they occur is the emotion. Common sense says, we lose our fortune, are sorry and weep; we meet a bear, are frightened and run; we are insulted by a rival, and angry and strike. The hypothesis here to be defended says that this order of sequence is incorrect ... and that the more rational statement is that we feel sorry because we cry, angry because we strike, afraid because we tremble ... Without the bodily states following on the perception, the latter would be purely cognitive in form, pale, colorless, destitute of emotional warmth. We might then see the bear, and judge it best to run, receive the insult and deem it right to strike, but we should not actually feel afraid or angry"* [37]. Consequently, in the opinion of James, the reason for emotional experience is not one or another agitating event, but the defined system of the physiological, solid changes, which are received and are realized as emotion. According to James, "we are distressed, because we are weeping, we are

angered, because we deliver impact, we are frightened, because we shake". Lange particularly added that vasomotor changes are the emotions. It was largely supplanted by the Cannon-Bard theory [94]. Example of James-Lange theory is showed on Figure 2:

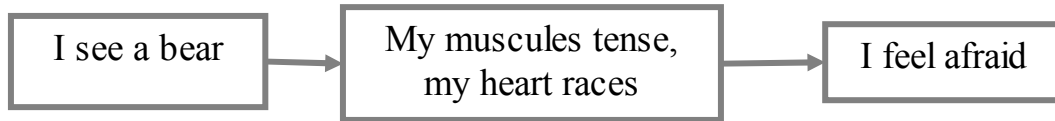


Figure 2: Example of James-Lange theory

We can conclude that Emotion results from the evaluation of the bodily reactions that are provoked by events.



Figure 3: Emotional process by James-Lange

To the experimental check of James - Lange theory was dedicated the experiences of many scientists. Frequently at the basis of these experiences lies the following assumption. It is known that with emotional excitation adrenaline is produced in the blood, under the effect of which occur different solid changes: trembling appears, the rhythm of the heart changes, etc. But if we artificially create this external set of emotions can man feel the appropriate psychological state? If yes, then James was right, and precisely these states are felt as emotion. If no, then... however, let us restrain from the final conclusions.

A great significance for understanding these physiological phenomena was the discovery of the nervous centre of emotions in the depths of the brain. Implanting into the sub cortical regions of the brains of animals microelectrodes, scientists could establish that the irritation of some sections caused the experience of pleasure, and the irritation of others caused the experience of suffering (the "centres of happiness" and "centres of suffering"). The centres, whose irritation arouses anger, fear, friendliness and so on were also discovered. Also there are studies which indicate in the brain of man the centres which respond by specific emotions.

2.5 Emotional Expressiveness

Emotional reactions are connected not only with the activity of internal organs. They are manifested in the external expressive motions. The universality of motion as an indicator of emotions indicated by the Russian physiologist Ivan Mikhaylovich Sechenov [34] in his remarkable book "Reflexes of the brain". He wrote: "does a child laugh when he sees the toy, did Garibaldi smile, when he was chased for the love of his country, does a girl shake with the first thought about love, did Newton create the world laws and wrote them on paper? Everywhere the final factor is muscular motion".

Why are expressive emotional motions necessary? In the opinion of Charles Darwin, these are vestiges of the expedient actions. The stress of muscles, the compression of cams, grind of the teeth with anger ("anger - this the slow down fight") - all this is heritage of our distant ancestors, who solved debatable problems with the aid of the cams and the jaws. "For an example", writes Darwin, "it suffices to recall about this motion as the inclined position of eyebrows in man, who suffers from the grief or the anxiety... Or such motions, as hardly noticeable lowering of his mouth they must be considered as last tracks or the remainders the more sharply pronounced in the past motions, which made intelligible sense".

Expressive motions, in the present, serve as the involuntary accompaniment of emotions; they play an enormous communicative role, they help the contact between people, ensure emotional contact between them. Specifically, because of the mimicry (expressive motions of face), pantomimist (expressive motions of entire body), to the emotional components of speech and so on, we learn about the experiences of another person, we are penetrated by these experiences, and we construct our interrelations with those surrounding in accordance with them. Understanding the language of emotions helps us to find accurate tone in the contact with those surroundings. Emotions are most full and vividly expressed by changes on the human face. Not without reason the German writer Lichtenberg noted that "the most entertaining surface on the earth, is a human face". Specifically, on face of another person we

"read" the happiness and grief, pensiveness and anger, love and hatred. In exactly the same manner others "read" the diverse nuances of feelings and emotions on our face.

From what elements is added the "language of emotions", as is mastered by man? Numerous studies were dedicated to these questions. It was explained that the eyes and mouth have the greatest value for the expression of emotions. Not without reason in the works of Lev Tolstoy are described eighty five nuances of the expression of eyes and ninety seven nuances of smile.

But usually when we read the emotion on the face we consider the entire situation, which prompts the nature of emotional experience. Happiness and joy are guessed more rapidly than fear and suffering.

The emotional state of the evaluator influences the accuracy of the determination of emotion from the external manifestations, because, people have a tendency to assign those experiences, by which they are involved, to others.

The principle of "physical actions", i.e. the recreations of emotion according to its external precise expression, was proposed by Konstantin Stanislavski [45] for truthful mapping onto the scene of the emotional life of characters. Here there is in the form, of course, not only a mimicry, but also other methods for the external expression of emotions: gestures, motions, poses and so on. One of the strongest ways of the expression of emotions and feelings is speech. Intonation, sound intensity, rhythm - all this always, from one side, depends on our emotional state and, from the other side, serves as the means of its expression.

The language of emotions is universal, similar for all people and is a collection of the expressive signs, which express these or other emotional states. We can correctly understand the emotions of people of other cultures and nationalities. But this universality is not absolute. There are specific national differences, which are determined by traditions and customs. For example, in some parts of Africa laughter is the index of consternation and even confusion and it is not a completely compulsory sign of merriment. In some countries of Asia, it is awaited

from the guest eructation after eating, in sign that he is completely satisfied. The same gesture, notes the American psychologist Shibutani [46], in the American society hardly will involve repeated invitation of the guests.

The forms of the expression of emotions depend on the rules of decency accepted. In Russia, for example, it is not accepted to laugh loudly in public places, and to generally attract the universal attention by the manifestation of its emotions. There are specific features in the manifestation of the emotions, which depend on the temperament of the person, his education and habits. Sometimes emotions leave unique imprints on the expression of the face of an individual. Not without reason we speak about people who are concerned, merry, astonished and so on. However, this "psychologization" of appearance can be the result of the not entirely correct "reading" of the natural special features of the face.

2.6 Emotional life of personality

The set of moods, fits of passion, feelings and passions of man forms his emotional life and his individual quality as emotionalism. This quality can be defined as the tendency of man to react emotionally to different stimulus, affecting his circumstances of life and his ability to survive differently in force and quality: from the moods to the passions. By emotionalism it is also understood the force of the influence of emotions on the thinking and the behavior.

Discussing about feelings of man, we have already noted that they can be primitive and complex. However, what are such as complex feelings? These are such emotions, which at their basis rest on the highest morals accepted by man, on the moral standards and the values of behavior. The dignity of feelings is determined not by the nature of these feelings, but by purposes and eventual results of those behaviors, which man accomplishes under the effect of these feelings. If man, having randomly made some good for another, feels happiness because of this, then this feeling can be named noble. If, on the contrary, he appears to regret the fact

that someone from his actions became better, or, for example, if a feeling of envy appears because it is good for someone, then such emotions will not be named noble.

The complex emotions of man are the motives of behaviors, i.e., they are capable of impelling and of shipping man, of stimulating him to accomplish specific actions and behavior. This was vividly described by well-known Dutch philosopher and psychologist Baruch Spinoza [36]. The nature of people, he asserted, is such that for the most part, when someone feels bad, others feel compassion, and if someone feels good, others envy him. Compassion and envy are difficultly compatible emotions. However, they, unfortunately, are frequently encountered almost equally, making people look like emotional two-faced Januses.

2.7 Influence of emotions on the behavior of man

The behavior of man depends considerably on his emotions and a different emotion differently influences behavior. There are the so-called sthenic emotions, which increase the activity of all processes in the organism, and the asthenic emotions, which impede them. Sthenic, as a rule, are the positive emotions: satisfactoriness (pleasure), joy, happiness, and asthenic are negative: displeasure, grief. Let us examine each form of emotion in more detail, including mood, temporary insanity, feeling, passion and stress. We already analysed these emotional phenomena from biological and psychological perspectives and now we will see their influence on the behavior of man.

Mood creates the specific tone of the organism, i.e. its overall attitude (hence the name "mood") to the activity. The productivity and quality of labour of someone in a good, optimistic mood is always higher than of someone with a pessimistic disposition. A person who is always optimistically disposed is more attractive to others than a person who has constantly a bad mood. The surrounding people enter into the contact with much desire with a smiling person, than with someone with an unkind face.

Temporary insanity plays in the life of people another role. It is capable of immediately mobilizing energy and resources of the organism for suddenly solving emergency tasks or overcoming the unexpectedly appeared obstacle. This consists on the basic vital role of temporary insanity. In the appropriate emotional state man sometimes accomplishes tasks that he usually is not capable to realise. A mother when saving her child, does not feel pain; she does not think about the danger for her own life. She is in the state of temporary insanity. The mass of energy expended at this moment is enormous. It is very uneconomic, and therefore for continuation of normal activity, leisure is compulsorily necessary to the organism. Temporary insanity frequently plays a negative role, making the behavior of man uncontrolled and even dangerous for others.

Even more significant than moods and temporary insanity is the vital role of **feelings**. They characterize man as personality, are sufficiently steady and possess the independent justifying force. The attitude of man toward the surrounding world is determined by feelings. They become the moral regulators of behavior and interrelations of people. Training man from a psychological point of view is the process of the formation of his noble feelings, which include sympathy and kindness for others. Feelings of man, unfortunately, can be low, for example envy, malice, hatred. Into the special class there are included the aesthetical feelings, which determine the attitude of man toward the world of beautiful. The wealth and variety of human feelings is a good level indicator of its psychological development.

Passions and **stresses** in contrast to moods, temporary insanity and feelings, play in life, in essence, a negative role. Strong passion suppresses remaining feelings, needs and interests of man, it makes him limited in its aspirations, and stress generally destructively acts on psychology, behavior and the health status.

2.8 Basic classifications of emotions

Among questions about the emotions, which are much easier assigned than to answer them, there is the most natural and simple question: *Are there emotions, such as there are feelings?* Here appear difficulties, first of all, because of the enormous variety of emotional phenomena. Indeed it is possible to classify them differently:

- by the "sign" (plus - minus) of experience: pleasant/unpleasant;
- according to the nature of need, which is the basis of experience, biological or spiritual;
- on the object, on the phenomenon of the surrounding world, which caused emotion or feeling; - they activate or prevent, depending on their influence on human activity;
- according to the degree of manifestation - from the low "pleasant" to passionate love and so on;

But there is one additional difficulty, connected with the need for determining one or another emotional experience verbally.

Is it easy to accurately designate by words what you feel, linking a verbal label to the emotion?

There are many different diagrams for the designation of emotional phenomena. For example, the founder of scientific psychology Wilhelm Wundt proposed to characterize emotions in three directions [95]:

1. pleasure/displeasure;
2. stress/rarefaction;
3. excitation/braking.

The contemporary American researcher of emotions Izard considers a number of fundamental emotions, and everything else as derivatives. The fundamental include [32] :

1. interest/agitation;
2. happiness;
3. surprise;
4. suffering;
5. anger;
6. aversion;
7. contempt;
8. fear;
9. shame;
10. fault.

From the derivatives of fundamental emotions appear, for example, such complex emotional states, as anxiety, which can combine in itself fear, anger, fault, interest - excitation. Complex emotional experiences also include love and hostility.

Whatever list of emotions are examined, a interesting special feature is always revealed: from any positive emotion - which we consider as pleasant, it is possible to select the appropriate or perhaps better to say the opposite emotion that also composes the so-called polarity of feelings and emotions.

It is important to note that people can differ very essentially from each other not only in the nature of the lived emotions, on their force, but also in the ability to sympathize, to be anxious. This ability is called **empathy**. According to American psychologist Carl Rogers [96]: "empathy is not blindly paraphrasing back to someone (a therapeutic client) what they

said, but de-centering and sensing the full richness of the world of that person and then genuinely expressing a response."

2.9 Forms of emotional states

The emotional experiences of personality are distinguished not only by the object, by which they are caused, but by their force and stability. And here we have a wide spectrum, beginning from hardly noticeable light experiences to the stormy emotional flashes. Mood is the emotional state, which during the specific time tinctures the entire mental life of man. This is seemingly the emotional background, the emotional motif of life and activity. An active person is always located under some emotional sign: this can be light melancholy or quiet happiness, the thirst of activity either than the experience of rest, the state of the expectation of something pleasant or uneasiness, etc.

What does the mood depend on? Sometimes mood seems to be inexplicable. But mood is always caused by something real, it has internal or external reasons.

Let us begin from the physical state of man. Specifically it generates the overall mood, which is called health. Sometimes poor health or the lowered vital tone, can alert against some disturbances in the organism, about the incipient disease.

The source of the mood could be distinguished by different vital facts. In this case even small facts, to which we give no attention, can nevertheless spoil the mood.

But the most frequent and most essential source of mood, an even stronger source of our emotional states, is our activity. Success and positive estimation increase our mood. Failure, underestimation or negative estimation reduce our mood. Here is the opposite effect: with the good, merry mood any work succeeds. This, incidentally, has been noted by psychologists, who work in the industry. The vital observations, and special studies showed that a good mood is a powerful factor for an increase in productivity of labour. It was also explained that the

painting of the accommodation, and clear rhythm of working process can influence mood, but, probably the main thing is interrelation between people in the working place.

Other people are a generally powerful source of our mood. The English thinker John Locke, wrote, already hundred years ago [97]: "To love our neighbour as ourselves is such a truth for regulating human society, that by that alone one might determine all the cases in social morality.". Thus, other people, their relation to us, their attention and concern, words and behavior, even view and smile form our mood.

2.10 Temporary Insanity and Passions

Mental conditions opposite to mood are temporary insanity - stormy, short-term emotional flashes, which seize entire personality of man. Sometimes in the state of temporary insanity, anger, fear, happiness and so on, man seemingly loses self-control, loses authority over oneself, gives up oneself entirely to experience. In the artistic literature it is possible to find numerous bright descriptions of such affective states. For example the state of Mtzyri from the poem of Mikhail Lermontov, when the hero escaped from the monastery to the native land and strayed in the wood:

“Then I fell on to the ground;

And in the frenzy I sobbed;

And gnawed the damp breast of the soil,

And tears, tears flowed into it,

By scalding river...”

Is it possible to somehow regulate the state of temporary insanity, to overcome it? First of all, it is necessary to bring up endurance and composure in oneself. Now and then people fall into the authority of temporary insanity because of the irresponsibility and the sensations of

impunity. It is possible to say that they return themselves into the authority of temporary insanity and use this consciously as means of pressure onto others.

Perhaps, passion is the strongest and brightest emotional state of man. In contrast to temporary insanity, this steadfast, all-encompassing feeling, for its satisfaction causes the aspiration to dynamic activity. Not without a reason it is told that: great passion produces great energy. In his letter [35] to teenagers I. P. Pavlov wrote: "Science requires from man large stress and great passion. Be passionate in your searching".

2.11 Conclusion

The emotional universe of personality: this is not simply a beautiful means. It is worthwhile to resemble again and again: our psyche is unique and integral. It is entirely pierced by emotional experiences. It can ensure concord and unity of personality in some cases and ensure discord, discrepancy, internal state of conflict in others.

These different and, at the same time, connected approaches to the concept of emotion help us understand and develop the artificial structure of emotional character. This structure will never be perfect, because there are no exact models to describe emotion. But using these different approaches we can modulate the artificial emotional universe which can simulate, in some aspects, the real emotional system of the person.

This chapter contained a revision about the most important aspects of Human Emotion especially those concerning the functionalities of Emotion. We focus on discussing the emotional basis, states and behaviors that can be usefully applied or transposed to the development of an Emotional Multi-Agent System. Although this section may be considered somewhat lengthy, the concepts discussed therein are essential for subsequent formalizations developed in the following chapters. This detailed study of emotion enable us to define a model of emotion adequate for agents with complex emotional and temperamental architecture

which approach the emotional process from both: psychical and physical perspectives. It is very important to understand the basis of emotional behaviors and analyse the different theories related to emotional phenomena in order to create the computational mind model for a multi-agent system.

Chapter 3 Temperament – Typologies of Personality

3.1 Introduction

Temperament² is the characteristic of an individual from the perspective of his dynamic special features of his mental activity, i.e. rate, rapidity, rhythm, intensity, which compose his activity of mental processes and states [47].

The analysis of the internal structure of temperament presents significant difficulties, caused by the absence in the temperament (in its usual psychological characteristics) of the united content and united system of external manifestations. Attempts of this analysis lead to the isolation of three main leading components of the temperament, which relate to the spheres of the **general activity** of individual, his **motors** and his **emotionalism**. Each of these components possesses a very complex multidimensional structure and different forms of “psychological manifestations”.

The widest value in the structure of temperament has its component, which is designated as the general mental activity of the individual. The essence of this component consists mainly in the tendency of personality toward self expression, effective mastery and conversion of

² Lat. *temperamentum* --- the proper proportion of features; from *tempero* -mixed up of the proper proportion

external reality. Of course, in this case, the direction, the quality and the level of the realization of these tendencies are determined by other ("meaningful") special features of the personality: by its intellectual and characterological special features, by the complex of its relations and motives. The degrees of activity are distributed from the apathy, to intercity and passive observation at one pole to the highest degrees of energy, powerful swiftness of actions and constant lift on other pole.

To the group of the qualities, which compose the first component of temperament, closely adjoins (or even, possibly, it enters into it as a component part) the group of the qualities, which compose the second - engine, or motor, - component, leading part in which the lead qualities are connected with the function of engine (and specially - speech-motor) apparatus. The need for isolation in the structure of temperament of this component is caused by special importance of motors as the means, with the aid of which is actualized the internal dynamics of mental conditions with all its individual gradations. Among the dynamic qualities of engine component it should be distinguished **rapidity, force, sharpness, rhythm, amplitude** and a set of other muscular motions (part of them characterize the vocal motor activity). The totality of the special features of muscular and vocal motor activity composes that facet of the temperament, which more easily others yield to observation and estimation and therefore frequently serves as basis for the judgement about the temperament of the individual [48].

The third basic component of temperament is "**emotionalism**", which is the extensive set of properties and qualities, which characterize the special features of appearance, flow and the curtailment of unique feelings, passions and moods. In comparison with other component parts of temperament this component is most complex and possesses its own branched structure. As the fundamental characteristics of "emotionalism" we distinguish sensitiveness, impulsiveness and emotional lability. **Sensitiveness** expresses the highly emotional receptivity of the subject, his sensitivity to the emotiogenic actions, ability of him to find the base for the emotional reaction, while for others there is no existing base. The term "**impulsiveness**" designates the

rapidity, with which the emotion becomes the motive force of behavior and actions without their preliminary consideration and conscious solution. By **emotional lability** it is usually understood the speed, with which ceases this emotional state or occurs the change of one experience by another.

The basic components of temperament form in the reports of human behavior the unique unity of motives, actions and experiences, which makes it possible to speak about the integrity of the manifestation of temperament and give us the possibility to delimit the temperament from the other mental formations of man - its directivity, nature, abilities, etc.

A question about the manifestations of temperament in the behavior is inseparably connected with a question about the factors that cause it. In the history of the study about personality [49] it is possible to isolate three main systems of views on this question. The earliest of them are the humoral theories, which connect temperament with the properties of various fluids of the organism. The classification of temperament, based on the study of Hippocrates, represented most vividly this group of the theories of temperament. He considered that the level of the vital activity of the organism is determined by the relationship between four fluids, which circulate in human body, - by blood, by bile, by black bile and by mucus (lymph, phlegm). The relationship of these liquids, individual in each organism, was designated in Greek by the term "krisis" (mixture, combination), which in the transfer into the Latin language sounds as "temperamentum". On the basis of the theory of Hippocrates it was gradually formed the study about four types of temperament based on a quantity of main fluids, whose hypothetical predominance in the organism gave name to the basic types of temperament: sanguine³, choleric⁴, melancholy⁵ and phlegmatic⁶.

In the new time the psychological characteristic of these types of temperament was generalized and systematized for the first time by German philosopher Immanuel Kant [98]

3 from the Latin *sanguis* - the blood

4 from the the Greek *chole* - bile

5 from the Greek *melaina* - black bile

6 from the Greek *phlegma* - mucus

that allowed, however, in its interpretations the mixing of the features of temperament and the character. Kant considered the qualitative special features of the blood as the organic basis of temperament, i.e. he adopted the position of the supporters of humoral theories. He divides temperament into

1. the temperament of feelings (sanguine - temperament of man with merry disposition, melancholy - the temperament of man of gloomy disposition) and
2. the temperaments of activity (choleric - the temperament of man of quick tempered, phlegmatic - the temperament of cold-blooded person).

P.F. Lesgaft considered the traditional types of temperament as the manifestation of the special features of the system of blood circulation and metabolic rate [49]. Thus, there are four temperaments that possess specific electromagnetic nature:

1. electrical - choleric - extravert - returning - less passionate (the less impassioned), the man;
2. magnetic - melancholy - introvert - consumer - is more passionate (the more impassioned), the woman;
3. electromagnetic (with the predominance of electrical effect) - sanguine - extravert - returning - less passionate (the less impassioned) - the woman;
4. magneto-electric (with the predominance of magnetic effect) - phlegmatic - introvert - consumer - is more passionate (the more impassioned), man;

Another science, which is occupied by a study of the innate temperaments is astrology, which reached for its long and imposing existence, and appears to achieve great successes. But nevertheless and it cannot give the specific answer to a question, who is a person in his essence. Astrology speaks, for example, that a person is Capricorn, because he was born when the sun was located in the constellation of Capricorn. But empirically we observe another Capricorn and see in it the mass of distinctive qualities, it is more accurate to say, they are

absolutely opposite to each other. An astrologer such as a psychologist, certainly, will explain this phenomenon, because they have a mass of means in their arsenal for the interpretation, but, to the concretely undertaken person this has no relation.

Consequently, astrology, as science, is highly useful in the motivational plan, or in the social equivalent; however, in the individual - it is weak. I.e., if we give astrology the basis, from which it will be developed, with its rich archives from the observations of people, it can become the science in the course of time, which does not have an equal to itself on the value and the prevalence, and, certainly, usefulness.

Today, both astrology and psychology determines the temperament of man on the basis of experience and observations, i.e., the empirical nature of man is compromised, about which Arthur Schopenhauer says: "individual nature is innate: it is not created by skill or by the subjected circumstances to chance, but there is a work of nature itself. It is shown already in the child, revealing there, on a low scale. This is why with completely identical training and circumstances in two children we obviously observe the most varied natures; with these natures one necessarily lives to the old age ".

Hence it follows that this nature, may possibly be determinant, since it is given to man from generation and therefore it exists in the present. But it cannot be determined in the appearance of a child, on his actions and still less on him, using in this case hereditary theory, since such innate nature therefore individual, in that sense, is given to man by nature. Consequently, in order to determine the innate nature of man, the following condition is necessary: This nature will be called innate, if it determines, that with the certain conditions of generating the man, the latter, independent of environment, will be allotted by the specific temperament. I.e., the nature of man, must be determined a priori by the generation of man, only then is it possible to call it innate and individual.

Tentatively it is possible to outline at least seven distinguishing features (criteria) of the formal properties of personality (predominantly temperament) from the meaningful

characteristics of personality. Temperament should be understood, from our point of view, only as a mental property of personality, which:

1. is inherited;
2. highly correlates with the properties of the nervous system and the properties of other biological subsystems (humoral, solid and so on.);
3. is stable during the continuance of the life of man;
4. is universal and is manifested in all spheres of activity and vitality;
5. is characterized as the measure of the active voltage of man;
6. reflects the most generalized attitude of man towards peace, society and oneself;
7. does not relatively depend on the content (i.e. sense, motive, purpose and so on.) activity, contact and knowledge.

3.2 A General Framework for Describing the Central Nervous System and Pavlov's Theory

“The nervous system and the automatic machine are fundamentally alike in that they are devices, which make decisions on the basis of decisions they made in the past.”

Norbert Wiener

In reality, it is familiar the dependence of the flow of mental processes and the behavior of man on the functioning of the nervous system, which performs a dominant and controlling role in the organism. The theory of the connection of some general properties of nervous processes with the types of temperament was proposed by Ivan Pavlov and underwent development and experimental confirmation in the works of his followers. Pavlov, studying the special features of the production of the conditioned reflexes in dogs, focused attention on individual differences in their behavior and in the flow of conditioned-reflex activity [16, 35].

These differences were manifested, first of all, in such aspects of behavior as speed and the accuracy of the formation of the conditioned reflexes, and also in the special features of their damping. These circumstances made it possible to Pavlov to advance the hypothesis about the fact that they cannot be explained only by the variety of experimental situations and that at their basis lay some fundamental properties of nervous processes - excitation and braking. These properties include the force of excitation and braking, their steadiness and mobility. Pavlov distinguished the force of imagination and brake power, considering their two independent properties of the nervous system.

The force of **excitation** reflects the fitness for work of the nerve cell. It is manifested in the functional endurance, i.e., in the ability to maintain prolonged or short-term, but strong excitation, without converting in this case to the opposite state of braking.

Brake power is understood as the functional fitness for work of the nervous system in the implementation of braking and is manifested in the capability for the formation of different brake conditional reactions, such, as extinction and differentiation.

Steadiness - equilibrium of the processes of excitation and braking. The relation of force of both processes decides, is this individual if it is balanced or unbalanced, when the force of one process exceeds the force of the other.

Mobility - nervous processes - is manifested in the rapidity of the passage of one nervous process to another. The mobility of the nervous processes is manifested in the capability for a change in the behavior in accordance with changing living conditions. The measure of this property of the nervous system is the rapidity of the passage from one action to another, from the passive state to the active, and vice versa.

Sluggishness - opposition of mobility. The nervous system is more inert, the more the time or efforts are required in order to pass from one process to another.

The isolated properties of the nervous processes form the specific systems, the

combinations, which in his opinion, form the so-called type of nervous system, or the type of higher nervous activity. It is composed of the totality of the basic properties of the nervous system - force, steadiness and mobility of processes characteristic for the individual, distinguishing strong and weak types. As a further base of division serves the steadiness of the nervous processes, but only for the strong types, which are divided into those balanced and not balanced. The unbalanced type is characterized by the predominance of the excitation above the braking. The strong balanced types are divided into the mobile and the inert, when the mobility of nervous processes is the base of division.

The isolated types of nervous system not only in quantity, but also according to the fundamental characteristics correspond to four classical types of the temperament: strong, balanced, mobile - sanguine person; strong, balanced, inert - phlegmatic person; the strong, unbalanced type with the predominance of excitation - choleric; weak type - melancholic.

Pavlov understood the type of nervous system as innate, relatively weakly subjected to changes under the action of environment and training. In his opinion, the property of the nervous system forms the physiological basis of the temperament, which is the mental manifestation of the type of nervous system.

The types of nervous system, established in studies on animals, were proposed by Pavlov to extend also to people. At present in science many facts about the properties of the nervous system are accumulated, and in proportion to their accumulation researchers attach increasingly smaller value to the types of nervous systems; the value of the studies of the separate fundamental properties of the nervous system first of all is emphasized, while the problem of separation into the types steps back to the second plan. Since the types are formed from the combinations of the properties indicated, only the deeper knowledge of the latter can ensure understanding and realization of typologies. However, there is no doubt that each person has a well-defined type of nervous system, whose manifestation, i.e., the special features of temperament, composes the important side of individually psychological

differences.

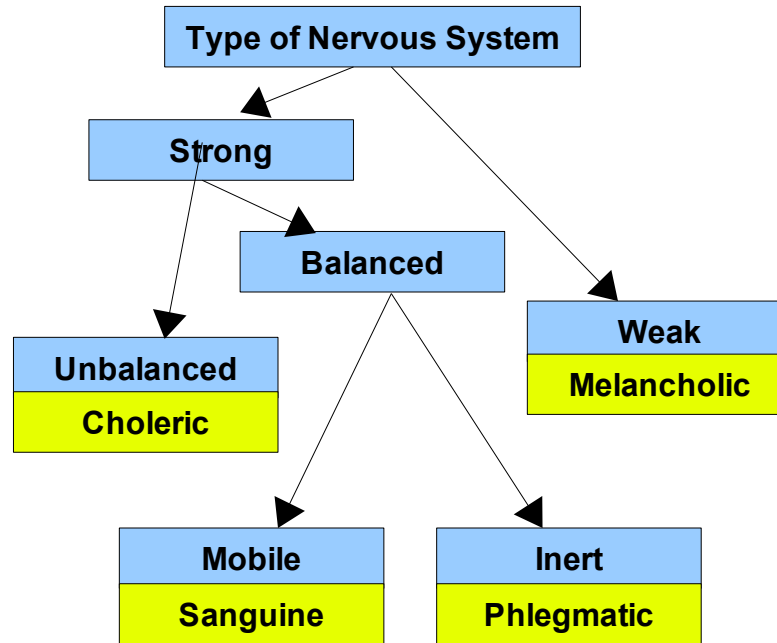


Figure 4: Central Nervous System Diagram

The definite scientific explanation of temperaments was given by Ivan Pavlov's study about the types of higher nervous activity. Pavlov opened three properties of the processes of excitation and braking [16, 49]:

- the force of the processes of excitation and braking;
- the steadiness of the processes of excitation and braking;
- the mobility of the processes of excitation and braking.

The force of the nervous processes characterizes fitness for work, endurance of the nervous system and indicates the ability of it to transfer either prolonged or short-term, but very strong excitation or braking. The opposite property (weakness of nervous processes) characterizes the incapacity of nervous cells to maintain the prolonged and concentrated excitation and braking. The steadiness of nervous processes is a relationship between excitation and braking. In some people these two processes are balanced mutually, while

equilibrium is not observed in others: the process of braking or excitation predominates. The mobility of nervous processes is their ability to rapidly change each other, rate of the motion of nervous processes (irradiation and concentration), the rapidity of the appearance of a nervous process in response to the irritation, the rate of the formation of new conditional connections. The combinations of the properties of the nervous processes indicated were assumed as a basis to determine the type of higher nervous activity. Depending on the combination of force, mobility and steadiness of the processes of excitation and braking four basic types of higher nervous activity are distinguished.

Pavlov correlated the types of nervous systems with the psychological types of temperaments isolated them and revealed their complete similarity. Thus, temperament is a manifestation of the type of nervous system into the activity, the behavior of man. As a result the relationship of the types of nervous system and temperaments appears as follows:

- strong, balanced, mobile type ("living") - sanguine temperament;
- strong, balanced, inert type ("calm") - phlegmatic temperament;
- strong, not balanced, with the predominance of excitation ("unrestrained") - choleric temperament;
- weak type - melancholic temperament.

Temperament should be understood as the individually unique properties of psyche, which determine the dynamics of human mental activity, which are equally manifested in the diverse activity independent of its content, purposes, motives, and remain constant at the ripe age and in its interconnection characterizes the type of temperament. Concrete manifestations of the type of temperament are varied. They not only are noticeable in the external manner of behavior, but as if piercing all sides of psyche, is substantially manifested in the cognitive activity, to the sphere of feelings, motive and the actions of man, and also in the nature of mental work, the special features of speech. At present, science has available sufficient

evidence in order to give the complete psychological characteristics of all types of temperament according to the specific ordered program.

However, the following basic properties of temperament are usually separated for the composition of the psychological characteristics of the traditional four types:

- *Sensitivity* is determined by the fact, that the smallest force of external actions is necessary for the appearance of any mental reaction of man, and the speed of the appearance of this reaction.
- *Reactivity* is characterized by the degree of involuntariness of reactions to the external or the internal actions of identical force (critical observation, offensive word, sharp tone - even sound).
- *Activity* testifies about how intensive it is (energetically) for man to act on external peace and get over the obstacle in the achievement of the objective (persistence, endeavour, the concentration of attention).
- *The relationship between reactivity and activity*, determines what the human activity depends on: from random external or internal circumstances (mood, random events) or from the purposes, the intentions or the persuasions.
- *Plasticity* and *rigidity* testify, how easily and flexibly man is adapted to the external actions (plasticity) or how inert is his behavior.
- *Extraversion, introversion* determine, what the reactions and the activity of man predominantly depend on- from surface impressions, which appear at the given moment (extravert), or from the means, the ideas and the thoughts, connected with the past and the future (introvert).



Figure 5: Image of woodcut from 18th century text by Johann Kaspar Lavater: Four Temperamental Types

Taking into account all enumerated properties, it is possible to give the following psychological characteristics of the basic classical types of temperament:

SANGUINE PERSON. Man with increased reactivity, but in this case activity and reactivity are in balance. He is lively, energetically responds to everything which attracts his

attention, possesses living mimicry and expressive motions. Laughs loud on the insignificant occasion, and an unessential fact can anger him. From his face it is easy to guess his mood, relation to the object or the person. He has a high threshold of response; therefore he does not note the very weak, be it sonic and light stimuli. Possessing increased activity and being very energetic and operational, he actively starts for the new matter and he can work a long time without tiring. He is capable of rapid concentration, is disciplined, when desired can hold in control the manifestation of feelings and involuntary reactions. Rapid motions are inherent, flexibility of mind, resourcefulness, rapid rate of speech, rapid start in new work. High plasticity is manifested in the changeability of feelings, moods, interests and tendencies. The sanguine person easily concurs with new people, rapidly gets accustomed to new requirements and the situations. He can switch from one task to another effortlessly, but is also retrained, seizing new habits. As a rule, he has a larger degree of response to surface impressions, than to the subjective means and the ideas about the past and the future, he is extravert. In the sanguine person feelings easily appear, and are easily changed. In the sanguine person it is easily formed and altered new temporary connections, large mobility of stereotype, it is reflected also in the mental mobility of sanguine people that they reveal a certain tendency towards instability.

CHOLERIC. Like the sanguine person, this person is characterized by small sensitivity, high reactivity and activity. But in the choleric, reactivity clearly predominates over activity; therefore it is not bridled, not restrained and impatient. He is quick tempered. He is less plastic and is more inert than the sanguine person. Hence - the large stability of tendencies and interests, great persistence, possibly make difficult the switching of attention, he is faster extravert. People of this temperament are rapid, are excessively mobile, unbalanced, they are excited, all mental processes proceed in them rapidly, intensively. The predominance of the excitation over the braking, characteristic of this type of nervous activity, is vividly manifested in the impetuosity, the gustiness, the hot temper, the irritability of choleric. Hence the expressive mimicry, hasty speech, sharp gestures, the unrestrained motions. The feelings of

people with choleric temperament are strong, usually vividly manifested, rapidly appear; mood sometimes sharply changes. The unbalanced state, characteristic of choleric, is connected also to his activity: matters are undertaken increasingly and passionately, showing in this case gustiness and rapidity of motions, works with the lift, passing throughout the difficulty. But a person with the choleric temperament can rapidly waste the reserve of nervous energy in the process of work and then can begin the sharp decrease in activity: lift and enthusiasm disappear, mood sharply falls. In the contact with people the choleric allows sharpness, irritability, emotional impetuosity, that impedes the possibility to objectively evaluating behavior of people, and on this basis creates conflictous situations in the association. Superfluous straightness, hot temper, sharpness, intolerance now and then makes closeness heavy and unpleasant in the association with such people.

PHLEGMATIC PERSON possesses high activity, which considerably predominates over the small reactivity, the small sensitivity and the emotionalism. It is difficult to make him laugh or sadden - when everyone else laughs, he can remain imperturbable. With the large troubles he remains calm. Usually he has poor mimicry, motions are inexpressive and retarded, just as speech. He is unresourceful, with difficulty in switches of attention and is adapted to the new situation, but slowly reconstructs habits. In this case he is energetic and operational. He is characterized by patience, endurance, composure. As a rule, he difficulty converges with new people, weakly responds to surface impressions, and is introvert. A drawback in the phlegmatic person is his sluggishness, low mobility. Sluggishness affects also the stagnation of its stereotypes, difficulty of its reconstruction. However, this quality, sluggishness, has positive values since it contributes to soundness to the constancy of personality.

MELANCHOLIAC. Man with high sensitivity and small reactivity. The increased sensitivity with the large sluggishness leads to the fact that the insignificant occasion can cause tears, he is excessively touchy, painfully sensitive. Mimicry and motions are

inexpressive, the voice is quiet, motions are poor. Usually he is unsure of himself, he is timid, at the least difficulty forces it to lower hands. The melancholic is not energetic, not persistent, easily tires and is poorly operational. He is easily distracted and has unstable attention, the retarded rate of all mental processes. The majority of melancholics are introverts. The melancholic is shy, irresolute, timid. However, in the calm, customary situation the melancholic can successfully manage vital tasks.

It is already solidly established that the type of temperament in man is innate, but precisely what properties of his innate organization depends on is not explained yet.

3.2.1 Eysenck Methodology

One of the things Pavlov tried with his dogs [16] was conflicting conditioning - ringing a bell that signalled food at the same time as another bell that signalled the end of the meal. Some dogs took it well, and maintain their cheerfulness. Some got angry and barked like crazy. Some just laid down and fell asleep. And some whimpered and whined and seemed to have a nervous breakdown.

Pavlov believed that he could account for these personality types with two dimensions: On the one hand there is the overall level of arousal (called excitation) that the dogs' brains had available. On the other, there was the ability the dogs' brains had of changing their level of arousal - i.e. the level of inhibition that their brains had available.

- Lots of arousal, but good inhibition: sanguine.
- Lots of arousal, but poor inhibition: choleric.
- Not much arousal, plus good inhibition: phlegmatic.
- Not much arousal, plus poor inhibition: melancholy.

Arousal would be analogous to warmth, inhibition analogous to moisture. This became the inspiration for Hans Eysenck's theory [22].

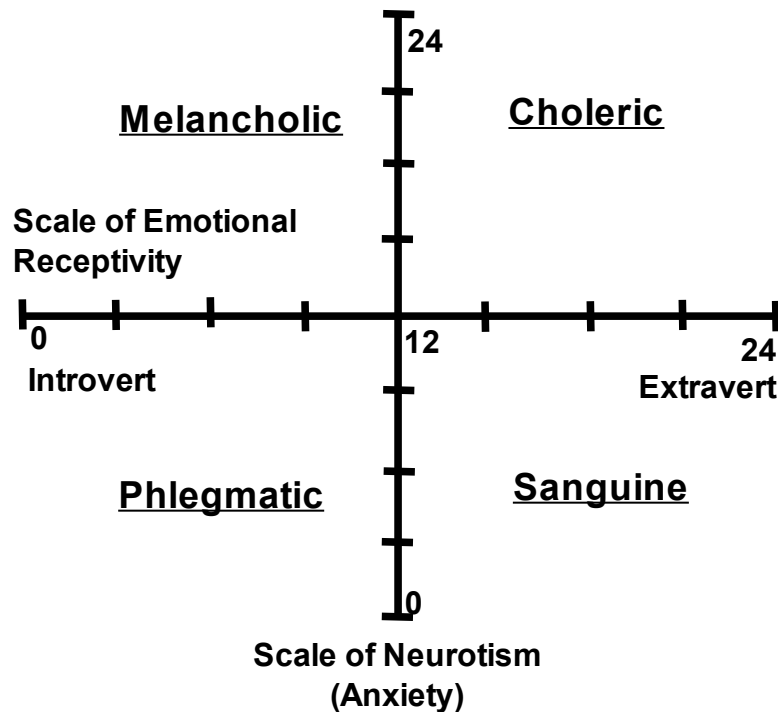


Figure 6: Scale of temperamental classification by Eysenck

In the works of Eysenck a neurophysiological interpretation of the basic measurements of temperament was given, among which were separated - the factor of extraversion -introversion and the factor of neurotism. A high mark according to the first scale corresponds to the higher threshold of the activation of reticular formation. Another property - neurotism corresponds to the level of the activation of the limbic system: the increased neurotism, higher reactivity to the events in the internal organism. As the basis of the factor concept of Eysenck temperament is assigned three fundamental measurements - extraversion -introversion, neurotism (emotional stability - emotional instability) and psychosis.

Using the methodology of Eysenck [22] we can perform the personality test to describe the temperament of the individuals by Introvert/Extravert characteristic and Anxiety (Figure 5).

The horizontal scale (from 0 to 24) is the scale of emotional receptivity. It characterizes

the level of the sociability of man:

- 2 or less – deep introvert, extremely unsociable and locked person;
- 2 - 10 – introvert, unsociable and locked person;
- 11 - 13 – an average level of sociability;
- 14 or more – extrovert, sociable person.

The vertical scale - scale of neurotic (anxiety), characterize the emotional stability or instability of human psyche:

- 11 - 13 – personality is moderately steady emotionally;
- 10 and less – emotionally unstable personality, it is always disturbed;
- 14 and more – emotionally steady person up to emotional coldness.

3.2.2 Influence of the type of temperament on the activity

The dynamic features of the personality of man appear not only in the external manner of behavior, not only in motions - they are manifested in the mental sphere, in the sphere of motive, in the general fitness of work.

Naturally, the special features of temperament are shown in the training exercises and in the working activity. But the main subject consists in the fact that differences on the temperaments - are not on the level of the possibility of psyche, but on the uniqueness of its manifestations. It is established the absence of dependence between the level of achievements, i.e., the eventual result of actions, and by the special features of temperament, if activity flows under the conditions, which can be defined as normal. Thus, independently of the degree of mobility or reactivity of the individual in the normal situation the results of activity in principle will be identical, since the level of achievements will depend mainly on other factors, in particular on the level of motivation and abilities.

At the same time the studies, which establish this regularity, shows that depending on temperament the method of realization of activity, changes. Depending on the special features of temperament people are distinguished not by the eventual result of actions, but by the method of achieving the results. Studies with the purpose to establish dependence between the method of fulfilling the actions and the special features of temperament were carried out. In these studies it was considered the individual style of activity as a way toward reaching the results or the method of solution of the specific problem, caused mainly by the type of nervous system. The results of the studies of the overwhelming majority of the authors, independently of the special features of the groups being investigated and experimental situations, in which the method of fulfilling the actions typical for the data of individuals was studied, show that the type of nervous processes, has an essential effect on the formation of the specific style of activity.

The sanguine person should be continuously posed the new, as far as possible interesting problems, which require concentration and stress. It is necessary to constantly switch on dynamism and to systematically encourage efforts.

The phlegmatic person must be implicated in dynamism and interest. He requires systematic attention and, thus, cannot be switched from one task to another.

For the melancholic it is not admitted not only the sharpness, roughness, but also a simply increased tone and irony. He requires special attention, should be in time praised for the appeared successes, the resoluteness and the will. A negative estimation should be used as careful as possible, in every way possibly softening negative actions. The melancholic is a most sensitive and vulnerable type, with whom it is necessary to be to maximally soft and benevolent.

How a person realizes his actions, depends on temperament, but in this case it does not depend on their meaningful side. Temperament is manifested in the special features of the flow of mental processes, influencing the speed of recollection and the strength of

memorization, the fluency of cognitive operations, stability and the switching capacity of attention.

3.3 Temperamental Scale - Pleasure Arousal and Dominance (PAD)

Analysis of emotional states leads to the conclusion that human emotions such as anger, fear, depression, elation, etc. are discrete and we need to define some kind of measurements to have a basic framework to describe each emotional state using the same scale. After studying the appraisal theory we find the Mehrabian model [1], [2] more suitable for computational needs since it defines three dimensions to describe each emotional state and provides an extensive list of emotional labels for points in the PAD space (Figure 7) and gives an impression of the emotional meaning of combinations of Pleasure, Arousal and Dominance (PAD).

"Temperament" is distinguished from emotional states in that it refers to an individual's stable or lasting emotional characteristics (i.e., emotional traits or emotional predispositions). More precisely, temperament is an average of a person's emotional states across a representative variety of life situations. A set of three PAD temperament scales has been developed and was shown to provide a reasonably general description of emotional traits or temperament [1,2,8,10,11,12].

3.3 Temperamental Scale - Pleasure Arousal and Dominance (PAD)

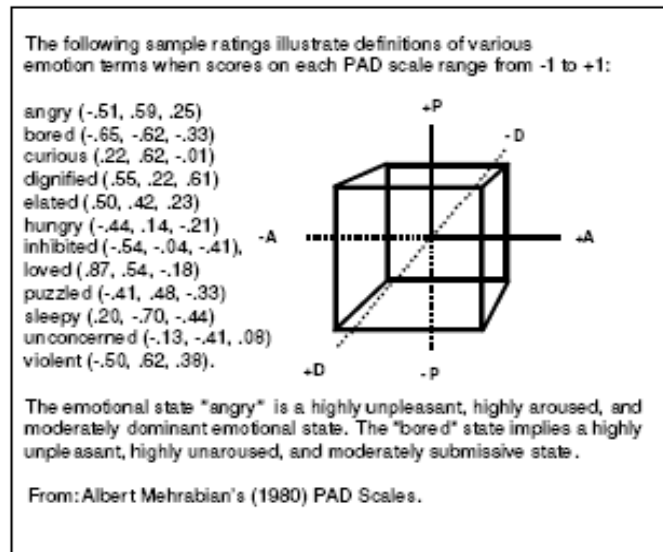


Figure 7: Mehrabian Temperamental Scale

The three dimensions of the PAD temperament model define a three-dimensional space where individuals are represented as points, personality types are represented as regions and personality scales are represented as straight lines passing through the intersection point of the three axes. Mehrabian uses +P, +A and +D to refer pleasant, arousable and dominant temperament. Respectively, and by using -P, -A and -D to refer unpleasant, unarousable and submissive temperament, respectively. Since most personality scales load on two or more of the PAD temperament dimensions, Mehrabian defines them using the four diagonals in PAD space as follows:

Exuberant (+P+A+D) vs. Bored (-P-A-D)

Dependent (+P+A-D) vs. Disdainful (-P-A+D)

Relaxed (+P-A+D) vs. Anxious (-P+A-D)

Docile (+P-A-D) vs. Hostile (-P+A+D)

In the Analysis of the Big-Five Personality factors in terms of the PAD temperamental model [2] Mehrabian found the relationship between five temperamental types and the PAD

scale. He describes this relationship using linear regressions. The resulting equations are given below for standardized variables with a 0.05 significant level:

$$\text{Extraversion} = 0.24P + 0.72D \quad (1)$$

$$\text{Agreeableness} = 0.76P + 0.17A - 0.19D \quad (2)$$

$$\text{Conscientiousness} = 0.29P + 0.28D \quad (3)$$

$$\text{Emotional Stability} = 0.50P - 0.55A \quad (4)$$

$$\text{Sophistication} = 0.28A + 0.60D \quad (5)$$

Mehrabian also proposed three linear regression Analysis to describe each of the PAD scales in function of these temperamental types with a 0.05 significant level:

$$\text{Trait Pleasure} = 0.59 \text{ agreeableness} + 0.25 \text{ stability} + 0.19 \text{ extraversion} \quad (6)$$

$$\text{Trait Arousability} = -0.65 \text{ stability} + 0.42 \text{ agreeableness} \quad (7)$$

$$\text{Trait Dominance} = 0.77 \text{ extraversion} - 0.27 \text{ agreeableness} + 0.21 \text{ sophistication} \quad (8)$$

We will use this result to determine the emotional state of the agents depending on their temperamental type. This will be described in the next chapter.

3.4 Analysis of Personality Factors in Terms of the Big-Five Temperamental Model

The Big Five factors and their constituent traits can be summarized as follows [88]:

- *Openness to Experience (or Sophistication)* - Appreciation for art, emotion, adventure, unusual ideas; imagination and curiosity.
- *Conscientiousness* - A tendency to show self-discipline, act dutifully, and aim for achievement (spontaneousness vs planned behavior).
- *Extraversion* - Energy, surgency, and the tendency to seek stimulation and the

company of others.

- *Agreeableness* - A tendency to be compassionate and cooperative rather than suspicious and antagonistic towards others (individualism vs cooperative solutions).
- *Neuroticism* (or *Emotional Stability*) - A tendency to easily experience unpleasant emotions such as anger, anxiety, depression, or vulnerability (emotional stability to stimuli).

Some scholarly works refer to the Big Five as the Five-Factor Model.

Extraversion (also "extroversion") is marked by pronounced engagement with the external world. Extraverts enjoy being with people, are full of energy, and often experience positive emotions. They tend to be enthusiastic, action-oriented individuals who are likely to say "Yes!" or "Let's go!" to opportunities for excitement. In groups they like to talk, assert themselves, and draw attention to themselves.

Introverts lack the exuberance, energy, and activity levels of extraverts. They tend to be quiet, low-key, deliberate, and less dependent on the social world. Their lack of social involvement should not be interpreted as shyness or depression; the introvert simply needs less stimulation than an extravert and more time alone to re-charge their batteries.

Agreeableness reflects individual differences in concern with cooperation and social harmony. Agreeable individuals value getting along with others. They are therefore considerate, friendly, generous, helpful, and willing to compromise their interests with others. Agreeable people also have an optimistic view of human nature. They believe people are basically honest, decent, and trustworthy.

Disagreeable individuals place self-interest above getting along with others. They are generally unconcerned with others' well-being, and therefore are unlikely to extend themselves for other people. Sometimes their scepticism about others' motives causes them to be suspicious, unfriendly, and uncooperative.

3.4 Analysis of Personality Factors in Terms of the Big-Five Temperamental Model

Agreeableness is obviously advantageous for attaining and maintaining popularity. Agreeable people are better liked than disagreeable people. On the other hand, agreeableness is not useful in situations that require tough or absolute objective decisions. Disagreeable people can make excellent scientists, critics, or soldiers.

There is some criticism on the use of the terms altruism-egoism in this context. Evolutionary Biology has extensively researched the mechanisms of altruism and concluded that 'agreeableness' differs fundamentally from 'altruism'.

Conscientiousness concerns the way in which we control, regulate, and direct our impulses. Impulses are not inherently bad; occasionally time constraints require a snap decision, and acting on our first impulse can be an effective response. Also, in times of play rather than work, acting spontaneously and impulsively can be fun. Impulsive individuals can be seen by others as colourful, fun-to-be-with, and zany. Conscientiousness includes the factor known as Need for Achievement.

The benefits of high conscientiousness are obvious. Conscientious individuals avoid trouble and achieve high levels of success through purposeful planning and persistence. They are also positively regarded by others as intelligent and reliable. On the negative side, they can be compulsive perfectionists and workaholics. Furthermore, extremely conscientious individuals might be regarded as stuffy and boring. **Unconscientious** people may be criticized for their unreliability, lack of ambition, and failure to stay within the lines, but they will experience many short-lived pleasures and they will never be called stuffy (i.e. dull, boring, unimaginative).

Neuroticism or (inversely) **Emotional Stability** refers to the tendency to experience negative feelings. Those who score high on Neuroticism may experience primarily one specific negative feeling such as anxiety, anger, or depression, but are likely to experience several of these emotions. People high in Neuroticism are emotionally reactive. They respond emotionally to events that would not affect most people, and their reactions tend to be more

intense than normal. They are more likely to interpret ordinary situations as threatening, and minor frustrations as hopelessly difficult. Their negative emotional reactions tend to persist for unusually long periods of time, which means they are often in a bad mood. These problems in emotional regulation can diminish a neurotic's ability to think clearly, make decisions, and cope effectively with stress.

At the other end of the scale, individuals who score low in Neuroticism are less easily upset and are less emotionally reactive. They tend to be calm, emotionally stable, and free from persistent negative feelings. Freedom from negative feelings does not mean that low scorers experience a lot of positive feelings; frequency of positive emotions is a component of the Extraversion domain.

Openness to Experience (or **Sophistication**) describes a dimension of personality that distinguishes imaginative, creative people from down-to-earth, conventional people. Open people are intellectually curious, appreciative of art, and sensitive to beauty. They tend to be, compared to closed people, more aware of their feelings. They therefore tend to hold unconventional and individualistic beliefs, although their actions may be conforming (see agreeableness). People with low scores on openness to experience tend to have narrow, common interests. They prefer the plain, straightforward, and obvious over the complex, ambiguous, and subtle. They may regard the arts and sciences with suspicion, regarding these endeavors as abstruse or of no practical use. Closed people prefer familiarity over novelty; they are conservative and resistant to change.

3.5 Conclusions

In this chapter we made a revision of the most important temperamental studies and present the theories which we use as fundamental for our work: Pavlov's theory about the superior nervous system, Eysenk theory about temperamental classification by the Neurotism and Emotional stability and Mehrabian models for temperamental classification using

Pleasure, Arousal and Dominance scales. These theories will be used to define an emotional architecture and personality functions for the computational agents as described in chapter 5. Pavlov's and Eysenck's theories will be used to define the physical layer of the emotional architecture and Mehrabian's theory will be used to define the psychical layer. These different approaches to the same temperamental phenomena let us to specify an emotional model for the Multi-Agent System using modular and multi-layer architecture.

Chapter 4 Emotional Agents – State-of-the Art

“Such an emotion model enables the character to show the right emotion with the right intensity at the right time, which is necessary for the convincingness of its emotional expressions.”

Bartneck, [51].

4.1 Introduction

In this chapter, we will present a brief analysis of the work developed by other researchers, in the area of emotional agents, that have influenced our work. Although the amount of research in this area has increased over the last few years and numerous authors now address Emotion from a functional point of view, we will focus on some particular researchers whose work is considered a reference. We studied the work of Joost Broekens and Doug DeGroot [8, 78, 79] because of the integration of the Mehrabian PAD model [4] into multi-agent system (Similar models have also been used by Breazeal and Scassellati). Also we have considered Aaron Sloman [18, 27] work because of his deep and brand approach to emotional architecture. We also studied the work of Eugénio Oliveira and Luís Sarmento because of detailed study performed in the area of emotional agents.

We will try to describe the work of these researchers with some detail because several of the concepts we developed emerged from their research. Many other researchers have influenced our work, so we will also present a brief review of different works which are focused on emotional programming and has influenced our strategy.

Finally, we will end this Chapter by making a review of the most relevant points, in our opinion, of the works developed by these researchers.

4.2 Broekens and DeGroot

Joost Broekens and Doug DeGroot⁷ work takes an approach that incorporate some of Damásio and Mehrabian [78, 79] theories and study emotions using game scenarios. They are investigating how, and to what extent, emotion can regulate information processing, more specifically information processing that has an effect on learning. For example, a simulated happy agent might learn differently than a simulated sad agent. In short: they investigate computational aspects of emotion in adaptive behavior. Their work is very useful for our project because of scalability and modularity of the developed framework.

The authors analyse the relation between cognitive appraisal theory and computation. They argue that it is useful to have a theory-independent formal notation to describe structural appraisal theories (i.e., the behavior of processes that play a role in appraising a situation, how these processes are linked to each other, what the resulting emotions could be, etc.).

The FeelMe framework, implemented in PacMan game, [4] is a modular approach to computational emotions and is based on a strict separation of the computational emotional process in five main steps (Figure 8).

⁷ Researchers at the LIACS (Leiden Institute of Advanced Computer Science), Leiden University, the Netherlands where they study the appraisal-based computational cognitive-emotion systems

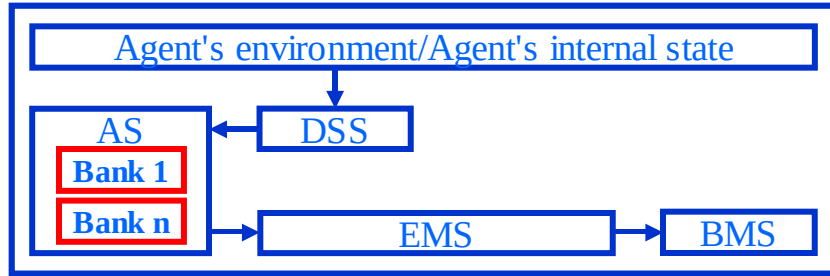


Figure 8: Overview of the components of the FeelMe framework

Broekens and DeGroot developed this framework for computational emotions to study the effects of emotion on decision-making by using emotions as first-order objects in reasoning [80].

The Decision Support System (DSS) provides mediated access to the existing system and translates the information received by the agent before sending it to the Appraisal System.

The Appraisal System (AS) continuously emotionally evaluates the constructed objects and interprets these in terms of values on a set of subjective measures, called appraisal dimensions. The evaluation of the AS results in a continuous stream of n-dimensional vectors representing the appraisal-results, with n equal to the number of appraisal-dimensions. These vectors are sent to the Emotion Maintenance System.

The Emotion Maintenance System (EMS) continuously integrates the appraisal-results and maintains the agent's emotional-state. Broekens and DeGroot explain that the emotional-state of an agent can thus be understood as a continuously moving point in an n-dimensional space of appraisal dimensions.

The Behavior Modification System (BMS) selects, controls, and expresses the agent's emotional behavior. The behavioral choices are based on the agent's emotional-state and additional knowledge the agent has.

Broekens and DeGroot choose three appraisal dimensions defined by Mehrabian:

- *Pleasure*: related to goal congruency;

- *Arousal*: related to novelty and attention needed for the event;
- *Dominance*: related to the influence PacMan has on its environment, i.e. PacMan's power;

EMS simply integrates the appraisal results from the Appraisal Banks.

They also introduce context-sensitive appraisal banks to facilitate the development of scalable appraisal models. Authors argue that runtime-scaling of appraisal models is useful in domains in which computation time is an unknown factor, because it enables trading-off emotional quality with available computation time, just like 3D-graphic-engines and chess engines [4, 78, 80]. The experiment also indicates that their signal-based approach is flexible regarding the frequency of appraisal. This flexibility enables a different form of runtime-scaling, namely scaling based on a trade-off between temporal quality and performance.

4.3 Aaron Sloman

Aaron Sloman⁸ work takes an approach that incorporates some of what Minsky calls the society of the mind, and examines how different theories of mind give rise to different theories of emotion [21]. It likewise examines how certain computational architectures might be more suited to modelling emotion as described by a given theoretical framework.

According to Sloman, this exploration will help us understand which Architectures are able to explain a specific form of intelligence, after being properly instantiated. In fact, Sloman seeks to develop Architectures that are capable not only of explaining Intelligence, both in Humans and in insects, but also Architectures that may effectively explain other

⁸ Prof. of Philosophy and Computer Science at the University of Birmingham, UK, where he studies the evolution of mind and the "design" of mind. Sloman is the lead researcher of the Cognition and Affect Group (CogAff) located at Birmingham University. The CogAff group has been dedicated to the study of Agent Architectures for years and has had the involvement of several researchers with relevant work on Emotion in AI. The work and ideas developed by Sloman and other members of the CogAff Group founded what is known as the "Birmingham School" in respect to the relation established between Cognition and Emotion.

observable phenomena, for example, in patients with brain diseases.

The Agent Architecture proposed by Sloman involves the combination of two other traditional Architectures: the “three towers” model and the “three layers” model [27].

The “three towers” model comprises three parallel subsystems that are conceptually vertical within the Agent Architecture:

- the **Perception Subsystem** that is responsible for extracting data from the environment where the Agent is operating;
- the **Action Subsystem** that allows the Agent to act upon the environment;
- the **Central Processing** subsystem that mediates perception and action and is capable of controlling both of these subsystems.

In order to achieve a globally successful performance, there is usually a great interaction level among these three subsystems. For example, the Action Subsystem may provide direct feedback to the Central Subsystem (proprio-perception) or it may interact with the Perception Subsystem to allow effective coordination of some tasks (e.g.: hand-eye coordination). Moreover, despite the existence of the three conceptually different subsystems, the actual implementation of an Architecture using the “three towers” model may blur such well-defined distinctions. Some of the Architecture’s components (e.g.: visual system) may belong both to the Perception Subsystem and to the Central Subsystem.

Sloman use architectures of autonomous agents to explain different emotions. This architecture is also called “three layer” model it is deeply inspired in Evolutionary theories: each of the autonomous agents would have been developed in different stages of the evolutionary path of organisms based on the capabilities of the previous agents [18].

- **Reactive agents:** primary emotions:
 - Fear, joy, etc;

- **Deliberative agents:** secondary emotions:
 - Shame, relief;
- **Reflective agents:** tertiary emotions:
 - Adoration, humiliation.

Sloman draws a relationship between Emotion and the interactions established between the Architecture's subsystems. In fact, Sloman argues that Emotional States arise naturally from interactions established between these subsystems, with no need for a dedicated Emotion-generating mechanism. Sloman divides Emotional Phenomena into three categories directly connected to the three layers in the Architecture. Following the definitions proposed by Damásio closely, Sloman agrees on the existence of Primary and Secondary Emotions but introduces an additional concept: Tertiary Emotions.

According to Sloman, Primary and Secondary Emotions result from the interactions established between Alarm Mechanisms and other subsystems located in the Reactive and Deliberative Layers. Primary Emotions, such as being startled, frozen with terror or sexually aroused, are supported by Alarm Mechanisms located in the Reactive Layer, which are mainly concerned with processing sensory information (inside and outside the environment) and triggering fast Reactive Mechanisms. This interaction is believed to be similar to the role of the Limbic System in Humans.

Secondary Emotions are supported by mechanisms in the Deliberative Layer and include emotions such as apprehension, relief and other semantically rich emotions that require deliberative capabilities. Secondary Emotions result mainly from Alarm Mechanisms concerned with evaluating internal cognitive responses (e.g.: the chances of success of a risky plan) that are not directly linked to the perceived environment.

Tertiary Emotions, on the other hand, result from the mechanisms located in the Meta-Management Layer. Therefore, Sloman argues that they are probably exclusive to Humans.

They include emotions related with thought and attention control such as infatuation, humiliation and thrilled anticipation. These Emotions interfere with Deliberative processes by diverting the attention from current tasks and triggering introspective processes, in spite of the Agent's attempt to ignore such interruptions.

4.4 Velásquez

Juan Velásquez's work represents a very interesting approach to the study of Emotional Mechanisms because it includes a simple, modular and extendable Architecture that explicitly supports Primary and Secondary Emotions, as defined by Damásio and by James-Lange [21, 99, 100]. Additionally, Velásquez has also developed a physical robot whose decision-making process is based on the proposed Architecture, providing an alternative hardware implementation of Emotional Mechanisms.

Velásquez follows a Biological perspective concerning the study of Emotions. The author considers Emotions as biological phenomena that have been conserved through various stages of evolution and that have a deep relation with survival and adaptation. Velásquez establishes as a basic assumption for the development of computational Emotional Mechanisms the need to understand and model the neurological structures that support Emotion. This goes in the opposite direction of other more descriptive approaches as those leading to Cognitive Appraisal Models. In this sense, Velásquez' approach is quite different from many researchers, who have based their architectures exclusively on Cognitive Appraisal Models (such as the OCC Model [7, 39]), since it includes both Cognitive and non-Cognitive components of Emotion.

The Architecture proposed by Velásquez is extremely modular and establishes a very high-level relation between five groups of systems:

Perceptual Systems;

Motor Systems;
Behavior Systems;
Emotional Systems;
and Drive Systems (Motivational System).

The actual implementation of these systems is based on a network of non-linear processing units called Basic Computational Units (BCU), which are composed by three elements:

a set of Inputs;
an Appraisal Mechanism; and
a set of Outputs.

Higher level structures, such as the five groups of systems mentioned before, are built from the aggregation of these Basic Computational Units in complex networks. Interaction between high-level systems is also established by connecting the output of one or more BCU's from one subsystem to the input of BCU's in another subsystem. This way, the entire Architecture is a large network of BCU's.

The fundamental component of the Appraisal Mechanism inside BCU's is what Velásquez calls Releasers. Releasers are described as “computational units that filter sensory data and identify special conditions which will provide excitatory (positive) or inhibitory (negative) input to the system they are associated with”. Releasers can be regarded as functions capable of evaluating (sensory) input and generating an output signal that depends on the relevance of the input. There are two types of Releasers, the Natural Releasers, which are hardwired from development, and Learned Releasers that can be learned by associating certain stimuli with Natural Releasers.

Velásquez also insists on combining both cognitive and non-cognitive factors of Emotion.

He divides Emotional Releasers (i.e. Releasers of BCU's inside the Emotional System) into four categories:

1. *Neural*. Neural Releasers are triggered by neuro-physiological conditions or compounds such as neurotransmitters, hormones, environment conditions, etc.
2. *Sensorimotor*. These Releasers are influenced by sensorimotor conditions, such as facial expression or body posture, that have the capability of triggering emotional mechanisms and eliciting Emotions.
3. *Motivational*. Includes all Releasers triggered by Motivational forces, which include both the Drive System and the Emotional System itself.
4. *Cognitive*. Cognitive Releasers account for Emotions triggered by cognitive processes, such as appraisal, comparisons, attribution, beliefs and memories.

All Neural, Sensorimotor and Motivational Releasers implemented in the Architecture are Natural Releasers (i.e. pre-wired). Cognitive Releasers were implemented as Learned Releasers. It is interesting to note that the Cognitive Releasers Velásquez had implemented in previous versions of the Architecture were Natural Releasers, based on Cognitive Appraisal theories. However, Velásquez reimplemented Cognitive Releasers using Learned Releasers because he considered that Cognitive Appraisal theories had limited capability to explain the underlying brain processes that support Emotion.

The Activation of BCU's in Emotional Systems follows a different function from that of BCU's in Drive Systems. It includes an extra term that accounts for the excitatory or inhibitory influence of other Emotional Systems, and also another term that introduces temporal decay behavior. Velásquez claims that these Activation functions enable the Architecture to support several different types of Emotional Phenomena, including:

- **Primary Emotions**. Primary Emotions are related with the activation of certain Emotional Systems, such as Disgust or Fear, by Natural Releasers. Primary Emotions

are fundamental in providing the Agent with adaptation capabilities to immediate environment conditions. Velásquez brings the example of Fear Emotional System, which may be activated by a Natural Releaser that detects a dangerous situation, and generates the appropriate defensive context to cope with it.

- **Secondary Emotions.** As we have seen, Velásquez has devised special releasers called Learned Releasers that are capable of learning relations between certain stimuli and the activation of Natural Releasers. The activation of Learned Releasers can thus be considered as the mechanism that supports Secondary Emotions (Damásio). Secondary Emotions tend to emerge after Agents develop a certain environment experience and start developing associations between events, objects and Primary Emotions, which are always present because they are hard-wired. The new Learned Releaser will be able to influence the action selection in future situations. Whenever the Agent reencounters the emotionally tagged stimulus (the person), the Learned Releaser will trigger the associated Emotional response (Fear).

- **Emotion Blends and Mixed Emotions.** Although admitting that Emotion Blends and Mixed Emotions are not consensual matters within Emotion research, Velásquez claims that his Architecture may also support them. According to Velásquez, in spite of the absence of an explicit model, Emotion Blends might emerge naturally by the simultaneous activation of two or more Emotional Systems. The co-activated Emotional Systems would subsequently be able to bias one or more non-conflicting perceptual or behavior systems.

- **Moods.** Velásquez follows the view that Moods differ from Emotions mainly in what concerns the level of arousal. In this perspective, Moods would be explained by a state of low activation of particular Emotional Systems. Emotional Systems in such a low activation state would have the potential to become highly activated even in response to smaller stimuli. Velásquez describes this behavior as being consistent with

the established theories about Moods.

- **Temperament.** Architectural support for Temperament comes from the possibility of varying the parameters associated with Emotional Systems: thresholds, gains and decay rates. Velásquez gives the example of a “ grumpy” Agent that would be configured by lowering the activation threshold and decay rate for Anger and increasing those for Joy. It is not clear, however, if such a variation is performed exclusively during the initial setup of the Agent, or if it may also be done automatically by the Agent during its interaction with the environment. This would represent another opportunity for adaptation.

Velásquez proposed a simple and modular model for Emotional phenomena, following a strong neuro-biological inspiration. The model makes a clear distinction between Primary and Secondary Emotion. The author addresses mainly the problem of behavior selection within a set of possible behaviors.

4.5 Lola Cañamero

Cañamero has developed extensive work in this field [101-103]. One of Cañamero’s work main focuses is the problem of Action Selection in Autonomous Agents with multiple goals (concerns).

Cañamero has developed an Architecture where Emotions play a key role. For the author, Emotions help reorganize goal priority in special circumstances and work closely with Motivation by amplifying their relative importance [21]. Cañamero focuses her work on Primary/Basic Emotions which she defines as being those more closely related with survival and elementary goals. Primary Emotions usually have very strong physiological and expressive manifestations. Different (Primary) Emotions have resulted from a long Evolutionary path and help Individuals achieve Goals, closely related with self-survival, by

changing the balance established between the Individual and its (Internal/External) environment. The author gives the following examples:

- **Fear** is related to protection from environment influences;
- **Anger** is responsible for blocking environment influences;
- **Anxiety** is concerned with diminishing the risk of dealing with unknown environments.

Cañamero supports her study in the following hypothesis: if Emotions play an important role in Biological Agents, increasing their Adaptation and Autonomy in complex, dynamic, partially controlled and uncertain environments, then, Artificial Agents operating in environments with similar characteristics will probably need similar mechanisms in order to be successful. Cañamero observes that Emotional Mechanisms provide an interesting Engineering solution, because they are able to interact with several behavioral and cognitive subsystems simultaneously. Furthermore, they are strongly connected with Goals rather than with particular behaviors, which contributes to an increased flexibility in dealing with the environment.

Cañamero points out the following functional properties of Emotional mechanisms:

- **Action Guidance and Motivation.** Contributes to categorizing events regarding goals. Change goal or motivation to deal with an urgent situation. Amplify the Effects of Motivation.
- **Bodily Adaptation.** Prepare the Individual to deal with Danger, unexpected events and opportunities.
- **Signalling Relevance of Events to Others.** Expression of Emotional State may be used as reference for social behaviors.

Cañamero defines a fundamental relation between Emotion, Motivation and Behavior in

the context of Action Selection. Following the view of Fridja [104], Ortony et al. [39] that relate Emotions with Goals, the author argues that the link between Emotion and Behavior is established through Motivation, instead of a simpler direct relation. This indirect relation is advantageous because it contributes to a more flexible and broad behavioral set. Cañamero insists in distinguishing Emotions from Motivation or Drives, disagreeing with other authors that propose a strong similarity between Basic Emotions and Motivation or Drives.

Alternatively, Cañamero considers Emotions mechanisms that “modify” or “amplify” Motivation, therefore biasing the selection of behavior to be activated. Emotional Mechanisms continuously monitor internal and external environments to detect relevant events that require an appropriate response. This response is indirectly requested by a change in the Motivational System. Emotions are thus considered a second order control mechanism, capable of acting upon the motivational control mechanism and changing or resetting the Goal/Motivational priorities.

Cañamero defines six emotional primitives that address needs, mostly related with survival functions:

1. **Anger:** Mechanism that is triggered when the accomplishment of a goal is menaced. Anger is a mechanism capable of blocking influences from the environment.
2. **Boredom:** Mechanism intended to stop a repetitive behavior that is proving to be inefficient. The triggering event is a prolonged inefficient behavior.
3. **Fear:** An Emotional state triggered by the presence of Enemies. It functions as a Defensive Mechanism.
4. **Happiness:** Mechanism intended to obtain re-equilibration after the accomplishment of a Goal.
5. **Interest:** Triggered by the presence of a novel object in order to stimulate the interaction with it.

6. **Sadness:** Triggered by the inability to attain a specific goal and results in a global reduction in the activity of the Abbot. “Sad” Abbots enter a suspended state waiting for the occurrence of changes in the environment or in their internal state.

Another important issue that Cañamero brings to discussion is the need for established means to evaluate the influence of Emotional Mechanisms in the Agent’s performance. As any other evaluation activity, evaluating Emotional Mechanisms may be extremely complex but, as pointed out by the author, only by defining common metrics, evaluation criteria and test-beds will it be possible to track objectively the development of Emotional Agents and compare different Emotional Agent Architectures. In our opinion, this is certainly a very significant subject, as it can be easily confirmed by the amount of different Architectures proposed. In fact, research in MAS in general and Emotional Agents in particular suffers from a great deal of subjectivity and from a lack of consistent concept definitions.

4.6 Sandra Clara Gadanho

Another interesting approach to the use of Emotional-like mechanisms has been pursued by Gadanho which combines Emotions with Adaptive Control and Reinforcement Learning [82]. She study usefulness of emotions in autonomous robots and particularly motivated by neurophysiological research which suggests that, side-by-side with rational cognition, emotions play an important role in the process of decision making. Her work has been trying to transpose some of functional value of natural emotions into the control of artificial creatures. As she said, she recognizes that emotions play a particularly important role in social interaction, but she is mainly interested in their use in decision making as a way to increase the adaptiveness and autonomy of artificial agents in their interaction with unstructured and dynamic environments.

The authors address the problem of designing an Adaptive Controller for a simulated

Robot, operating in a continuous real-time environment. The Perception of the simulated Robot employed in their experiments comprises a set of eight sensors, which allow it to detect obstacles in its surroundings, and light sensing capabilities, with which the robot can detect light points in the environment. Using two side motors for locomotion, the robot has to make its way in a labyrinth-like environment, delimited by walls and obstacles, searching for valuable energy that it needs in order to survive. The Robot is constantly consuming energy from its limited-life battery that can only be refilled at specific points available throughout the environment and identified by a detectable light.

However, these energy refilling points have themselves limited capability and require a considerable recharge time before they can be used again by the Robot. Therefore, the Robot must constantly search for the best alternative energy points available. The simulation system introduces a certain percentage of noise in the values read by the sensors and in the effective power delivered to the motors, creating supplementary problems in both Perception and Control. The Robot has three preprogrammed behaviors available that build its (compound) Action/Behavior set:

1. Avoid Obstacles;
2. Seek Light;
3. Follow Walls.

Gadanho and Hallam's [83] goal is to develop a controller that is able to optimally choose the appropriate behavior from the three possible behaviors available, according to the current state of the environment. The controller is built using a Reinforcement Learning approach, in particular Q-Learning.

However, an environment such as the one described before (real-time, continuous, dynamic) creates a serious difficulty for the convergence of Learning algorithms as well as for the global efficiency of the Controller itself. In fact, a continuous environment imposes the

intrinsic difficulty of defining state transitions, since a new (multi-dimensional) state can be found at virtually any step. For this reason, the authors devised a specific Agent Architecture that explicitly uses Emotional concepts to tackle the problem just described. The Emotional mechanism developed involves the following concepts and organization:

- **Sensations:** values obtained by using data collected from the Robot's sensors and also from other events calculated using the Robot's internal variables (e.g.: level of actuators).
- **Feelings:** values obtained by combining the value of Sensations with the value of Hormones.
- **Emotions:** The level of each Emotion results from combining the values of several Feelings. Although there are several Emotions at stake, the robot behavior will be defined by just one of them that is considered to be the Dominant Emotion. The Dominant Emotion is selected according to pre-defined threshold levels at every step of the simulation.
- **Hormone System:** a System that combines the values of several Emotion levels and produces Hormones. These Hormones will be used to influence the level of the Feelings in combination with Sensations. The Hormone System acts as feed-back loop and it helps stabilize the value of Feeling and Emotions, in spite of possible quick changes in Sensation's values.

Using this architecture, the problem of state transition was solved by triggering transitions not directly from sensory information, which changes too quickly and is prone to instability, but from changes in Emotional levels instead. When the level of one Emotion suffers a change higher than a predefined threshold value, a new state transition is triggered.

The authors have successfully employed this strategy in training a controller for the Robot, using Q-Learning. The Q-Learning algorithm was capable of converging and produced

an efficient controller. The authors have also compared the performance of the controller developed using emotion triggered state transition with controllers developed using other strategies. Specifically, they have developed another controller using Q-Learning, but used a fixed interval of time to trigger state transitions. According to the authors, these two controllers showed similar performances in controlling the Robot, but the one developed using Emotion-triggered transitions was able to converge in significantly less steps (one sixth of the steps). This reduced computational effort is extremely important in real-time control situation such as the one in the experiment, because it releases processor power to other concurrent processes, if needed.

4.7 Andrew Ortony, Gerald L. Clore, and Allan Collins.

Andrew Ortony⁹, together with Gerald Clore¹⁰ and Allan Collins¹¹, has produced seminal work relating emotion to cognition, and consequently modelling emotion in AI.

Their theory is based on “*the assumption that progress in psychological research on emotion can be attained through an analysis of the cognitions that underlie emotions*” [39] . They examine the cognitive structure of emotions in general, as well as that of individual emotion. In particular, they examine the cognitive psychology of appraisal, which again we think is a key framework for dealing with emotion in speech, since it is the basis of the sort of heuristic assessment that we want systems to make about user needs and intention; and which we would likewise hope to enable the user to make about the intention expressed by the

9 Andrew Ortony is well-known cognitive scientist, is formally Professor of Psychology, Education, and Computer Science at Northwestern University

10 Gerald Clore is Prof. of Psychology at the University of Virginia. His current work focuses on the idea that affect per se represents information used in cognitive processing (as opposed to the view that Emotion provides information by association).

11 Allan Collins is Prof. of Learning Sciences at Northwestern. His widely-cited book [39] explores the relationship of emotion to cognition, and as such serves as a starting point for a number of models of emotion in AI.

system. They provide an extensive framework for understanding many of the issues addressed by other authors in this bibliography, such as how emotions are elicited by events, by objects, by context, and by interaction with others. We find their approach to be the most appealing in general of everything we have reviewed. Their ideas could almost be described as a pragmatics of emotion, and it is quite in line with the ideas in [38].

As Bartneck wrote [52], this model specifies 22 emotion categories based on valenced reactions to situations constructed either as being goal relevant events, as acts of an accountable agent (including itself), or as attractive or unattractive objects. It also offers a structure for the variables, such as likelihood of an event or the familiarity of an object, which determines the intensity of the emotion types. It contains a sufficient level of complexity and detail to cover most situations an emotional interface character might have to deal with.

4.8 Paolo Petta

Petta¹² [40] studies the creation of autonomous intelligent agents and synthetic characters. He argues, from a fairly pragmatic perspective, that emotions are prerequisite to autonomy and proactivity. He examines the adaptive nature of emotion, particularly from the standpoint of the appraisal theories of emotion. This point of view particularly appeals to me since it combines certain pragmatic elements of behaviorism with the subjective perspective I think is necessary in the formation of intention. He follows his theoretical analysis with a lengthy description of the TABASCO (tractable appraisal-based architecture framework for situated cognizers) architecture, which is an architectural framework for building “situated cognizers” software agents that use emotion as a guide for interacting with the environment and for decision making.

¹² Paolo Petta is a computer scientist at the Austrian Research Institute for Artificial Intelligence, and founder of its research group Intelligent Software Agents and New Media.

4.9 Nico H. Frijda

Nico H. Frijda's¹³ work [104, 105] is considered an important study on emotion, once again, from a cognitive perspective (also studied by Lazarus [93]). The cognitive perspective assumes that thought and emotion are inseparable and all emotions are seen as the product of a cognitive appraisal process (Figure 9).

The approach taken pays more attention than some other cognitive theories to behavioral issues, and in particular develops a clear definition of the “emotion process” that begins with stimulus, transitions through various phases of what others might call appraisal and finally results in an action tendency. By other words, emotion results from the evaluation of the environment in relation to the agent’s goals, needs, beliefs and desires. This evaluation is both necessary and sufficient for an emotion to occur.

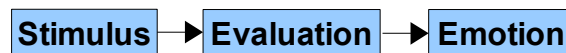


Figure 9: Emotional Process

This is examined as a matter of cognitive process, as opposed to a strict behavioral model, which outwardly might fit a similar description. Frijda also examines how this theory of emotion, which he describes as functionalism, “collides” with a variety of other emotional definitions, such as many expressed in [42]. In simplistic terms, his theory, is an in-depth examination of the function of emotion coloured by the point of view that emotion is in some way “helpful.” He defend that in the absence of physiological arousal, we decide what to feel after interpreting or explaining what has just happened. Two things are important in this: whether we interpret the event as good or bad for us, and what we believe is the cause of the event. In primary appraisal, we consider how the situation affects our personal well-being. In secondary appraisal we consider how we might cope with the situation.

This is, of course, terrifically useful in the development of an operational definition for

¹³ Nico H. Frijda is Prof. of Psychology at the University of Amsterdam and a widely-cited authority on the psychology of emotion

use in computation, since the underlying assumption in that endeavour is of the pragmatic utility of emotion.

4.10 Rosalind W. Picard

Picard¹⁴ examines emotion in computing from two perspectives: an intellectual/philosophical/psychological standpoint; and a more pragmatic, implementational perspective [91]. She articulates a general reasoning that it is necessary for machines to be able to deal with emotion in order to exhibit true intelligence; a subtle analysis of the distinction between imitating and duplicating emotions, and how this must be applied in defining and evaluating machine emotion; and—less common in such volumes—a thoughtful discussion of some of the concerns that must be responsibly addressed in the pursuit of “engineering” emotion in machines. She also examines ways of designing systems that recognize and exhibit emotion, addressing a range of low-level, mid-level, and high-level issues, which she differentiates as signals, patterns, and concepts. Also Picard makes the novel argument that, once we have empowered machines to do all of the things we need them to do, i.e., by giving them signalling, prioritization, regulatory mechanisms, and a way of interacting with the world that seems intuitive to us, we have already given them emotions, whether or not that is the word we use.

4.11 Rolf Pfeifer

Pfeifer¹⁵ articulates in his work [92] a framework for understanding the domains in which emotion is operative, or the roles it takes on: e.g. Emotion as process; the events and

¹⁴ Rosalind Picard work at the faculty in the Media Lab at MIT.

¹⁵ Rolf Pfeifer is Prof. of Computer Science at the University of Zurich and has written widely on artificial intelligence and intelligence in general.

conditions that generate emotion; the influence of emotion on the system (and further generation of emotion); Emotions goal oriented nature; and Emotion as heuristics, that is, how Emotion helps to interpret situations and make predictions. He examines a number of AI models for emotion, which he separates into two categories: those in which emotion is the primary focus of the system, and those in which emotion augments the functionality of the system. His work is somewhat historical, but it highlights how the essential issues have not really changed in the past 15 years.

4.12 Ana Paiva

Ana Paiva¹⁶ is a group leader of the researchers in the area of Intelligent Agents for a new generation of the Human-Computer interactions, specially synthetic characters, affective interactions and emotion based agent architecture's. Her work is focused on Intelligent Virtual Agents in collaborative scenarios and on the concept of emotion which steams from OCC cognitive theory of emotions [108-110]. She argue that an emotion type represents a family of related emotions differing in terms of their intensity and manifestation. Thus, as she specify, when an emotion type is referred, such as Fear, it does not specify the particular emotion associated with the word fear. Instead, it references the possible set of emotions resulting from appraising the prospect of a goal expected to fail, with varying degrees of intensity – concern, fright, petrified. Therefore, the attributes considered in the model she proposed for the description of an emotion are:

- *Type*: The type of the emotion being experienced;
- *Valence*: Denotes the basic types of emotional response. Positive or negative value of reaction;
- *Target*: The name of the agent/object targeted by the emotion;

¹⁶ Ana Paiva is Professor at IST Technical University of Lisbon, INESCID

- *Cause*: The event/action that caused the emotion;
- *Intensity*: The intensity of the emotion;
- *Time-stamp*: The moment in time when the emotion was created or updated;

Her work is very interesting and useful in our project, specially because of integration of Big-Five Personality Factors in the emotional architecture and Appraisal Theory implementation. She also developed many software application with the proposed emotional architecture which are very useful for evaluation and analysis.

4.13 Eugénio Oliveira and Luís Sarmento

Eugénio Oliveira¹⁷ and Luís Sarmento¹⁸ examine Humane Emotions from the Damásio perspective and specify the emotional architecture for Multi-Agent system [21, 107] using BDI Agents. A great deal of their work has been devoted to exploring a vast amount of dispersed bibliography about Human Emotion so that a deeper understanding of Emotional-Mechanisms and their interaction with Cognition could be achieved.

The Architecture they developed is rather general and can be transposed to other application scenarios. It is composed of several Functional Modules that are grouped in two layers, according to the Goals they help to achieve. They build the Basic Control Agent Layer on top of the Agent Skeleton Layer and is connected to the Agent's Fundamental Goal in the fire-fighting environment, survival. This layer possesses all the necessary capabilities to address this Goal. At the same time, this layer is responsible for managing and providing processor time to the layer placed immediately above, the Basic Deliberative Layer, which is

¹⁷ Eugénio Oliveira is Full Professor at the University of Oporto, Department of Computing and Electrical Engineering, Faculty of Engineering, and the responsible for the NIAD&R-Distributed Artificial Intelligence & Robotics Group. He also belongs to the Coordination Committee of LIACC-Artificial Intelligence and Computer Science Laboratory of the University of Porto (including 3 different groups).

¹⁸ Luís Sarmento is researcher at NIAD&R-Distributed Artificial Intelligence & Robotics Group

connected with higher-level goals and Capabilities.

The Emotional Architecture they developed includes three different Emotional Mechanisms, namely “Fear” , “Anxiety” and “Self-Confidence”. Each Emotional Mechanism tries to address specific environment situations, either threats or opportunities, and alters some of the Architecture’s parameters available at the three aforementioned levels. These changes are intended to adapt the Agent’s current Capabilities to the specific state of the environment. The exact conditions that lead to the elicitation of a given Emotional Mechanism are identified by several Emotional Evaluation Functions, distributed throughout the Architecture’s elements.

The main results of their work are:

- a generic Functional Model of Emotional-Mechanisms;
- an Emotion-based Agent Architecture where Emotional Mechanisms have a functional purpose;
- the establishment of a clear connection between Emotional Mechanisms and specific components of distributed mentalist-like Agent Architectures;
- the application of three Emotional-Mechanisms, whose functionalities are strongly related with Agent’s performance, in a specific application scenario: “Fear” , “Anxiety” and “Self-Confidence”;
- a complete simulation platform based on a relevant real-world problem (Fire-Fighting).

Their work is very useful because of deep study of the Human Emotion and Emotional Agent Architecture's and the development of the generic platform which could be used in different application scenarios.

4.14 Summary and Conclusions

In this Chapter, we made a brief review of some of the works on the area of emotional agents that influenced most the development of our own work. The authors share the notion that Emotions are phenomena tightly connected to Agents that operate in complex worlds, and that help them in dealing with such complexity. Most of the work presented was concerned with the problem of Action-Selection and adaptation to the environment, especially the work by Velásquez and Cañamero. Emotional Mechanisms were involved in changing or complementing the Agent's basic motivations that lead to action. Emotional mechanisms were also used as a way to control resources and schedule internal processing (interrupt, swap). This was shown to be particularly useful for Agents whose processing resources are limited and that have to deal with multiple and simultaneous Goals. We have also seen how Emotion could be used in improving Agent Learning capabilities by providing an alternative source of information for the learning process. Emotional Information is more stable and more compact than the information available exclusively through sensors, speeding up the learning process.

Additionally, the process of learning itself could be modulated according to the activity of Emotional Mechanisms in order to improve convergence.

All these Architectures seem to have a complementary view about the functional role of Emotion. However, in most cases the authors focus only on a particular possible use of Emotion, and do not include other interesting perspectives that have been identified throughout the literature. We believe that there is still a lot of work to do in that direction, and that this is a challenging endeavour for AI.

Chapter 5 Computational Approach to Emotional Agents

There is no branch of mathematics, however abstract, which may not some day be applied to phenomena of the real world.

Nikolai Ivanovich Lobachevsky

5.1 Introduction

Before we start to define our emotional model let us discuss briefly the concept of artificial intellect. Some researchers consider the intellect as a **skill to solve complex problems**; others consider it as a **capability for learning, generalization and analogies**; a third group - as the possibility of **interaction with the external environment by contact and perception**. Nevertheless many researchers of AI are inclined to accept the definition of machine intellect, proposed in the beginning of the 50s by the outstanding English mathematician Alan Turing.

The Turing Test was designed to provide a satisfactory operational definition of

intelligence. Turing defined intelligent behavior as the ability to achieve human-level performance in all cognitive tasks, sufficient to fool an interrogator. Roughly speaking, the test he proposed is that the computer should be interrogated by a human via a Teletype, and passes the test if the interrogator cannot tell if there is a computer or a human at the other end.

Attempts to build machines, capable of reasonable behavior, have a considerable inspiration on the ideas of the MIT professor Norbert Wiener, one of the outstanding personalities in the Artificial Intelligence history. Besides mathematics he possessed wide knowledge in other areas, including neuro-psychology, medicine, physics and electronics. Wiener was convinced that the most promising scientific studies are situated on the frontier zones, which cannot be specifically carried to one or another concrete discipline. They lie somewhere on the joint of sciences; therefore they do not usually approach them so strictly. "if some problem of Psychology has Mathematical nature, he explained, that ten psychologists which are inexpert in mathematics will advance as far as just one of them" [85]. We find the Wiener's idea very inspiring, specially in the domain of emotional programming, as the psychology phenomena which we study from a mathematical approach.

As we reference in previous chapters, we choose the approach to emotional programming through the implementation of artificial personalities and the integration of the emotional decision model based on the appraisal theory. The innovation of our approach consists in the duality of our emotional character: it processes the information and gives the output using two different engines, physical and psychological. In our model the temperament of the agent is defined as the configuration of his mechanical engines and the personality functions which simulates his psyche as the decision mechanism. The emotional response of the agent possesses a dual mechanism: it is physical (such as motor and sensor force, face expression, mobility) and psychical (such as a vector which defines his internal emotional state).

We also need to emphasize the difference between the agent's temperamental state and agent's emotional state. Temperament, as we already defined, is the steady characteristics of

the agent which is “innate” and do not suffer alterations during the agent’s life. On the other side, the emotional state of the agent is the dynamic set of values which depends on the external influences, and on the agent’s temperament.

We can define emotion as a short episode triggered by an (internal/external) event composed of

- subjective feelings
- inclinations to act
- facial expressions
- cognitive evaluation and
- physiological arousal.

And emotions have a role of heuristic relating events to goals, needs, desires, beliefs of an agent and evaluate their personal relevance and help decision-making.

So, for instance, two agents with different temperaments and the same emotional states on some temporal period, which receive the same external input will have different responses on both, the physical and the psychical mechanism. We also define different sets of needs and motivations for each temperamental type by the influence of the agent’s performance and stimuli on the team work. This modular, but complementary approach, is the core of the innovation of our emotional system and our aspiration of its usability.

We assume a two layer architecture for our emotional model. One layer is physical and describes the superior Nervous system from the Pavlov perspective. The other layer is psychical and works with the appraisal model created by Mehrabian.

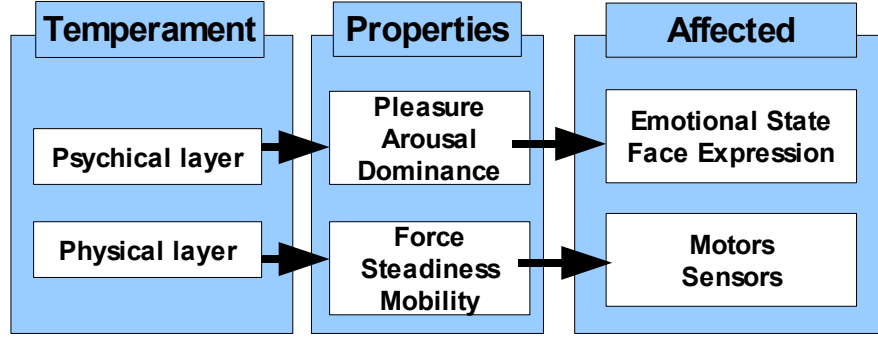


Figure 10: Temperamental Architecture

In order to perform evaluation of agent needs, motivations and stimulus we will create an appraisal bank [4] which will define the relationship between the constructed objects and subjective measures, called appraisal dimensions.

5.2 Previous Assumptions

Before proceeding with the discussion on Human Emotion, we shall make some previous assumptions for the sake of generalization. We now introduce, at this point, the notion of Emotional State and several other definitions, fundamental for the subsequent sections.

Let us first assume that an Agent operating in a complex environment requires a set of specific capabilities to deal effectively with such complexity. These capabilities allow the Agent to endure in the environment and address multiple other needs. Let us also assume that if such capabilities, although limited, are reasonably sophisticated (either as a result of a long process of evolution or as a consequence of thorough design and implementation), they are almost certainly related to various operating parameters that control their individual activity.

The results achieved by the Agent in the environment will depend on how the specific parameters of its individual Capabilities are instantiated.

5.2.1 Software Agent

A software agent is computer program "whose state is viewed as consisting of mental components such as beliefs, capabilities, choices, and commitments" [41]. Another agent definition, according to Russel and Norvig [42], is based in biological information processing models - an agent is a program that implements a mapping from perceptions to actions. In addition to the idea of perceptions and actions, an agent has a state and an architecture that determines how perceptions from sensors are available to the agent, and determines the agent program execution, agent state update, and selected action execution.

5.2.2 Emotional State

An Agent's Emotional State is a particular instantiation of operating parameters for the complete set of Capabilities (physical or cognitive) it possesses. An Emotional State defines a global operating context in which the Agent's available resources are concentrated in the achievement of a specific Goal or set of Goals. An emotional state actually is not just a computer science approach to emotions. Many emotion theorists use this concept of a state to define emotion [8, 73, 76].

5.2.3 Emotional Agent

Emotional Agents (EA) are agents whose internal structure or behavior is inspired by ideas of emotion. An Emotional Agent is an Agent that is able to operate under different Emotional States. An Emotional Agent will always be operating under one specific Emotional State.

5.2.4 Temperament

An Agent's Temperament is a set of functions and properties which defines the "Personality" of the Agent, i.e. works to process the emotional states and system inputs of the

agent and defines the appropriate output as emotional states, behaviors or physical expressions.

We will now proceed with a more specific discussion on Human Emotion where we will try to introduce some additional concepts to reinforce the functional perspective of Emotion.

5.2.5 Motivation

Motivated or goal-directed [53] behaviors are sets of actions that direct an agent towards a particular goal. Interaction with the goal either promotes the survival of an individual or maintains the species. Motivated behaviors include, for example, sleep/wake, ingestive, reproductive, thermoregulatory, and aggressive/defensive behaviors. They are often accompanied by emotion or affect. In our project we focus the attention on the aggressive/defensive and ingestive behaviors.

5.3 Appraisal Theory

Appraisal theories [54] argue that emotion arises from two basic processes: appraisal and coping. Appraisal is the process by which a person assesses his or her overall relationship with the environment, including not only current conditions, but events that led to this state and future prospects. Appraisal theories argue that appraisal, although not a deliberative process in itself, is informed by cognitive processes and, in particular, those processes are involved in understanding and interacting with the environment (e.g., planning, explanation, perception, memory, linguistic processes). Appraisal maps characteristics of these disparate processes into a common set of intermediate terms called *appraisal variables*. These variables serve as an intermediate description of the person–environment relationship and mediate between stimuli and response. Appraisal variables characterize the significance of events from an individual’s perspective. Events do not have significance alone, but only by virtue of their interpretation in the context of an individual’s beliefs, desires, intentions and past events.

The coping strategies performed over the selected plan depends on the character's emotional state and personality.

A common classification of appraisal theories is based on a structural versus a process-based description [78]. Structural theories of appraisal (also called black-box models or structural models) describe the structural relations between:

- the environment of an agent and perception of this environment: *perception*;
- the agent's appraisal processes that interpret the perceived environment in terms of values on a set of subjective measures, called appraisal dimensions¹⁹: *appraisal*;
- the processes that relate these values to the agent's emotions: *mediation*.

Process theories of appraisal describe the cognitive operations, mechanisms and dynamics by which the appraisals, as described by the structural theory, are made and how appraisal processes interact. In other words, a structural theory of appraisal aims at describing the declarative semantics of appraisal, while a process theory of appraisal complements this description with procedural semantics.

The majority of computational models of emotion embedded into virtual agents are based on appraisal theories, cognitive theories of emotion that attempt to explain why a certain event results in one emotional response rather than another and why a certain emotion can be elicited by different events. The key concept of appraisal theories is that the subjective evaluation of the environment in relation to the agent's goals is responsible for emotions [75]. This evaluation is called appraisal. Appraisal theories contrast with, for example, the James-Lange theory, which we already described in the Chapter 2. In this theory, an emotion is the interpretation of the bodily reactions that are provoked by an event, while appraisal theories assume that bodily reactions are a result of the emotion, which is a result of cognitive evaluation. Appraisal theory also contrasts with the Schacter-Singer cognitive theory.

¹⁹ An appraisal dimension influences emotion and can be considered as a variable - e.g., agency or valence - , used to express the result of the appraisal of a perceived object - e.g., a friend.

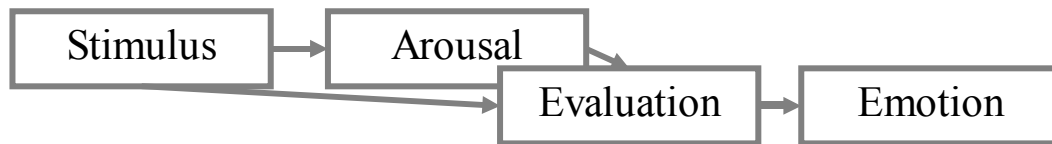


Figure 11: Schacter-Singer Appraisal Theory

In this theory, that is also called two-factor theory, an emotion results from the cognitive evaluation labelling the arousal of the organism. Arousal results directly from events, and cognitive processing is not needed for this. Thus, the emotion is based on arousal and differentiated by cognitive evaluation, while appraisal theory assumes that arousal itself is a result of cognitive evaluation. In short, appraisal theory focuses on emotion being a result of the cognitive evaluation of the environment in relation to the agent's goals (desires, concerns and needs), which explains its popularity in computational models of emotion.

Typically, appraisal theories that are used for computational models of emotion are descriptions of the relations between events, appraisal of events, and emotions. Such descriptions are abstract, but computational models are concrete. The most difficult task of our work is the gap between the level of abstraction of these structural description of appraisal theories and computational model of emotion.

In Appraisal Theory Emotion: is a result of the evaluation of the environment in relation to the agent's goals, needs, beliefs and desires (=appraisal). Evaluation in terms of appraisal dimensions: variables expressing a certain emotional aspect of a situation, e.g. valence or arousal. Appraisal Assumption: evaluation is both necessary and sufficient for an emotion to occur.

In this work we implemented BDI based agents: these are the agent's whose thinking are based on beliefs, desires and intentions. They possess basics to which appraisal based emotions can be added.

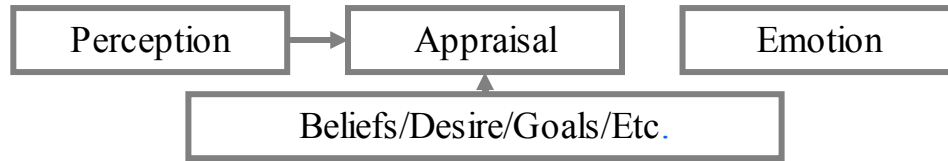


Figure 12: BDI Based Agent Architecture

One of the appeals of cognitive appraisal models as the basis of a computational model is the ease with which appraisal can be tied to the belief, desire and intention (BDI) framework often used in agent systems.

5.4 Agents Behaviors

To study the concept of emotional behaviors let us first analyse the animal behaviors and the essence of the behavioral concept. A *behavior* is a mapping of sensory inputs to a pattern of motor actions which are used to achieve a task. For example, if a horse sees a predator, it flattens its ears, lowers its head, and paws the ground, as wrote Murphy [72]. She pointed that the action and sequence of behavior patterns are always the same, regardless of details which vary each episode.

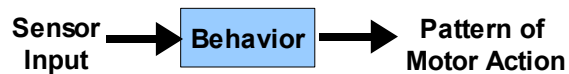


Figure 13: Graphical definition of a behavior

Following the definition of Arkin [86] a behavior implements a partial mapping from a set of stimuli to a set of responses.

Behaviors can be divided into three broad categories:

- *reflexive behaviors* are stimulus-response (S-R);
- *reactive behaviors*, which are executed without conscious thought;
- *conscious behaviors* are deliberative;

Reflexive behaviors, in our model, are defined by the “innate” characteristics of the agent which are the same to all agents, it can be described like a universal model of agent survival, such as becoming anxious or sad after collisions or running from dangerous agents. Some specific behaviors are also considered reflexive, while they are not used by all agents on the system. These are special behaviors depending on the agent’s temperament and its “central nervous system”, such as more or less sensitivity to the danger or anxiety level which appears in certain conditions.

Reactive behaviors, in our system, are behaviors we “teach” to the agent through the specification of the behavioral knowledge base which varies for each temperament. We aspire to include in our system some type of learning in order to have a complete learning behavioral mechanism.

Conscious behaviors, in our model, are behaviors which the agent makes by planning and analysis of the different ways to complete the goal and by choosing one or another action by evaluation of the probability of success.

Arkin’s [86] analysis of Behavior Based (BB) systems defines a behavior as a mapping β , between a stimulus domain, s , and a range of responses, r :

$$\beta(s) \rightarrow r$$

Generalised for a behavior, a particular response r_i is defined by the behavioral mapping, β_i of the relevant states s_i multiplied by the related gain values, g_i , an activation strength measure. This definition is presented in following equation:

$$r_i = g_i \times \beta_i(s_i)$$

In this framework Arkin suggests that a number of relations can be learnt:

1. The stimulus, s , for a given response, r .
2. The response, r , for a given stimulus, s .

3. The mapping β_i for the given stimulus domain and range of responses.
4. The magnitude of the response, g_i .
5. New behaviors, new stimuli or responses.

For a set of behaviors Arkin defines the global response ρ in terms of a coordination function C that arbitrates a set of behaviors B working on a set of stimuli S where the behaviors have a set of related gains G . The relation is expressed in following equation:

$$\rho = C(G \times B(S))$$

In this context Arkin suggests learning the following:

1. The subset of β_i to be included in B .
2. The relative strengths in G .
3. The coordination function C .

Typically, behaviors are hand-designed to perform a particular activity, attain a goal, or maintain some state. It is, of course, impossible to define an “optimal” behavior set. Nevertheless, practical experience has established a number of consistent guiding principles. Mataric [69, 71] describes basis behaviors as a useful tool for structuring and thus simplifying behavior synthesis, i.e., design. Mataric emphasises that, rather than trying to attain asymptotic optimality over a system’s lifetime, developers should focus on improved efficiency on a shorter time scale. He also suggests other ways of learning in behavior based systems, in particular learning behavior policies, learning models of the environment, learning models from the behavior activation history and learning from humans and other agents/robots [87].

Basis behaviors are a set of behaviors that are necessary in the sense that each either achieves, or helps to achieve, a relevant goal that cannot be achieved by other members of the set. Furthermore, a basis behavior set is sufficient for achieving the goals of the system/robot. Other desirable properties include simplicity, stability, robustness, and scalability. In addition

to the choice of behaviors themselves, an important issue in behavior-based systems is the action selection mechanism. This is a well studied problem that deals with coordinating individual behaviors in a manner that produces the most coherent global results in spite of possible disparities or conflicts between behavioral units. Two frequently employed methods are prioritization and fusion. Prioritization, wherein one behavioral unit is given the ability to overrule the output of others, is particularly useful for modelling those situations in which safety or survival dictates fast actions. Fusion involves the combination of output from various behaviors so that effects of each are incorporated, often using a weighted average, or related ideas. Fusion is useful for performing actions that make progress toward the achievement of multiple concurrent goals. In spite of the simplicity of the prioritization and fusion operations, they are often employed. Many more sophisticated alternatives exist; Pirjanian [70] provides an extensive review of significant work addressing the challenges of behavior selection.

5.5 Implementation of Pavlov's Theory

Temperament is a specific feature of Man, which determines the dynamics of his mental activity and behavior. Two basic indexes of the dynamics of mental processes and behaviors at present are distinguishable: activity and emotionality.

Activity is expressed in different degrees of tendency to act, to appear in the diverse activity. The manifestation of activity in different people is different. It is possible to note two extremes: from one side, high energy, fervency and swiftness in the mental activity, the motions and speech, while the other - passiveness, sluggishness, the apathy of mental activity, motion and speech. The second index of dynamics (emotionalism) is expressed in different degrees of emotional excitability, in the rapidity of appearance and the force of the emotions of man, and in the emotional sensitiveness (receptivity to the emotional actions). Four basic forms of temperament may be distinguished, which were named as follows: sanguine (living), phlegmatic (slow, calm), choleric (energetic, passionate) and melancholic (locked, inclined to

the deep experiences).

5.5.1 Fuzzy Logic Application

Fuzzy logic was first developed by Zadeh [28] in the mid-1960s for representing uncertain and imprecise knowledge [25]. This method provides an approximate but effective means of describing the behavior of systems that are too complex, ill-defined, or not easily analysed mathematically. Fuzzy variables are processed using a system called a fuzzy logic controller. It involves fuzzification, fuzzy inference, and defuzzification. The fuzzification process converts a crisp input value to a fuzzy value. The fuzzy inference is responsible for drawing conclusions from the knowledge base. The defuzzification process converts the fuzzy control actions into a crisp control action.

As we show on previous chapter, Pavlov's theory defines the temperamental model based on characteristics of the superior nervous system, but at the same time there are no pure temperamental types in nature, but there are mixtures of different properties which characterize one or another unique temperamental type. So, as we see, one person can have all temperamental types in different ratios. The different proportion of values: force, mobility and steadiness of processes of excitation and braking defines the unique temperamental type for each person. Based on this uncertainty we use Fuzzy Logic to describe and monitorize the temperamental types in our project. Let us analyse the most important variables for our model and their fuzzy interpretation [90].

5.5.1.1 Force

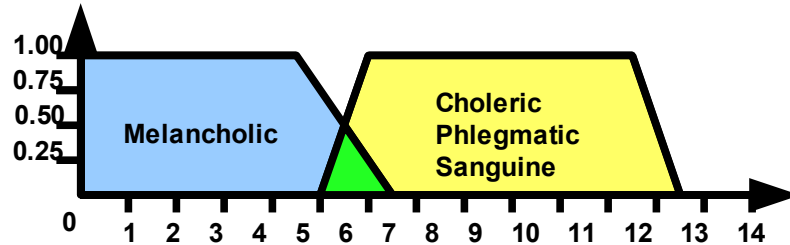


Figure 14: Motor and Sensor Strength

In our multi-agent system the force of excitation and braking processes is represented by the force of the motor and reach of the sensors. We perform the tests to identify the maximum accepted speed of the agents in our simulations environment to calculate the most logical fuzzy set. In the beginning of the simulation we generate the variable values to determine the unique combination which will represent some temperamental type. Using fuzzy logic we can determine which temperament we obtain for the agent. We define the superior limit for the force value in order to obtain a better simulation of the real world.

5.5.1.2 Mobility

The mobility of the agent is represented by its “persistence” to reach the goal and avoid negative emotions. For instance if some agent is “comfortable” in some place, and his mobility is low, he will not look to move to search other places. He will slow his motors and just stay in the same place until his emotional state changes and forces him to move quickly. At the same time, one agent who has a high mobility will search new places and new directories even if he is comfortable enough in some temporal phase. According to Mehrabian [8] arousal is highly correlated with activity and alertness so changing the Arousal we can control the Mobility of the agent.

5.5.1.3 Steadiness

The steadiness of the agent is the velocity of his emotional state variation. For example, more balanced agents have a slow variation of emotional state. For this we introduce the variable called Anxiety which is used to increase or decrease the Pleasure variable. The value of Anxiety depends on the temperament of the agent. We choose the values for anxiety based on the Eysenck test [22].

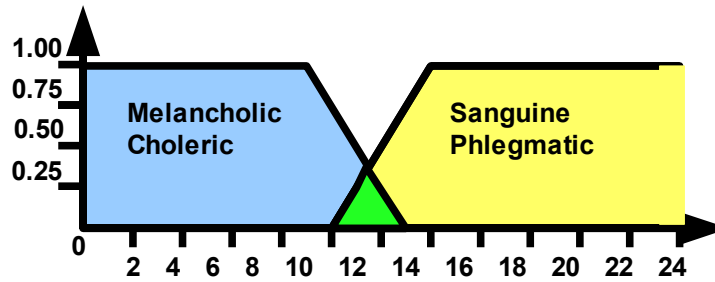


Figure 15: Anxiety Scale

5.5.1.4 Emotional Receptivity

This variables were based on the Eysenck test described on the second section. The Melancholic and Phlegmatic temperamental types are included in the Introverts group and the Sanguine and Choleric types are included in the Extroverts group. We will evaluate how they performance to reach the beacon, conditioned by their temperamental needs.

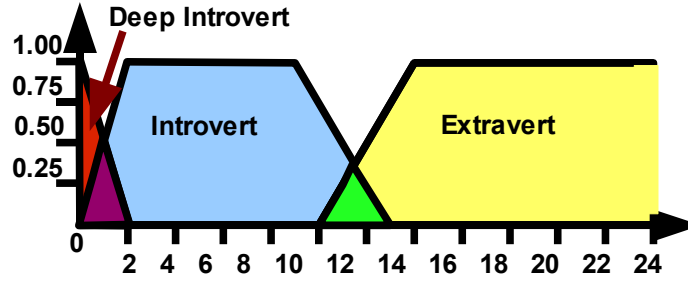


Figure 16: Emotional Receptivity Scale

5.6 Implementation of the PAD Model

Our approach does not prescribe a specific set of appraisal dimensions. We have chosen the Pleasure, Arousal, Dominance (PAD) personality-trait and emotional-state scales by Albert Mehrabian [1] because these dimensions are generally not considered to be appraisal dimensions. He argues that any emotion can be expressed in terms of values on these three dimensions, and provides extensive evidence for this claim [8]. This makes his three dimensions suitable for a computational approach. Mehrabian also provides an extensive list of emotional labels for points in the PAD space [1] and gives an impression of the emotional meaning of the combinations of Pleasure, Arousal and Dominance.

Each psychical temperamental type has different emotion changes depending on external influence from other agents and the proximity of the goal. Every temperamental type possesses different needs to improve Pleasure, Arousal and Dominance. The emotional-state of an agent can thus be understood as a continuously moving point in an n-dimensional space of appraisal dimensions.

Table 1: Mapping OCC into PAD Space [106]

Emotion	P	A	D	Mood	Octant
Admiration	0.5	0.3	-0.2	+P+A-D	Dependent
Anger	-0.51	0.59	0.25	-P+A+D	Hostile
Disliking	-0.4	0.2	0.1	-P+A+D	Hostile
Disappointment	-0.3	0.1	-0.4	-P+A-D	Anxious
Distress	-0.4	-0.2	-0.5	-P-A-D	Bored
Fear	-0.64	0.60	-0.43	-P+A-D	Anxious
FearsConfirmed	-0.5	-0.3	-0.7	-P-A-D	Bored
Gloating	0.3	-0.3	-0.1	+P-A-D	Docile
Gratification	0.6	0.5	0.4	+P+A+D	Exuberant
Gratitude	0.4	0.2	-0.3	+P+A-D	Dependent
HappyFor	0.4	0.2	0.2	+P+A+D	Exuberant
Hate	-0.6	0.6	0.3	-P+A+D	Hostile
Hope	0.2	0.2	-0.1	+P+A-D	Dependent
Joy	0.4	0.2	0.1	+P+A+D	Exuberant
Liking	0.40	0.16	-0.24	+P+A-D	Dependent
Love	0.3	0.1	0.2	+P+A+D	Exuberant
Pity	-0.4	-0.2	-0.5	-P-A-D	Bored
Pride	0.4	0.3	0.3	+P+A+D	Exuberant
Relief	0.2	-0.3	0.4	+P-A+D	Relaxed
Remorse	-0.3	0.1	-0.6	-P+A-D	Anxious
Reproach	-0.3	-0.1	0.4	-P-A+D	Disdainful
Resentment	-0.2	-0.3	-0.2	-P-A-D	Bored
Satisfaction	0.3	-0.2	0.4	+P-A+D	Relaxed
Shame	-0.3	0.1	-0.6	-P+A-D	Anxious

As we referred in the previous chapters, each psychological temperamental type has its own regression functions describing the dependence between the PAD values and the final emotional state of the agent: (6), (7) and (8). Using these regressions we can define the psychological temperament layer for our model. The influence of each PAD component to the temperamental type is shown in (1)-(5), so using them we can distinguish the different weights of the measures from the Appraisal Bank and personalize them for each temperamental type. Let us define and describe the Appraisal Bank we use for our project.

5.6.1 Appraisal Bank

The appraisal bank defines the needs, motivations and stimulus of the agent as a set of subjective measures, called appraisal dimensions. We based our idea on the work of Broekens and DeGroot [4] that develop and test an appraisal model on a PacMan experimental platform. To test if context sensitive appraisal banks facilitate the development of scalable appraisal models, we instrumented our system in two ways. First, a simple instrumentation based on appraisal bank that emotionally evaluates events related to survival. Second, a more complex instrumentation based on two appraisal banks, one related to survival the other related to reach the beacon and satisfy temperamental needs. In both banks we have used event-encoding to simulate emotional meaning of events. We now describe how events are interpreted by the two appraisal banks.

As we work with BDI agent's, their thinking are based on **beliefs**, **desires** and **intentions**. Their possess basics to which appraisal based emotions can be added.

Lets describe beliefs, desires and intentions of the agents in our simulation system:

Beliefs:

- angry agents are dangerous;
- wall collisions are painful;
- happy agents are friendly and nice;

Desires:

- reach the beacon;
- satisfies personal (temperamental) need like necessity of company of other agents or necessity of loneliness;
- don't get hurt;

Intentions:

- avoid threats (angry agents);
- avoid wall collisions;
- follow happy agents;

We define **Pleasure** as the *conductance of the goal*. For instance if the agent sees the beacon and no obstacle is present his pleasure is high, while if he sees a threat or loses the goal this is highly unpleasant. **Arousal** is the *amount of attention each event needs*, for instance to avoid threats the attention of the agent is needed and lose it needs no attention. **Dominance** is a measure that defines the *amount of freedom of the agent*. For example, if it sees a wall the dominance decreases but if it sees no obstructed way to the goal the dominance increases.

The weight we attribute to each event differs on their importance and thus we divided them into two groups of importance: high and medium. We will define the importance of each events on the simulation system, but each temperamental type has its own “value scale” for each need. We define the Appraisal Banks using mapping of OCC emotions (Table 1) presented by Gebhard [106].

The survival bank appraises only survival related events (Table 2). In our simulation system, survival events are related with the “painful” or “dangerous” events, such as wall collisions or proximity to the threat. The rationale for the P, A and D values is based on the guidelines described above. Pleasure depends on the level of obstruction versus conductance of an event related to a goal. For example, seeing a angry agent is moderately obstructing for survival, while collision is highly obstructing. Arousal is related to the amount of attention an event needs. For example, seeing a angry agent needs a moderate amount of attention while losing an angry agent needs no attention (because this agent poses no thread any more). Dominance is related to the amount of freedom the agent has. For example seeing a wall

decreases the amount of freedom, while losing a wall increases the amount of freedom.

Table 2. Appraisal Survival Bank

Event	Pleasure	Arousal	Dominance	Mood	Octant
See_wall	-0,2	0,2	-0,2	-P+A-D	Anxious
Collide_wall	-0,6	0,6	0,6	-P+A-D	Hostile
Lose_wall	0,5	-0,5	0,5	+P-A+D	Relaxed
See_threat	-0,5	0,5	-0,5	-P+A-D	Anxious
Near_threat	-1,0	1,0	1,0	-P+A+D	Hostile
Lose_threat	0,8	-0,8	0,8	+P-A+P	Relaxed

Next bank (Table 3) is related to agent temperamental needs. There are different temperamental needs for each agent, such as, for instance, necessity of loneliness or the company of other agents.

Table 3. Appraisal Temperamental Bank

Event	Pleasure	Arousal	Dominance	Mood	Octant
See_happy_agent	0,3	0,3	0,3	+P+A+D	Exuberant
Near_happy_agent	0,5	-0,5	0,5	+P-A+D	Relaxed
Lose_happy_agent	-0,3	0,3	-0,3	-P+A-D	Anxious

Using linear regressions presented by the Mehrabian [2] we can adjust the PAD values of each event with the agent temperament. We define agent temperament recurring to physical bank so, as we already referred, there are no pure temperamental types, but the mixtures of them, therefore, we will establish the relationship between PAD values and the Force, Steadiness, Mobility and Emotional Receptivity which we defined as the metric of the agent temperament. Temperaments we analyse in this project (using Pavlov's theory) are differentiated from the Big-Five Temperaments analysed by Mehrabian, so we will try to find some common characteristics (robust intersection between these two temperamental sets) to apply following regressions to our temperamental system.

$$\text{Trait Pleasure} = 0.59 \text{ agreeableness} + 0.25 \text{ stability} + 0.19 \text{ extraversion}$$

$$\text{Trait Arousability} = -0.65 \text{ stability} + 0.42 \text{ agreeableness}$$

$$\text{Trait Dominance} = 0.77 \text{ extraversion} - 0.27 \text{ agreeableness} + 0.21 \text{ sophistication}$$

We will distinct our temperamental types using Emotional Receptivity and Neurotism from Eysenk scale [22]. Let us analyse the relationship between the Central Nervous System characteristics which define four temperamental types (Choleric, Sanguine, Melancholic and Phlegmatic) and PAD dimensions using the information from Big-Five personality factors [2, 5, 10-12] and Eysenck theory. To define the relationship between these values we will use the next formulas defined by Mehrabian we describe on Chapter 3:

$$\text{Extraversion} = 0.24P + 0.72D$$

$$\text{Emotional Stability} = 0.50P - 0.55A$$

So, based on Eysenk scale, we have:

$$\textbf{Sanguine} = \text{Extraversion} + \text{Emotional Stability} = 0.74P - 0.55A + 0.72D$$

$$\textbf{Choleric} = \text{Extraversion} - \text{Emotional Stability} = -0.26P + 0.55A + 0.72D$$

$$\textbf{Phlegmatic} = \text{Introversion} + \text{Emotional Stability} = 0.26P - 0.55A - 0.72D$$

$$\textbf{Melancholic} = \text{Introversion} - \text{Emotional Stability} = -0.74P + 0.55A - 0.72D$$

In these four formulas we see the dependency between Pavlov's temperamental system and PAD values. So we can observe the clear dependence between these two layers. But in our temperamental architecture we have not implemented any of dependency between physical and psychical layers and we are trying to discover some kind of influence that one layer could have on the other layer through the temperamental configurations or common goals implementation. As we also refer, psychical layer controls the emotional state of the agent through PAD values, and the physical layer control the engine configuration (motors, sensors,

etc...) and the group interaction, based on temperamental needs of the agent (like extroversion/introversion or emotional stability).

On the Fig. 17 we can observe the relationship between the four temperaments and the PAD components.

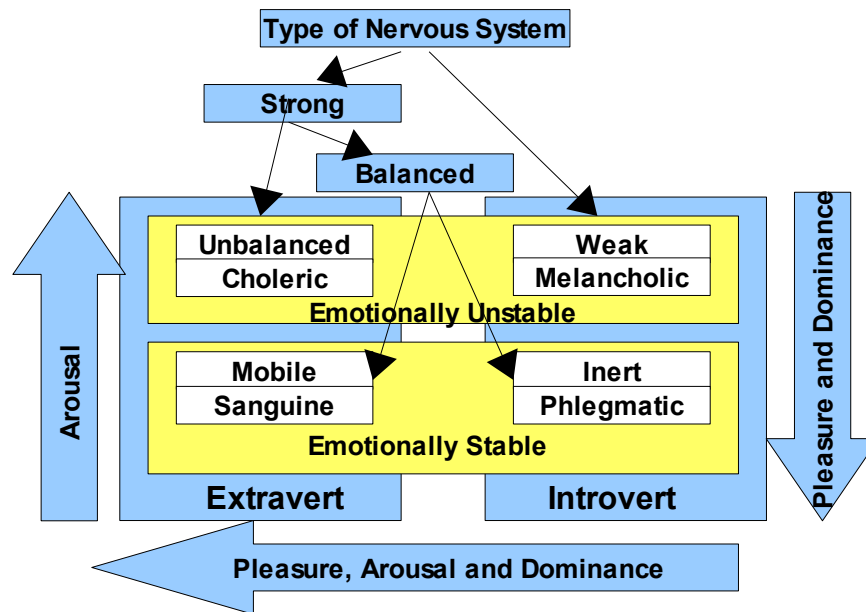


Figure 17: Central Nervous System vs PAD Model

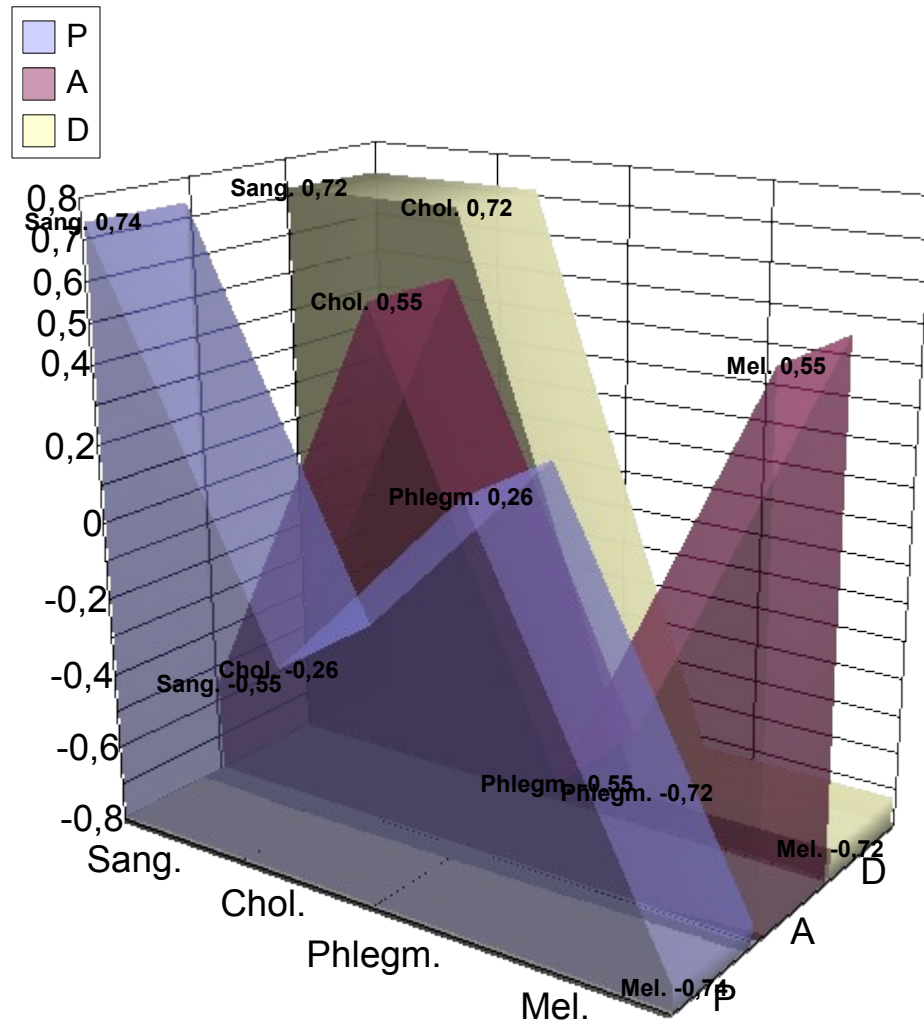


Figure 18: PAD vs Four Temperaments (Sanguine, Choleric, Phlegmatic and Melancholic)

Next bank (Table 4) is related to agent goals. As we assume, the agent have different motivations and the goal present the ingestive motivation (the beacon is also considered as a “cheese” and the agents is a mouse).

Table 4. Appraisal Goals Bank

Event	Pleasure	Arousal	Dominance	Mood	Octant
See_Beacon	0,6	0,6	0,6	+P+A+D	Exuberant
Near_Beacon	1,0	-1,0	1,0	+P-A+D	Relaxed
Lose_Beacon	-0,6	0,6	-0,6	-P+A-D	Anxious

So we define as very important agent's survival, which approach avoiding the threats. Medium importance is the performance of the agent in relation to the final goal of the simulation: reach the beacon. Also of medium importance is the satisfaction of the temperamental needs of each agent like look for a company.

In the simple instrumentation - using only the "survival" bank - context sensitivity is irrelevant because there is just one bank active at all times, but in the complex instrumentation context sensitivity is of importance and implemented in the following way. Since survival is more important than temperamental needs or goal accomplishment, the "temperamental" bank and "goal" bank is inhibited by the "survival" bank. This is implemented by weighing the contribution to the emotional state of the appraisal-result of the "goal" and "temperamental" bank relative to the amount of emotional activation (appraisal-intensity) in the "survival" bank. Formula (9) implements the weighing function, following Broekens and DeGroot model [4]:

$$\Delta_g' = \Delta_g \times \left(1 - \frac{|\Delta_s|}{\sqrt[3]{3}} \right) \quad (9)$$

where

Δ_g' is the weighted appraisal-result vector by the "goal" or the "temperamental" bank

Δ_g is the nonweighted vector

Δ_s is the length of the appraisal-result vector of the "survival" bank and the cubic

root of 3 is the maximum length of an appraisal-result vector²⁰.

Appraisal-results are integrated using following formula, where E_t is the emotional-state at time t , E_{t+1} is the new emotional-state, n is the number of appraisal banks and ΔPAD_{ti} the appraisal-result vector of bank i at time t .

$$E_{t+1} = E_t + \sum_{i=0}^n \Delta PAD_{ti} \quad (10)$$

The appraisal banks specifications is the very difficult task and their modifications produce different results from system evaluation. It is very interesting and exciting problem to find the most suitable configuration of the values for the appraisal banks and for different simulation scenario.

5.6.2 Coding Emotion-Related States

In the literature the overwhelming number of synthesis experiments regarded a very limited set of so-called "basic" or "fundamental" emotions, well known as "the big four / six" [2], described, for instance, on Mehrabian work. The problem with respect to real world applications is that these pure emotions almost never occur in natural data. Actually, the original motivation for the choice of emotional states where to target the extreme points in a cube spanned by these dimensions [1, 4, 6]. Burkhardt [84] admit that these categorisation is disputable and somewhat arbitrary. We choose the six target emotion-related states plus neutral, which are listed in Table 4, these emotional states are also annotated with their values of the widely used emotional dimensions activation, valence and dominance to provide more flexible classification of emotional state of the agent. We will use this information to simplify the classification of the emotional state of the near agents, instead of using the points on the PAD scale.

²⁰ Calculating intensity in a Pleasure-Arousal theory of emotion based on the length of the Pleasure-Arousal vector is psychologically plausible [76].

Table 5: Emotion Related States

Target emotion-related state	Dimensional classification	Values (PxAxD)
Neutral	-	$\{0\} \times \{0\} \times \{0\}$
Joyful	Aroused, pleasant, dominant	$]0,1] \times]0,1] \times]0,1]$
Friendly	Calm, pleasant, dominant	$]0,1] \times [-1,0] \times]0,1]$
Threatening	neither, unpleasant, dominant	$[-1,0] \times \{0\} \times]0,1]$
Bored	Calm, unpleasant, neither	$[-1,0] \times [-1,0] \times \{0\}$
Frightened	Aroused, unpleasant, subdominant	$[-1,0] \times]0,1] \times [-1,0[$
Sad	Calm, unpleasant, subdominant	$[-1,0] \times [-1,0] \times [-1,0[$

5.7 Integration of the Pavlov's Theory and PAD Model

On the Fig. 19 we represent the diagram which describes the relationship between the Simulation environment, Decision layer and Data layer. Physical Bank contains the fuzzy measures of force, mobility and steadiness. Values for motors and sensors are archived in Physical Bank for each temperamental type. This diagram presents a scheme for two temperaments and three agents, but as we already explain we use four temperaments for physical layer and 5 temperaments for psychical layer:

- Choleric, Sanguine, Phlegmatic and Melancholic defined in **physical layer** with different Fuzzy set's of values for Force, Steadiness and Mobility.
- Extraversion, Agreeableness, Conscientiousness, Emotional Stability and Sophistication in **psychical layer** which are described using Pleasure, Arousal and Dominance. In order to simplify our model we are using just Extraversion and Emotional Stability in this project.

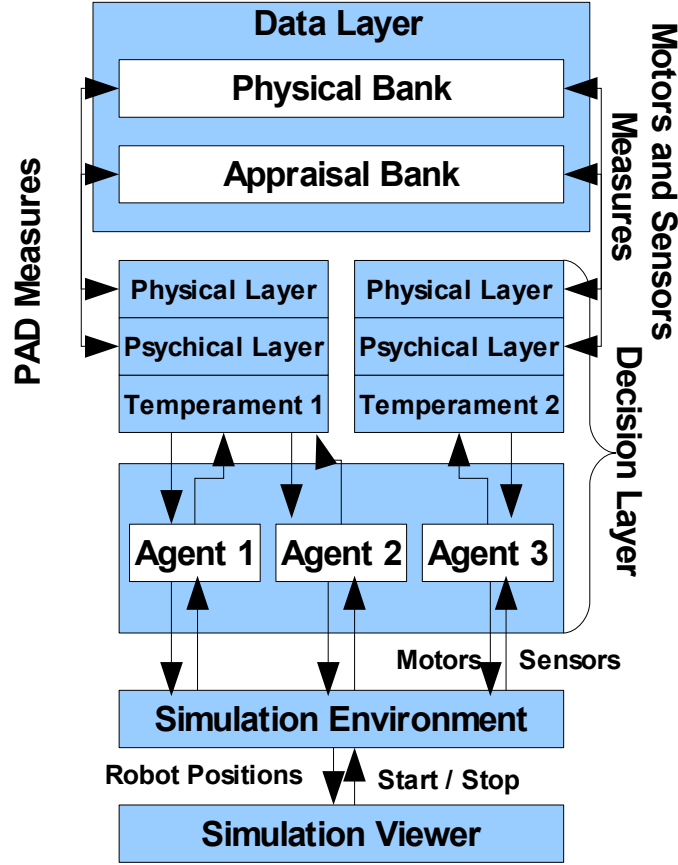


Figure 19: Multi Agent Architecture

On the Figure 17 we made a robust intersection between this two temperamental sets, in order to create uniform model on both layers: physical and psychical. We realize that this type of intersection is a complex task requiring a well-taken care of the psychologist. We made this robust approximation just to perform the implementation of our temperamental system.

5.8 Conclusions

In this Chapter we introduce the model of Temperamental Mechanisms that we propose and explain how it can be integrated in a Multi-Agent System. We present the modular multi-

layer architecture for implementation of a multi-agent system with Personality characteristics and emotional behaviors. Specifically, we try to demonstrate how such Emotional Mechanisms can be used to transpose functional Human Emotion interactions to Synthetic Agents. We also try to show how this can be advantageous for Agents in general, and especially for robotic agents with physical characteristics. We also explain how Emotional mechanisms may be configured to alter the global behavior of the Agent, enabling the development of Agents with different Temperaments.

Chapter 6 Simulation Environment

6.1 Introduction

We choose the Cyber-Mouse Simulation environment to implement and test our model because it offers an open, modular and flexible platform permitting unlimited applications and a fully configurable simulation system. It permits to add new sensors and functionalities to the robots, has fast performance and is adequate to test algorithmic models and their performance.

6.2 Ciber-Mouse as an Experimental Platform

Cyber-Mouse is a modality included in the Micro-Mouse competition organized by Aveiro University (Portugal), and running since 2001 every year. This modality is directed to teams interested in the algorithmic issues and software control of mobile autonomous robots. This modality is supported by a software environment, which simulates both robots and a labyrinth [14].

All virtual robots have the same kind of body. It is composed of a cylindrical shape, equipped with sensors, actuators, and command buttons. The simulator estimates sensor

measures which are sent to the agents. Reversely, receives and apply actuating orders coming from agents. Agents are given the following challenge: starting from their position in starting grid they must visit the target area and then return the their starting point. Score depends on fulfilment of challenge goals and on penalties suffered.

The Cyber-Mouse Simulation Environment is built as a distributed system [31]. The distributed system is composed by several independent processes: a simulator, the robotic agents and a graphical front-end. The simulator is responsible for creating and controlling the virtual world where competition takes place, it creates the labyrinth and the virtual bodies of robots. The robotic agents are developed by the competitors and are the “brains” of the robots, each agent controlling the body of a robot. The graphical front-end provides the visualisation and control tools. These processes communicate through UDP sockets which are used to send XML messages.

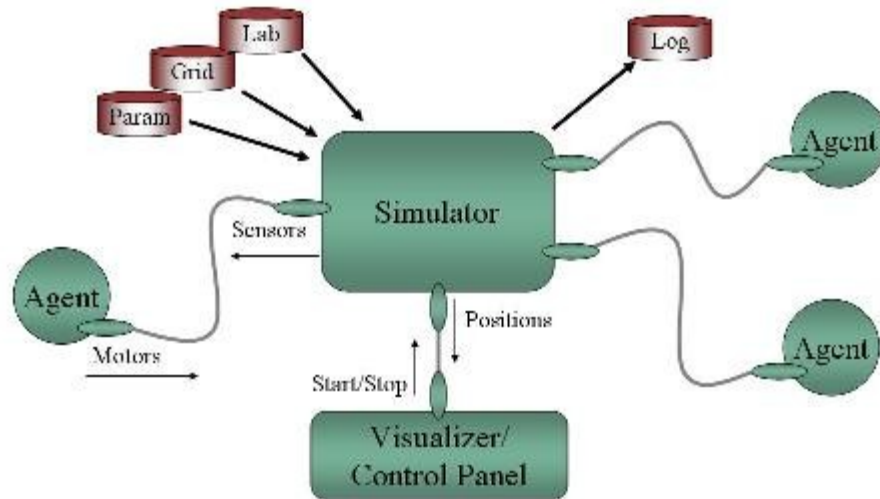


Figure 20: Ciber Mouse Simulation Model

Competitors have to develop a program (the robotic agent) that receives sensor data and controls robot movement acting on the motors. Sensors and motors are subject to noise, so agents have to deal with it. Competitors can choose the programming language and the operating system they most like to develop their agents. The organization provides

communication libraries for some popular programming languages (C/C++, Java, Visual Basic and Prolog).

Technically speaking, the task of the robots is to go from their starting position to the target area signalled by an IR light emitting beacon, and then return to their starting position. The final score depends on the distance from the starting to the ending point, on the time taken to return and on possible penalties due mainly to collisions with walls and other robots. During the competition, three robots compete at the same time in a distributed environment where the simulator and the robots are executed in four separate computers connected to an isolated IP LAN. However, the simulator and all robots may also be executed in a single computer.

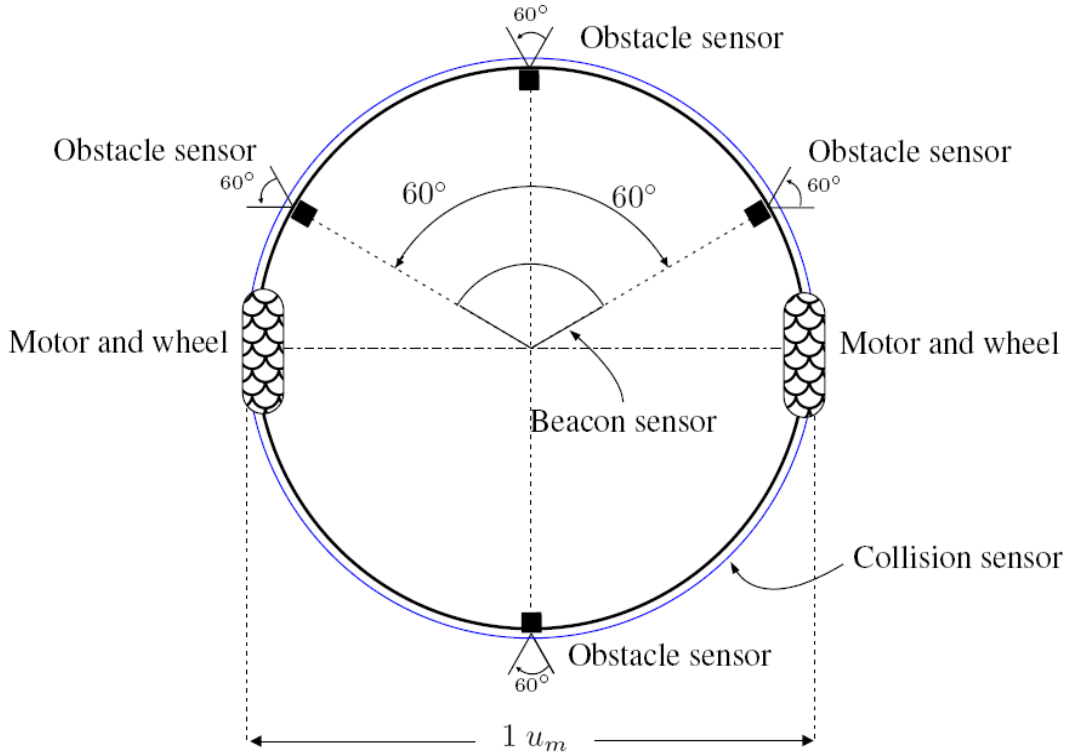


Figure 21: Body of the Virtual Robot (Ciber-Mouse: Rules and Technical Specifications)

The simulation system possesses a distributed architecture [31] where some types of applications communicate between each other, namely, a simulator, an application for each

agent and a viewer application (fig. 20). The architecture is client-server, where the simulator acts as the server and both the agents and the viewer, act as clients. This architecture is similar to the Simulation League of RoboCup [13].

The simulator shapes all the components of the robots hardware and the labyrinth. The simulation is executed in discrete time, cycle by cycle. In the beginning of each cycle of simulation the simulator sends to all the robotic agents in test the measures of its sensors, and to all the viewers the positions and information of the robots. The agents can answer with the power values to apply to the engines that command the wheels.

All robots in test have the same physical characteristics. All have the same sensors and the engines are identical. Each robot (fig. 21) is equipped with the following sensors [20]:

- three sensors of proximity facing front and facing 60° for each side and 1 proximity sensor heading backwards. The positions of these sensors may be changed by the agent.
- A Beacon sensor that indicates the difference between the robots' direction and the beacon's direction.
- A Ground sensor, indicates if the robot is at a beacon area.
- A Compass sensor that allows the robot to know its absolute orientation in the labyrinth.
- A Collision sensor, an active in the case of robot collision.

Sensor	Range	Resolution	Noise type	deviation	Latency	On request
Obstacle s.	[0.0, 100.0]	0.1	aditive	0.25	0	yes
Beacon s.	[-60, +60]	1	aditive	5	9	yes
Compass	[-180, +180]	1	aditive	5	9	yes
Bumper	Yes/No	 N/A			0	no
Ground s.	Yes/No	 N/A			0	yes

Figure 22: Sensor Characterization

The measures of the sensors include some noise added for the shape simulator in order to simulate real sensors. In order to detect the beginning of the test and possible interruptions each robot has two buttons:

- Start, active when the test is initiated.
- Stop, active when a test interruption exists.

In terms of virtual engines, robots are constituted by:

- Two wheels for two independent motors, one on the left and one on the right;
- Visiting LED, to light when a beacon area is reached and a returning LED to light when the robot starts returning and a finishing LED to light when the robot finishes its run.

Actuator	Range	Resolution	Noise type	Standard deviation
Motor	[-0.15, +0.15]	0.001	multiplicative	3%
<i>led End</i>	On/Off	 N/A		
<i>led Return</i>	On/Off	 N/A		
<i>led Beacon</i>	On/Off	 N/A		

Figure 23: Actuator Characterization

In each cycle of the simulation the agents receive the values measured by all its sensors and must decide what power to apply to each motor. The perception that a robotic agent has from the exterior environment is limited and noisy transforming it into the most appropriate tool to perform our work with almost realistic precision.

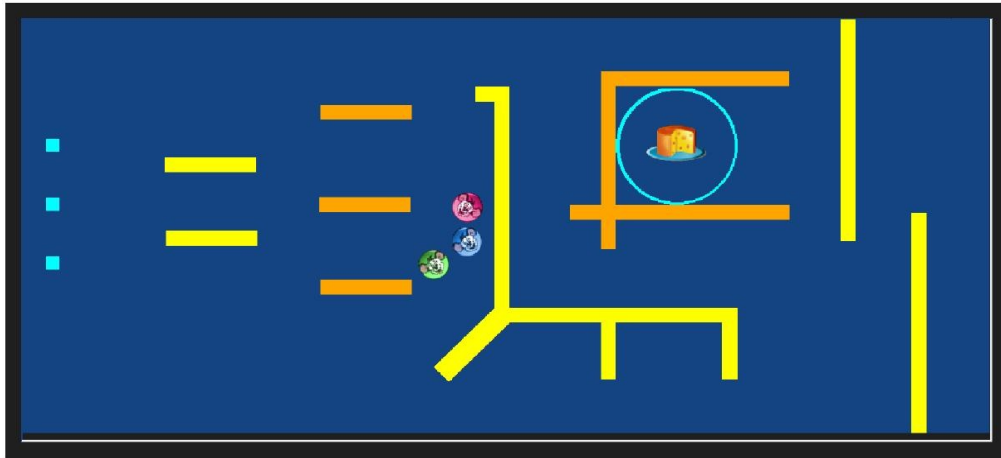


Figure 24: Ciber-Mouse Maze

The game scenario (see figure 24 for an example) is composed of a rectangular arena, delimited by walls, with obstacles and the target area inside. The target area is a circle with a beacon in its centre.

Obstacles are walls put up to difficult the robot's movement. A starting grid defines the robots initial positions. The following rules are observed:

Arena

1. The arena is 14 un. high and 28 un. Wide (1un is the robot's diameter).

Obstacles

2. All walls have planar surfaces, at least 0,4 un. wide.
3. All corners have angles ranging from 90 to 270 degrees.
4. Some walls can be higher than the beacon, defining shadow zones.
5. Any passage between walls is at least 1,5 un. wide.

Target area

6. The target area is at least 1, 0 un. wide.

7. The beacon in the centre of the target area does not act as an obstacle to the robot movement.

Communication between simulator and agents is based on UDP sockets, being the messages formatted into XML structures. There are 5 messages tags to consider: request for registry, grant response, refusal response, sensor data, and actuation order. You only need to read this section if you plan to use a programming language different from C, C++, or Java. Otherwise, we can use the libraries of functions available in the tool package (RobSock.h and ciberIF.java).

6.3 Cyber Mouse Modifications

To enable us to perform the experiences we have implemented new sensor, a vision sensor, that works by identifying other robots position and their emotional state. This sensor works as a kind of agent vision in the simulation environment.

We also add to the robots three virtual engines which works as the robot's emotional mind which is based on Pleasure, Arousal and Dominance values. In order to create an emotional model which simulate human multi-agent team we define a new variable, called own space. This variable define the “personal” area around the agent which pretend to simulate human own space. When some agent come too close to the other agent and invade his own space, the emotional state of the agent is negatively influenced and he try to move away to more comfortable position.

To evaluate our model we add more robots to the simulation system and perform different tests with 9 robots in each simulation cycle.

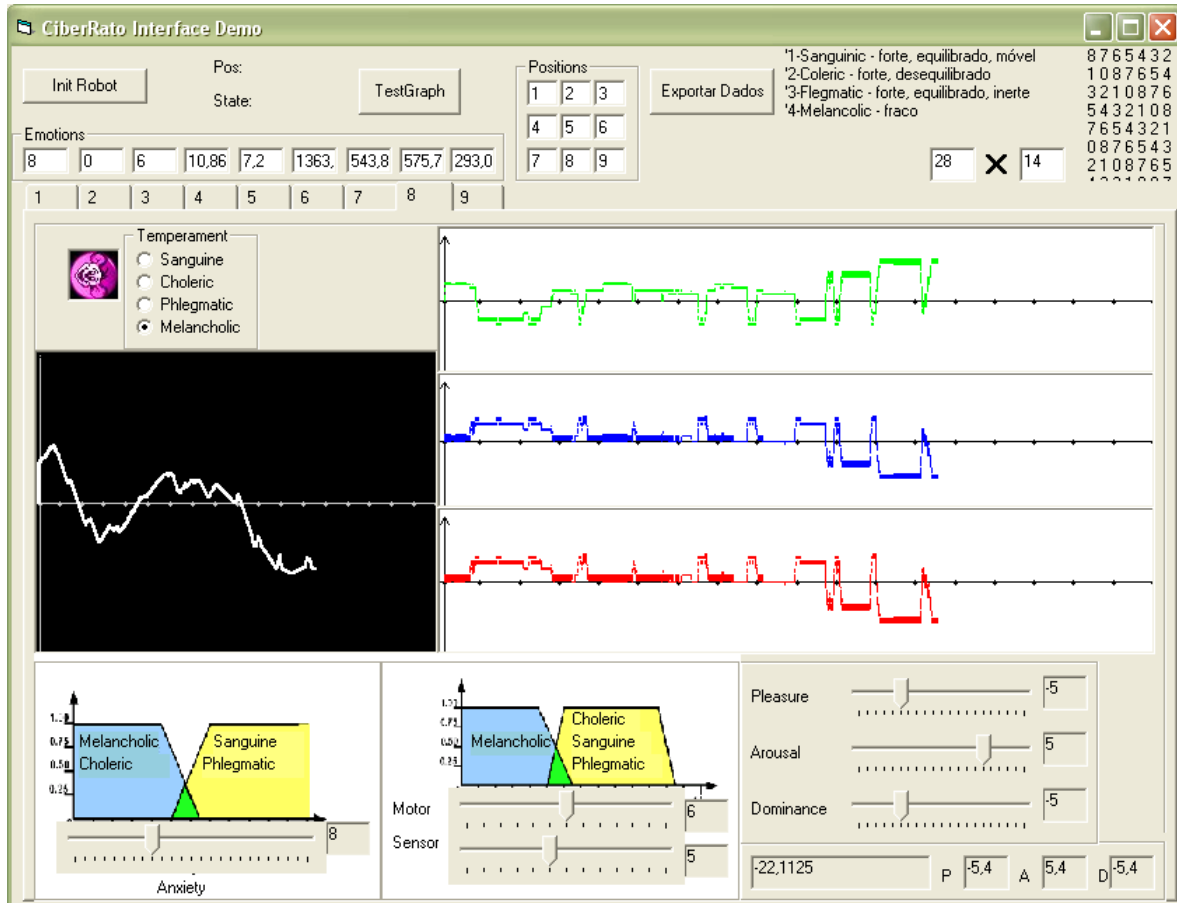


Figure 25: Screenshot of the Agent Control and Configuration Panel

To control and configure the agents we implement Control and Configuration Panel shown on Fig. 25. This panel let us to configure the agents temperament (Sanguine, Choleric, Phlegmatic and Melancholic), Anxiety/Emotional Stability, Sensor and Motor Force and, if it is necessary for some additional tests, manually configure PAD values, using slide bars. This panel also let us to monitory the agents emotional state (valence) and the PAD values in two different ways: numerical and graphical representation. On the Fig. 25 we can observe results of the random simulation when emotional state are graphically presented in black area, while Pleasure, Arousal and Dominance are presented in Green, Blue and Red graphics.

6.4 Conclusions

In this Chapter we present in detail the Cyber-Mouse Simulation Platform, and describe each of its composing elements individually. We thoroughly describe the simulated environment and discuss its most relevant properties for Agent development. We also present the implementation we made in order to adapt the simulation system to our needs and the Configuration/Control Panel which let us to monitor the agents.

Chapter 7 Experimental Results

This chapter, describes the methods used to test the major system components. Tests were performed to assess the system regarding its performance, temperamental characteristics and emotional behaviors analysis.

Each section of this chapter will starts by defining the different tests scenarios. The obtained results will then be addressed.

7.1 General Description of Evaluations

To perform our tests, we evaluated the agent's performance on reaching the goal. We also evaluated the appraisal values modifications during the simulation time. We performed the evaluation of an entire team of agents, in order to compare their performance with other teams of agents. During these evaluations we tried to analyse the difference between distinct temperamental teams and compare them in general terms (PAD scale and emotion valence), as well as their performance on reaching the goal.

We perform the evaluation on two different simulation scenarios:

- First scenario has few obstacles (walls) and a small arena. These conditions enable fast detection of the beacon to the agents, but force the interaction between agents

across the simulation arena.

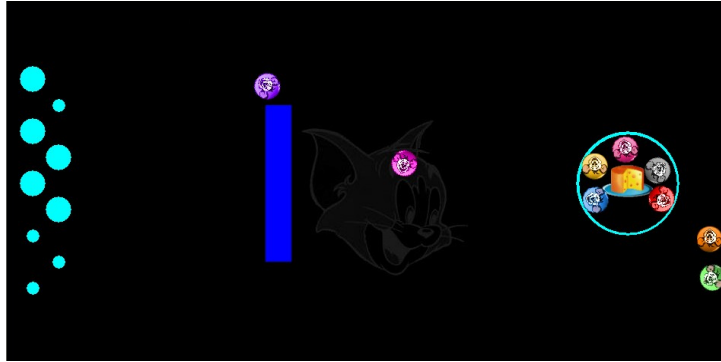


Figure 26: Example of the 1st scenario

- Second scenario has a lot of obstacles (walls) and a large arena. In this scenario the goal is very difficult to accomplish and the agents have enough space for team interaction (grouping or isolation).

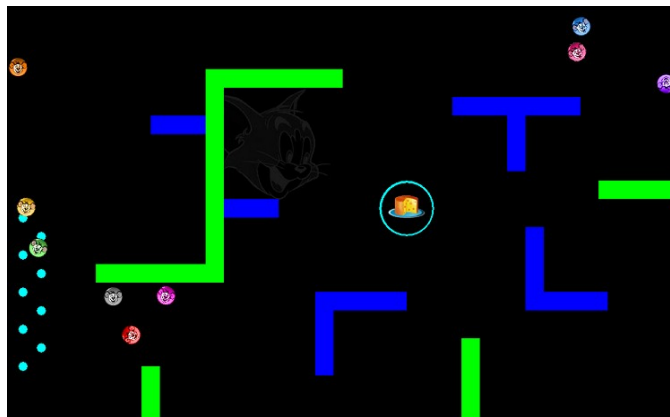


Figure 27: Example of complex scenario with large arena

- Third scenario has a lot of obstacles (walls) and a small arena. In this scenario the goal is very difficult to accomplish, and the agents have fewer space for team interaction (grouping or isolation).

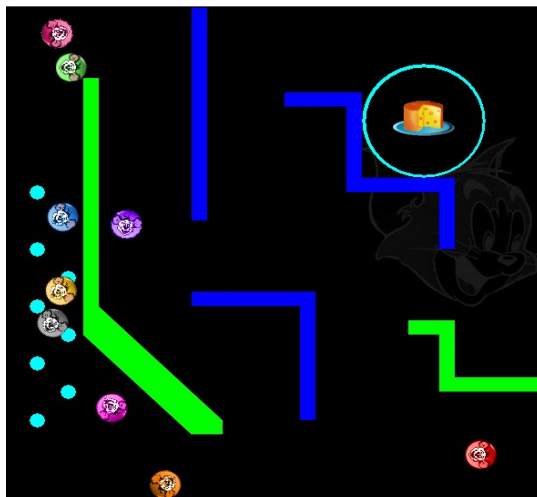


Figure 28: Example of the complex scenario with the small arena

We analyse our agent's performance on these three simulation scenarios and try to discover the advantages and disadvantages of using temperamental agents with this kind of simulation. We perform 10 interactions for each team/simulation scenario. The PAD values are presented in $[-10, 10]$ interval instead of $[-1, 1]$.

We present the detailed evaluation just for one simulation scenario and for one team. The other results are presented in more resumed manner.

7.2 Example of Evaluation of the Homogeneous Temperamental Team

We make this evaluation using homogeneous team with 9 agents who possess the same temperamental type, as well as the same physical characteristics.

7.2.1 Choleric Team

On Table 6 we can observe the average values of the different agent physical engines:

Anxiety (or Emotional Stability), Motor Strength and Sensor Strength. We can also see the average results of simulation time. To perform our tests we have defined the same simulation time for each team (180 seconds), but if some agent have accomplished the goal during simulation cycle, his simulation time is considered as a time he spend to accomplish the goal. For example, if we have some team with two agents and one of them has accomplished the goal in 200 seconds and other haven't accomplished the goal, the medium time of the team will be calculated as $(1800+200)/2=1000$ seconds and the best time will be considered as 200 seconds.

7.2.1.1 Simple Small Arena

Table 6: Average Values of the Temperamental Configuration

Anxiety	Motor Strength	Sensor Strength	Time	Best Time
4,81	11,11	10,22	155,18	31,60

As the result of this evaluation **26%** of the agents have reached the goal. Figure 29 shows the Emotional State (Valence) of the Choleric Homogeneous Team through the simulation.

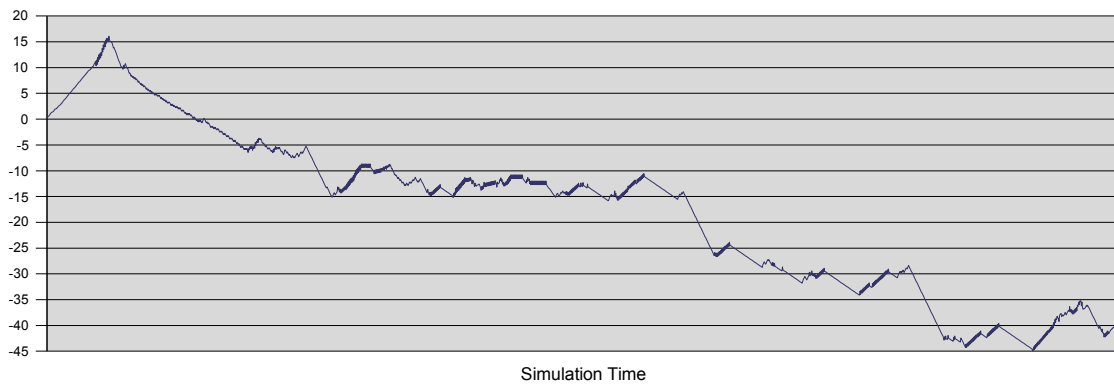


Figure 29: Emotional Valence (Choleric Homogeneous Team)

On the following figure we can observe the PAD values modulation during the simulation scenario.

7.2 Example of Evaluation of the Homogeneous Temperamental Team

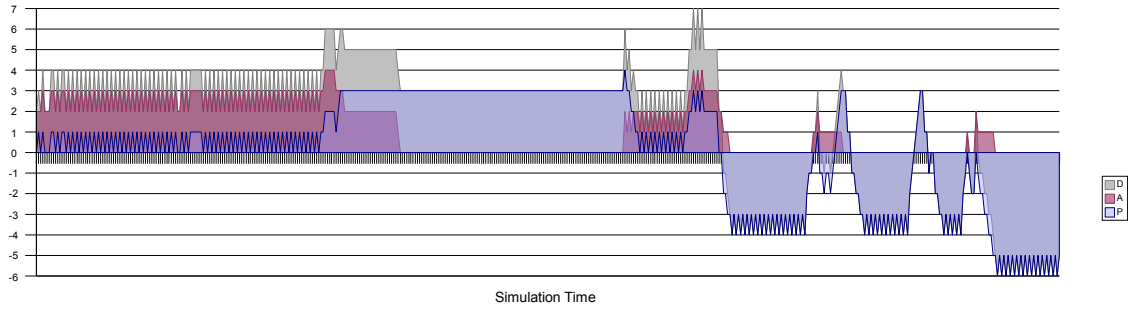
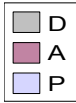


Figure 30: PAD Values (Choleric Homogeneous Team)



Colours for graphic interpretation (Fig. 30)

On the Table 7 we can observe the average values of Pleasure, Arousal and Dominance, as well as the average of all emotional states during the simulation and the average of the final emotional states.

Table 7: Appraisal Results (Choleric Homogeneous Team)

Pleasure	Arousal	Dominance	Average Emotional State	Final Emotional State
1,53	-0,41	1,53	0,70	-44,25

On the Table 7 we can see the extremes of the appraisal values.

Table 8: Maximum and Minimum of the Appraisal Values (Choleric Homogeneous Team)

	Pleasure	Arousal	Dominance	Emotional State
Maximum	7	7	7	366,08
Minimum	-6	-7	-6	-157,41

Using the same procedures we performed the evaluation of other teams of agents. Results

are presented in Section 7.4.

7.3 Non-Homogeneous Multi-Temperamental Team

We made this evaluation using homogeneous team with 9 agents who possess different temperamental types, as well as different physical characteristics. We evaluated the agents performance on reaching the goal and the PAD modifications during simulation. Also we performed the evaluation of an entire team of agents, in order to compare its performance with other groups of agents.

We test the team of agents with 3 Sanguine agents, 2 Choleric, 2 Phlegmatic and 2 Melancholic agents. The results of the evaluation are presented in the next section.

7.4 Evaluation Results

We have tested an implementation of the proposed computational mind model for emotional programming using temperamental decision algorithms in different scenarios. Using this model, we have implemented and tested different temperamental teams in different simulation scenarios.

In the following table we can see the final results of all performed evaluation and compare them.

Table 9: Labels for the Table 11

Title	Description
Eval.	The type of evaluation performed. We will use the index to distinct them.
%	Percentage of the agents which has accomplished the goal (Success)
B.T.	Best Time of the team across the all simulations
A.T.	Average Time of the agents team

Motor	Average value of the motor strength
Sensor	Average value of the sensor strength
Anx.	Average value of the Anxiety (or Emotional Stability)
P	Average Pleasure of the agents during simulation
A	Average Arousal of the agents during simulation
D	Average Dominance of the agents during simulation
E.S.	Average Emotional State of the agents during the simulation

Table 10: Scenario Descriptions

Evaluation	Description
1C	Choleric Homogeneous Team in the Small Simple Scenario
2C	Choleric Homogeneous Team in the Large Complex Scenario
3C	Choleric Homogeneous Team in the Small Complex Scenario
1S	Sanguine Homogeneous Team in the Small Simple Scenario
2S	Sanguine Homogeneous Team in the Large Complex Scenario
3S	Sanguine Homogeneous Team in the Small Complex Scenario
1M	Melancholic Homogeneous Team in the Small Simple Scenario
2M	Melancholic Homogeneous Team in the Large Complex Scenario
3M	Melancholic Homogeneous Team in the Small Complex Scenario
1P	Phlegmatic Homogeneous Team in the Small Simple Scenario
2P	Phlegmatic Homogeneous Team in the Large Complex Scenario
3P	Phlegmatic Homogeneous Team in the Small Complex Scenario
1H	Heterogeneous Multi-Temperamental Team in the Small Simple Scenario
2H	Heterogeneous Multi-Temperamental Team in the Large Complex Scenario
3H	Heterogeneous Multi-Temperamental Team in the Small Complex Scenario

In the following table we can see and compare a summary of the final results of all evaluations.

Table 11: Final Results

Eval.	%	B.T.	A.T.	Motor	Sensor	Anx.	P	A	D	E.S.
1C	26,00	31,60	155,18	11,11	10,22	4,81	1,53	-0,41	1,53	0,70
2C	16,00	67,80	165,43	11,22	10,44	5,89	-1,29	2,16	-1,29	-63,14
3C	7,40	136,20	172,22	11,00	10,00	6,00	0,06	0,14	0,06	-34,91
1S	33,00	19,00	147,95	10,89	10,30	20,04	-0,48	1,61	-0,48	-23,36
2S	5,00	172,50	179,72	10,85	10,30	20,74	0,22	0,38	0,22	-79,37
3S	0,10	172,80	179,83	11,00	10,00	20,00	-0,43	0,53	-0,42	-29,36
1M	11,11	110,80	173,53	6,00	5,00	8,00	0,13	1,14	0,13	-40,19
2M	0,11	137,90	163,66	6,00	5,00	8,00	0,03	0,57	0,03	-69,94
3M	0,00	180,00	180,00	6,00	5,00	8,00	1,45	-0,86	1,45	-59,98
1P	33,00	96,80	161,70	11,00	10,00	22,00	-0,54	1,77	-0,54	-43,34
2P	22,00	148,00	174,20	11,00	10,00	22,00	-1,39	2,11	-1,39	-61,17
3P	11,00	169,70	178,86	11,00	10,00	22,00	-1,05	1,65	-1,05	-45,55
1H	70,37	17,60	124,57	9,89	8,89	14,67	1,16	-0,06	1,16	7,68
2H	22,00	138,20	174,16	9,89	8,89	14,67	0,04	0,7	0,04	-75,13
3H	3,70	173,90	179,32	9,89	8,89	14,67	0,26	0,04	0,26	-35,00

On Figure 31 we can observe the dependencies between Team Performance and Emotional State of the agents. In our architecture the performance of the agents doesn't depend on appraisal mechanism which only controls the psychical layer of the agent and only influences his PAD values and the emotional state. The agents performance only depends on temperamental (physical) configuration of the agent (motors, sensors, anxiety, etc..) and his decision layer based on extrovert/introvert characteristics (as we already described in Chapter 5). So, we can see that the temperamental decision mechanism clearly influence the emotional state of the agent during the simulation.

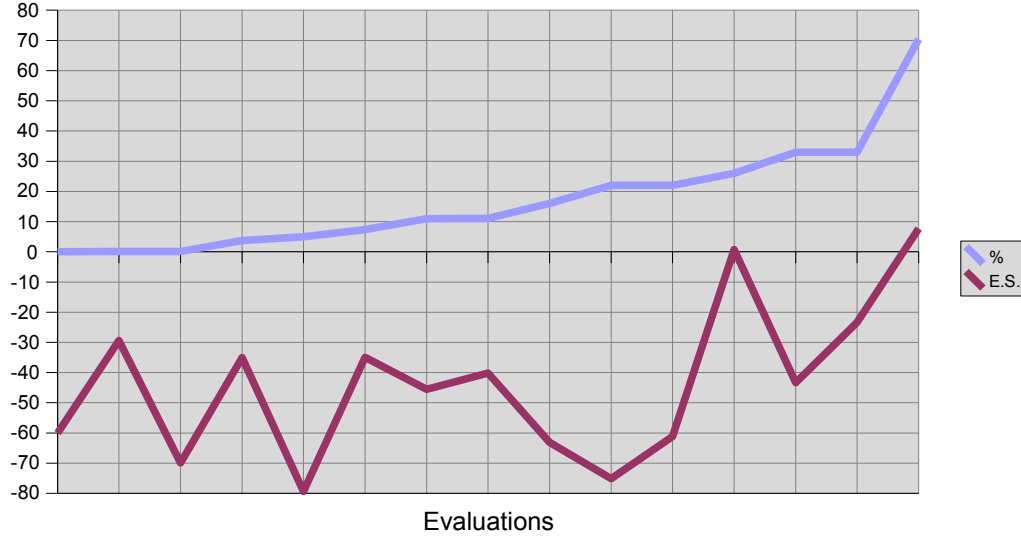


Figure 31: Team performance vs Appraisal Emotional State

In order to explain the nature of this influence we think that the implementation of the Pavlov's temperamental theory results in agents executing different grouping activities to satisfy their temperamental needs, so, this could influence the PAD values and consequently the Emotional State of the agent. Also we can analyse the influence of the system goals on the Emotional State of the agent (from the Appraisal Bank), and as we describe in Chapter 5, the decision temperamental mechanism works in order to accomplish some of these goals (avoid the walls or reach the beacon, for instance). So, even having no direct dependence between the implementation of these two layers, there are similar goals which are defined and this could explain the dependence between the agent performance and his Emotional State.

On Figure 32 we can see some dependencies between the agent performance and other relevant variables. For example, better agent performance corresponds to the major oscillation of the PAD values (we remind one more time that these two layers have no dependencies in our architecture).

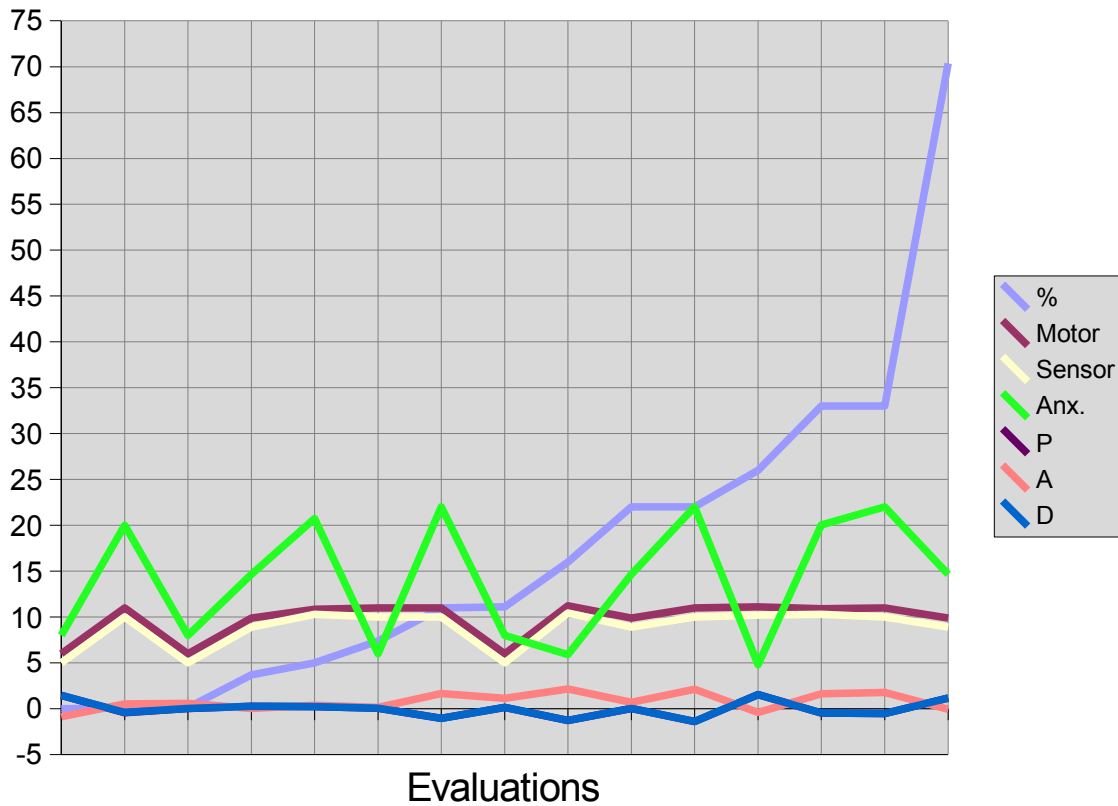


Figure 32: Team Performance vs PAD, Motor, Sensor and Anxiety values

On Figure 33 we can see values of the Team Performance and the Emotional State for each simulation scenario. So, as it was expected, the better performance corresponds to the first simulation scenario for all teams except the Melancholic Homogeneous team, but at the same time Phlegmatic homogeneous and Heterogeneous teams have good performance in the other scenarios.

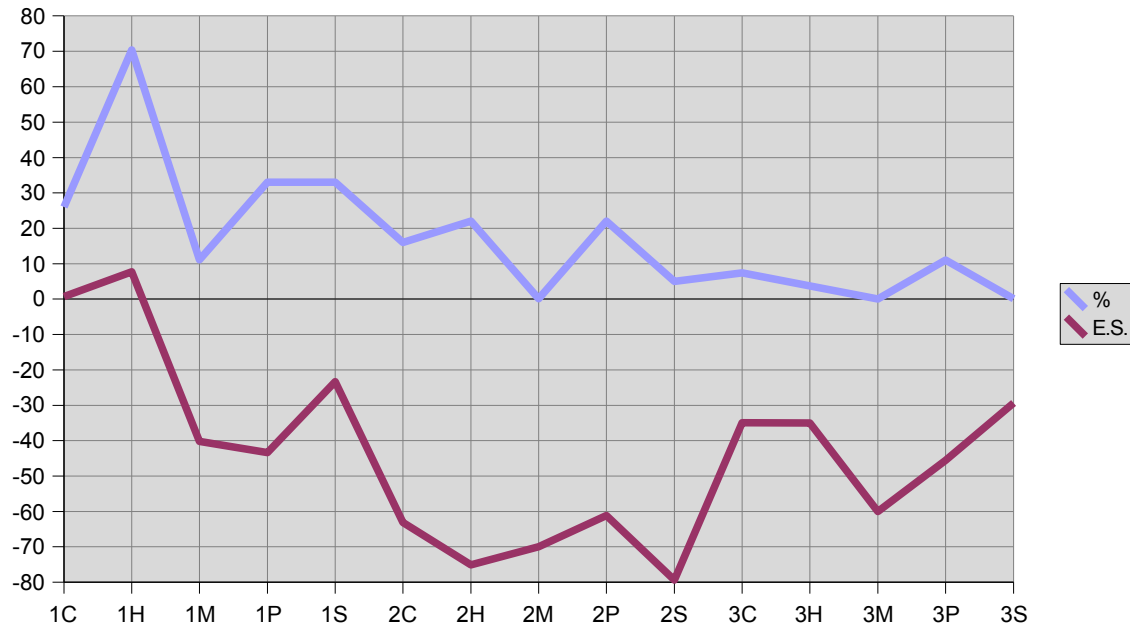


Figure 33: Team Performance and Emotional State by different scenarios

Agents Emotional state is good in the first and third scenarios, specially for the Choleric and Heterogeneous team, at the same time Melancholic and Phlegmatic teams Emotional State isn't so good.

Chapter 8 Conclusions

“We know that for a long time everything we do will be nothing more than the jumping off point for those who have the advantage of already being aware of our ultimate results”

Norbert Wiener

A main goal of this thesis was to develop and test a new model of a computational emotional mind using two different temperamental theories. For tackling this domain, we first had to study the basics of psychology and different approaches to evaluate emotional life of personality from temperamental perspective. As a rule, the theories of emotions can say too little about the role of emotions in the development of personality and about their influence on thought and action. The majority of the researchers of emotions are connected only with one of the components of the emotional process. Although some theories develop the separate aspects of the interrelations of emotion and reason, actions and personality, much still must be done both on the theoretical and on the empirical levels.

Also the computational theory of emotion is still too far from good performance and to fit the need in this area. There are many works that can satisfy just a small portion of the emotion programming. We believe that joining different theories and constructing modular emotional mechanisms which will be integrated on the artificial being could improve emotional programming. Also there is a very important question which we can not forget, and that is why

we need artificial emotions and how we can use them to improve the global performance of the artificial system.

In this work we have tried to implement emotional agents using two different approaches: appraisal theory with the PAD model and the central nervous system theory. We approach the concept of emotion from the physical and psychical perspective, defining the personality of the agent and analysing the different components of agent behaviors. We have simulated a kind of homogeneous and non-homogeneous society with different personalities and analysed their group and individual performances.

We can conclude that our approach produce very good results showing the dependence between two different layers (physical and psychical) which where implemented independently. So, as it already has been proved theoretically from psychological perspective, which define that our emotional process are dependent on our temperamental type, we could state that our architecture is consistent and show the same dependence between two layers. This let us a large room for future improvement and research on this area.

We can conclude that the modular approach to emotion programming is a very promising way to integrate emotions into multi-agent systems with different goals and configurations. Temperament helps to support agent's decision making and with proper use can improve the agent's performance and the global teamwork. Also, our system helps us analyse the configurations we could choose to implement the personality in the system with different and particular characteristics, helping us to select the variables and functions of personality with better fitness to the specific system.

Chapter 9 References

- [1] Mehrabian, A. Pleasure-Arousal-Dominance: A General Framework for Describing and Measuring Individual Differences in Temperament. *Current Psychology: Developmental, Learning, Personality, Social*, Winter, 1996, Vol. 14, No. 4, 261-292.
- [2] Mehrabian, A., Analysis of the Big-five Personality Factors in Terms of the PAD Temperamental Model. *Australian Journal of Psychology*, 1996, Vol. 48, No. 2, pp. 86-92.
- [3] Minsky, M., *The Society of Mind*, First Touchstone Edition, 1988.
- [4] Broekens J., DeGroot, D. Scalable and Flexible Appraisal Models for Virtual Agents, *CGAIDE*, 2004.
- [5] Mehrabian, A., Stefl, C. A. Basic Temperament Components of Loneliness, Shyness, and Conformity. *Social Behavior and Personality*, 1995, 23(3), pp. 253-264.
- [6] Hollinger, G. A., Georgiev, Y., Manfredi, A., Maxwell, B. A., Pezzementi, Z. A., Mitchell, B., Design of a Social Mobile Robot Using Emotion-based Decision Mechanisms, *IROS*, 2006.
- [7] Ortony, A., Clore, G.L., Collins, A. *The Cognitive Structure of Emotions*. Cambridge University Press, 1988.
- [8] Mehrabian, A., *Basic Dimensions for a General Psychological Theory*, Cambridge: OG&H Publishers, 1980.
- [9] Russel, J.A., A Circumplex Model of Affect. *Journal of Personality and Social Psychology*, 1980, No. 39, pp. 1161-1178.
- [10] Mehrabian, A., *Manual for the Trait Pleasure-Displeasure Scale*. Available from Albert Mehrabian, 1130 Alta Mesa Road, Monterey, CA 93940, 1994.
- [11] Mehrabian, A., *Manual for the Revised Trait Arousability (converse of the Stimulus Screening) Scale*. Available from Albert Mehrabian, 1130 Alta Mesa Road, Monterey, CA 93940, 1994.
- [12] Mehrabian, A., *Manual for the Revised Trait Dominance-Submissiveness Scale (TDS)*. Available from Albert Mehrabian, 1130 Alta Mesa Road, Monterey, CA 93940, 1994.

- [13] RoboCup Official Site, <http://www.robocup.org>
- [14] Lau, N., Pereira, A., Melo, A., Neves, A., Figueiredo, J., Ciber-Rato: Um Ambiente de Simulação de Robots Móveis e Autónomos, *Revista do DETUA / Ciber-Mouse: A Simulation Environment for Mobile and Autonomous Robots*, *DETUA Journal*, September, 2002, Vol. 3, No. 7, pp. 647-650.
- [15] Hille, K., Synthesizing Emotional Behavior in a Simple Animated Character, *Artificial Life*, 2001, Vol. 7, No. 3, pp. 303-313.
- [16] Павлов, И.П., *Общие типы высшей нервной деятельности животных и человека*, Москва, 1927/ Pavlov, I. P., *General Types of Superior Nervous System in Animal and Man*, Moscow, 1927
- [17] Damásio, A. R., *Descartes's Error: Emotion, Reason and the Human Brain*. Gosset/Putman, New York, 1994.
- [18] Sloman, A., Croucher, M., *Why Robots will have Emotions*, IJCAI, 1981.
- [19] Sartre, J.P., *The Emotions: Outline of a Theory*. New York, Citadel Press, 1993.
- [20] Lau, N. *Manual do Simulador Ciber-Rato./ Manual for Ciber-Mouse Simulator*, Aveiro University, Portugal, 2001
- [21] Sarmiento, L., *An Emotional-Based Agent Architecture*, Msc Thesis, Faculty of Science of Porto University, Portugal, 2004
- [22] Eysenck, H. J. , *The Scientific Study of Personality*, L., 1952
- [23] Kato, T. Arita, T., "A Robotic Approach to Emotion from a Selectionist Perspective", *Proceedings of the 9th International Symposium on Artificial Life and Robotics*, pp. 601-604, 2004 (Young Author Award).
- [24] Adamatti, D.F., Bazzan, A.L.C., "A Framework for Simulation of Agents with Emotions", *WORKCOMP 2002 (Workshop de Computacao)*, ITA, Sao Jose dos Campos, Sao Paulo, Brazil, 2002
- [25] Lakhmi C. Jain, Martin, N.M. "Fusion of Neural Networks, Fuzzy Systems and Genetic Algorithms: Industrial Applications"; *CRC Press, CRC Press LLC*, 1998; ISBN: 0849398045
- [26] Izard, C. E., Libero, D. Z., Putnam, P., & Haynes, O. M., "Stability of emotion experiences and their relations to traits of personality." *Journal of Personality and Social Psychology*, 64, 847-860, 1993
- [27] Sloman, A., *Beyond shallow models of emotion*. Cognitive Processing, 2(1):177–198, 2001. <http://www.cs.bham.ac.uk/research/cogaff/>.
- [28] Zadeh, L.A., "Fuzzy sets" Inform. Contr., Vol. 8, pp. 338-353, 1965.
- [29] Barteneva, D., Lau, N., Reis, L. P., "Analysis of Strategy Implementations Based on Temperamental Decision Algorithms for Emotion-Behavioral Multi-Agent Systems", *submitted to ICRA 2007*
- [30] Oliveira, E., Sarmiento, L., "Emotional advantage for adaptability and autonomy", *International Conference on Autonomous Agents*, Melbourne, Australia, pp. 305-312, 2003
- [31] RTSS 2006 The 27th IEEE Real-Time Systems Symposium Official Site

- http://www.ieeta.pt/~lau/web_ciberRTSS
- [32] Izard, Carroll E., *Human Emotions*. Plenum Press, New York, 1977.
 - [33] Коломинский Я. Л. *Человек: психология: Кн. для учащихся ст. Классов.-2 nd. Edition*, Moscow, Prosveschenie, 1986.
 - [34] Кон И. С. *Психология старшеклассника: Пособие для учителей* - Moscow, Prosveschenie, 1980.
 - [35] Немов Р. С., *Психология: Пособие для учащихся: 10-11 кл.*, Moscow, Prosveschenie, 1995.
 - [36] Спиноза Б., *О происхождении и природе аффектов/Психология эмоций: Тексты.* - М., 1984.
 - [37] James, W., "What is an emotion?", *Mind*, 9(34):188–205, 1884.
 - [38] Zimring, F., "Empathic understanding grows the person." *The Person-Centered Journal*, 7(2):101–113, 2000.
 - [39] Ortony, A., Clore, G. L., Collins, A., "The Cognitive Structure of Emotions." Cambridge University Press, Cambridge, UK, 1988.
 - [40] Petta, P., "The role of emotions in tractable architectures for situated cognizers." In Robert Trapp, Paolo Petta, and Sabine Payr, editors, *Emotion in Humans and Artifacts*. MIT Press, Cambridge, MA, 2002.
 - [41] Shoham, Y., "Agent Oriented Programming", *Artificial Intelligence*, 60(1),1993.
 - [42] Russell, K., Norvig, P., "Artificial Intelligence: A Modern Approach", Prentice Hall, 1995
 - [43] Kleinginna, P. R., Kleinginna, A. M., *A categorized list of emotion definitions, with suggestions for a consensual definition*. *Motivation and Emotion*, 5(4):345–379, 1981.
 - [44] Darwin, C., "The Expression of the Emotions in Man and Animals", 1872
 - [45] Станиславский К. С. "Моя жизнь в искусстве". Искусство, 1954
 - [46] Шибутани Т., "Социальная психология" Москва.: Прогресс 1969
 - [47] Небылицын, В. Д. "Темперамент", *Психология индивидуальных различий*. Изд-во МГУ, 1982.. С. 153-159 / Nebylicyn, V. D., "Temperament", *The psychology of the individual differences*, MGU (Moscow State University), 1982, pp.153-159
 - [48] Небылицын В. Д. *Основные свойства нервной системы человека*. М., 1966.
 - [49] Павлов И. П. *Полное собрание сочинений*. Изд. 2-е. Т. 3 — 4. М.; Л., 1951.
 - [50] Рубинштейн, С. Л. Темперамент и характер. — В кн.: *Основы общей психологии*. М., 1946.
 - [51] Bartneck, C., *How convincing is Mr. Data's smile: Affective expressions of machines. User Modeling and User-Adapted Interaction*, 11, pp. 279-295. 2001
 - [52] Bartneck, C., *Integrating the OCC Model of Emotions in Embodied Characters*, 2002
 - [53] Arbib, M. A., "The Handbook of Brain Theory and Neural Networks", The MIT Press, 2003
 - [54] Gratch, J., Mao, W., Marsella, S., "Modeling Social Emotions and Social Attributions", *Cognition and Multi-Agent Interaction*, Cambridge University Press, pp. 219-251, 2005
 - [55] Davidson, R. J., Scherer, K., & Goldsmith, H. H. (Eds.). *Handbook of affective sciences*.

- New York: Oxford University Press, 2003
- [56] Silverman, B. G. Human behavior models for game-theoretic agents: Case of crowd tipping. *CogSci Quarterly*, Fall, 2002
 - [57] Gratch, J. & Marsella, S. Fight the way you train: The role and limits of emotions in training for combat. *Brown Journal of World Affairs*, X(1)(summer/fall), 2003
 - [58] Marsella, S., Johnson, W. L., & LaBore, C. *Interactive pedagogical drama*. Paper presented at the Fourth International Conference on Autonomous Agents, Montreal, Canada, 2000
 - [59] Rothbaum, B. O., Hodges, L. F., Alarcon, R., Ready, D., Shahar, F., Graap, K., et al. Virtual environment exposure therapy for PTSD Vietnam veterans: A case study. *Journal of Traumatic Stress*, 12(2), pp. 263–272, 1999
 - [60] Lester, J. C., Stone, B. A., & Stelling, G. D. *Lifelike pedagogical agents for mixed-initiative problem solving in constructivist learning environments*. User Modeling and User-Adapted Instruction, 9(1–2), pp. 1–44, 1999
 - [61] Ryokai, K., Vaucelle, C., & Cassell, J. Virtual peers as partners in storytelling and literacy learning. *Journal of Computer Assisted Learning*, 19(2), pp. 195–208, 2003
 - [62] Shaw, E., Johnson, W. L., & Ganeshan, R. *Pedagogical agents on the Web*. Paper presented at the Proceedings of the Third International Conference on Autonomous Agents, Seattle, WA, 1999
 - [63] André, E., Rist, T., Mulken, S. V., Klesen, M. *The automated design of believable dialogues for animated presentation teams*. In J. Cassell, J. Sullivan, S. Prevost, & E. Churchill (Eds.), *Embodied conversational agents* (pp. 220–255). Cambridge, MA: MIT Press, 2000
 - [64] Cassell, J., Bickmore, T., Campbell, L., Vilhjálmsón, H., & Yan, H. Human conversation as a system framework: Designing embodied conversational agents. In J. Cassell, J. Sullivan, S. Prevost & E. Churchill (Eds.), *Embodied conversational agents* (pp. 29–63). Boston: MIT Press, 2000
 - [65] Oatley, K. & Johnson-Laird, P. N. *Cognitive theory of emotions*. Cognition and Emotion, 1(1), 1987
 - [66] Simon, H.A., *Motivational and emotional controls of cognition*. Psychological Review, 74, pp. 29–39, 1967
 - [67] Frank, R., *Passions with reason: the strategic role of the emotions*. New York: W.W. Norton, 1988
 - [68] Shaver, K.G., *The attribution of blame: Causality, responsibility, and blameworthiness*. New York: Springer-Verlag, 1985
 - [69] Mataric, M.J. Designing and understanding adaptive group behavior. *Adaptive Behavior*, 4(1), pp. 51–80, 1995
 - [70] Pirjanian, P., Behavior coordination mechanisms: State-of-the-art. Technical Report IRIS-99-375. Institute for Robotics and Intelligent Systems, University of Southern California, 1999

- [71] Shell, D.A., Mataric, M. J., “Behavior-Based Methods for Modeling and Structuring”, *Cognition and Multi-Agent Interaction*, Cambridge University Press, pp. 279-306, 2005
- [72] Murphy, R. R., *Introduction to AI Robotics*, MIT Press, Boston, 2000
- [73] Russell, J.A. “A circumplex model of affect” *Journal of Personality and Social Psychology*, 39, pp. 1161-1178, 1980
- [74] Schlosberg, H. ‘The description of facial expression in terms of two dimensions’. *Journal of Experimental Psychology*, 44, pp. 229-237, 1952
- [75] Roseman, I.J., Smith, C.A., “Appraisal Theories: Overview, Assumptions, Varieties, Controversies.” In K. R. Scherer, A. Schorr, & T. Johnstone (Eds.), *Appraisal processes in emotion: Theory, Methods, Research*, Oxford University Press, 2001.
- [76] Reisenzein, R., "Pleasure-Arousal Theory and the Intensity of Emotions." *Journal of Personality and Social Psychology* 67(3): pp. 525-539, 1994
- [77] Broekens, J., DeGroot, D., *Emergent Representations and Reasoning in Adaptive Agents.*, Third International Conference on Machine Learning and Applications (ICMLA 2004, Louisville KY, USA) (pp. 207-214), IEEE press, ISBN 0-7803-8823-2., 2004
- [78] Broekens, J., DeGroot, D., *Formalizing Cognitive Appraisal: From Theory to Computation*, Proceedings of the 18th European Meeting on Cybernetics and Systems Research (EMCSR 2006, Vienna, Austria) (pp. 595-600), ASCS: Vienna, 2006
- [79] Broekens, J., DeGroot, D., *Emotional Agents need Formal Models of Emotion*, Proceedings of the 16th Belgian-Dutch Conference on Artificial Intelligence (BNAIC 2004, Groningen, The Netherlands) pp. 195-202, ISSN 1568-7805, 2004
- [80] Broekens, J., DeGroot, D., *Using Negative Emotions to Impair Game Play*, 15th Belgian-Dutch Conference on Artificial Intelligence, pp.32–40, 2003.
- [81] Breazeal, C. and B. Scassellati, “How to build robots that make friends and influence people,” Proc. Int’l Conf. on Intelligent Robots and Systems, 1999.
- [82] Gadanho, S. C., *Emotional and cognitive adaptation in real environments*. In the symposium ACE’2002 of the 16th European Meeting on Cybernetics and Systems Research, Vienna, Austria, 2002.
- [83] Gadanho, S. C., Hallam, J. *Emotion triggered learning for autonomous robots*. In Dolores Cañamero, Chisato Numaoka, and Paollo Petta, editors, SAB ’98 Workshop on Grounding Emotions in Adaptive Systems, pages 31–36, August 1998.
- [84] Burkhardt, F., Audibert, N., Malatesta, L., Türk, O., Arslan, L., & Auberge, V., *Emotional prosody - does culture make a difference?*. Proc. Speech Prosody, 2006
- [85] Wiener, N., *Cybernetics*. MIT Press 1965 (1948)
- [86] Arkin, R.C., *Social Behavior. In Behavior-Based Robotics*, Chapter 9. MIT Press, Cambridge, MA., 1998
- [87] Dahl, T. S., *Behavior-Based Learning: Evolution Inspired Development of Adaptive Robot Behaviors*, PhD Thesis, University of Bristol, 2002
- [88] Wikipedia, Big Five personality traits, http://en.wikipedia.org/wiki/Big_Five_personality_traits [consulted at 17-12-2006]

- [89] Barteneva, D., Lau, N., Reis, L. P., “Implementation and Evaluation of a Flexible Appraisal Model and Temperamental Algorithms for Multi-Agent Systems”, Technical Report, Faculty of Engineering of Porto University, September, 2006.
- [90] Barteneva, D., Lau, N., Reis, L. P., “Implementation of Emotional Behaviors in Multi-Agent System using Fuzzy Logic and Temperamental Decision Mechanism”, *In Proceedings of the Fourth European Workshop on Multi-Agent Systems*, pp. 5-11, Lisbon, 2006
- [91] Picard, R. W., *Affective Computing*, MIT Press, 1997
- [92] Pfeifer, R., Studying emotions: Fungus eaters. *In Proceedings of the 2nd European Conference on Artificial Life*, pp. 916–927. Université Libre de Bruxelles, 1993.
- [93] Lazarus, R.S., *Emotion and Adaptation*. New York, NY: Oxford University Press, 1991
- [94] Cannon, W. B., *The James-Lange theory of emotion: A critical examination and an alternative theory*. American Journal of Psychology ;39:10-124, 1927
- [95] Blumenthal, A. L., “A Wundt Primer: The Operating Characteristics of Consciousness.” Ch. 4 in Reiber, R. W. and Robinson, D. K. *Wilhelm Wundt in History: The Making of a Scientific Psychology*. Kluwer Academic Publishing, 2001
- [96] Rogers, C. R., “*On Becoming a Person*”, Constable and Robinson; New Ed edition, 2004
- [97] Locke, J., *Memoirs relating to the Life of Anthony, first Earl of Shaftesbury*; Works, London, iv.233–43, 1777
- [98] Kant, I., *Anthropology from a Pragmatic Point of View*, Cambridge Texts in the History of Philosophy, 2006
- [99] Velásquez, J., *Modeling emotion-based decision-making*. In Dolores Cañanero, editor, Proceedings of the 1998 AAAI Fall Symposium Emotional and Intelligent: The Tangled Knot of Cognition, pages 164–169, Orlando, FL, USA, 1998. <http://www.ai.mit.edu/people/jvelas/papers/Velasquez-FS98.ps>.
- [100] Velásquez, J., *A computational framework for emotion-based control*. In Proceedings of the Grounding Emotions in Adaptive Systems workshop, SAB '98, Zurich, Switzerland, 1998.
- [101] Cañanero, L., *Designing emotions for activity selection*. Technical Report TR - DAIMI PB 546, University of Aarhus, 2000. <http://citeseer.nj.nec.com/384344.html>.
- [102] Cañanero, L., *A hormonal model of emotions for behavior control*. Presented as poster at the Fourth European Conference on Artificial Life (ECAL '97), Brighton, UK, 1997. <http://citeseer.nj.nec.com/canamero97hormonal.html>.
- [103] Cañanero, L., *Issues in the design of emotional agents*. In AAAI Fall Symposium on Emotional and Intelligent: The tangled knot of cognition, pages 49–54, Menlo Park, CA, 1998. <http://citeseer.nj.nec.com/437878.html>.
- [104] Frijda, N. H., *The Emotions*. Cambridge University Press, 1986.
- [105] Frijda, N. H., *Emotions are functional, most of the time*. In Paul Ekman and Richard The Nature of Emotion - Fundamental Questions. Oxford University Press, 1994.
- [106] Gebhard, P., ALMA – A Layered Model of Affect, *Proceedings of the Fourth*

- International Joint Conference on Autonomous Agents and Multiagent Systems (AAMAS'05)*, 29-36, Utrecht, 2005.
- [107] Pereira, D., Oliveira, E., Moreira, N., Sarmiento, L., "Towards an Architecture for Emotional BDI Agents", *In IEEE Proceedings of EPIA*, Covilhã, December 2005
 - [108] Dias, J., Paiva, A., "Feeling and Reasoning: a Computational Model for Emotional Characters", in *EPIA Affective Computing Workshop*, Covilhã, Springer, 2005
 - [109] Prada, R., *Teaming Up Humans and Synthetic Characters* - PhD Thesis, UTL-IST, Lisboa, Dezembro de 2005.
 - [110] Prada, R., Paiva, A.: *Believable groups of synthetic characters*. AAMAS2005: 37-43 ACM-Press

Appendix A – Psychology Glossary

Temporary insanity	Is the short-term state of strong emotional excitation.
Primary Emotions	Are the simplest, genetically caused emotional states: pleasure, displeasure, pain, fear, anger, grief and others.
Passion	Is the strongly expressed need and the enthusiasm of man by anything, that is accompanied by the deep emotional experiences, connected with the object of enthusiasm.
Stress	The state of emotional mental disorder, connected with the incapacity of man to act, reasonably and expedient, in the prevailing situation.
Feeling	Is the highest, cultural emotion of man, connected with the certain social subject: person, event, object.
Emotions	of experience, which appear in man under the effect of the general state of organism and satisfaction of his urgent needs.
Emotionalism	is the characteristic of man as personalities, which is manifested in the frequency of the appearance in it of diverse emotions and feelings.