IMPLEMENTATION OF EMOTIONAL BEHAVIOURS IN MULTI-AGENT SYSTEM USING FUZZY LOGIC AND TEMPERAMENTAL DECISION MECHANISM

Daria Barteneva[a] Nuno Lau[b] Luís Paulo Reis[c]

[a] *Faculty of Engineering, University of Porto*
R. Dr. Roberto Frias, 4200-465 Porto, Portugal, daria.barteneva@gmail.com
[b] *IEETA, Department of Electronics and Telecommunications, University of Aveiro,*
3810-193 Aveiro, Portugal, lau@det.ua.pt
[c]*LIACC-NIAD&R, Faculty of Engineering, University of Porto*
R. Dr. Roberto Frias, 4200-465 Porto, Portugal, lpreis@fe.up.pt

Abstract

In this paper we describe our work on computational mind model for temperamental decision algorithms using Fuzzy Logic and an implementation of an emotional-behavioral multi-agent system for analysis and evaluation of different strategies based on temperamental behaviors. We describe our approach to emotional model using temperamental decision system based on theory about general types of superior nervous systems in humans and animals and we explain how we can apply Fuzzy Logic on temperamental decision system. We describe the simulation environment used in this work to test and evaluate the strategies. We have conducted a set of robotic experiments in order to test the performance of the system on its first implementation phase. The results achieved showed that the different set of temperamental characteristics influences significantly the performance of the agents and give us very positive feedback to proceed with this research and implementation in new directions.

1 Introduction

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 behaviour 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 [14]. Each emotional behaviour can be described by the different states of physiological changes, feelings, expressive behaviour and inclinations to act. Psychologist describe the Emotion as a result of evaluation of each event as positive or negative for the accomplishment of the goals. Researchers have focused on the functions of emotion for computational models trying to describe some of behavioural responses to reinforcing signals, communications which transmit the internal states or social bonding between individuals, which could increase fitness in the context of evolution [1]. There are several arguments suggesting that emotion affect decision-making of the humans [2]. In the least, it is universally recognized that the benefits of humans having emotions encompass more flexible decision-making, as well as relativity [3]. As argued by Sloman and Croucher, emotional robots can prioritise their decision making process [19]. 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 [15]. Similarly, intelligent robots performing complex tasks must prioritise their activities in some manner. Emotional decision mechanism can work in order to prioritise actions and determining which task for an agent to perform.

In this work we approach the problem of building autonomous robots capable of interaction with each other and build strategies based on a temperamental decision system. As described in Pavlov's theory [4], all human and animal behaviours are coordinated by the Central Nervous System. We conclude that we can't study emotions without considering the particularities of the central nervous system. For defining our temperamental model we use Fuzzy Logic, since the subject of our study is very uncertain and there are no pure temperaments in the nature, but mixtures of different characteristics.

We will focus our work on temperament-based agents and in order to categorize the emotional feedback we use simplified Mehrabian PAD model [16] which we will complete in further work. We considered also the Damásio Theory [2] 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 [11], [12].

The temperamental agents were implemented using Visual Basic 6.0 and tested using Ciber-Mouse [7] simulator. We made some modifications to the simulator that we will describe later, in order to enable to perform the experiences needed for this work.

The paper is organized as follows. Section 2 presents the Temperament approach based on Pavlov's Theory in order to explain the fundamentals for the implementation performed for this project, and we present the Eysenck temperamental scale. Section 3 describes briefly the simulated environment and the changes introduced into Ciber-Mouse robotic simulator. Section 4 describes some experimental results. Section 5 describes the implementation of temperamental model using Fuzzy Logic and Mehrabian PAD simplified model. Section 6 describes the evaluation experiences we perform for this project. Finally Section 7 presents the conclusions and further work.

2 Temperamental Approach to Emotion Programming

Since remote antiquity scientists notice different behaviours between people which were a very individual and specific approach. Some people are very mobile, emotionally excited and energetic. Others are sluggish, calm and imperturbable. Some are sociable and easily contact with others. Some are cheerful, others locked and reserved.

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

2.1 Pavlov's Theory

2.1.1 Central Nervous System

Activity is expressed in different degrees of tendency actively to act, to appear in the diverse activity. It is possible to note two extremes: from one side, high energy, fervency and swiftness in the mental activity, the motions and the speech, while with another - passiveness, sluggishness, the apathy of mental activity, motion and speech. The second index of dynamicity is expressed in different degrees of emotional excitability, in the velocity 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).

The definite scientific explanation of temperaments was given by Ivan Pavlov's theory about the types of higher nervous activity. Pavlov opened three properties of the processes of **excitation** and **braking**[4],[9]:

1) the **force** of the processes of excitation and braking;
2) the **steadiness** of the processes of excitation and braking;
3) the **mobility** of the processes of excitation and braking.

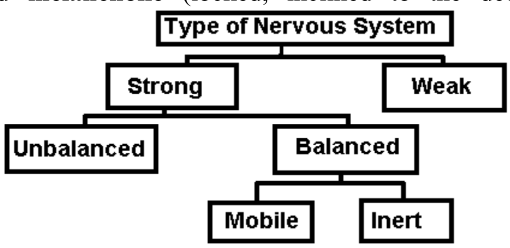

Fig. 1. Classification of higher nervous activity system

The combinations of the properties of nervous processes indicated were assumed as basis to determinations of 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 with it and revealed their complete similarity. Thus, temperament is a manifestation of the type of nervous system into the activity, the behaviour of man. As a result the relationship of the types of nervous system and temperaments appears as follows:

1) strong, balanced, mobile type - sanguine temperament;

2) strong, balanced, inert type - phlegmatic temperament;
3) strong, unbalanced, with the predominance of excitation - choleric temperament;
4) weak type - melancholic temperament.

2.1.2 Eysenck personality test

Using the methodology of Eysenck [8] we can perform the personality test to describe the temperament of the individuals by it **Introvert/Extravert** characteristic and its **Anxiety** (fig. 2).
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

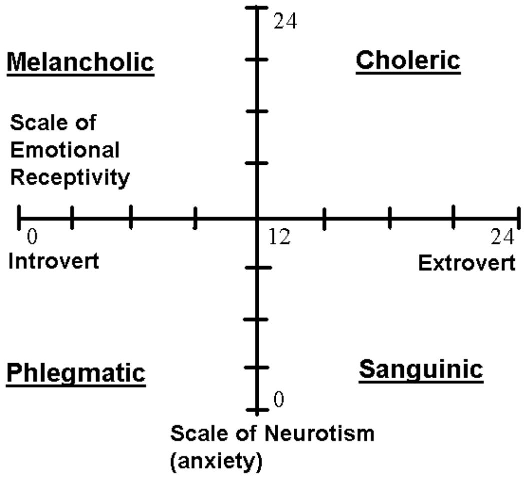

Fig. 2. Scale for the determination of the temperament, by Eysenck

3 Ciber-Mouse Environment

Ciber-Mouse is a modality included in the Micro-Mouse competition organized by Aveiro University (Portugal), and running since 2001 with every year periodicity. 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 [7].

The simulation system possesses a distributed architecture where some types of applications communicate among each other, nominated, a simulator, an application for each agent and a viewer application (fig. 3). The architecture is client-server, where the simulator acts as the server and both the agents and the viewer, acts as clients. This architecture is similar to the Simulation League of RoboCup [10].

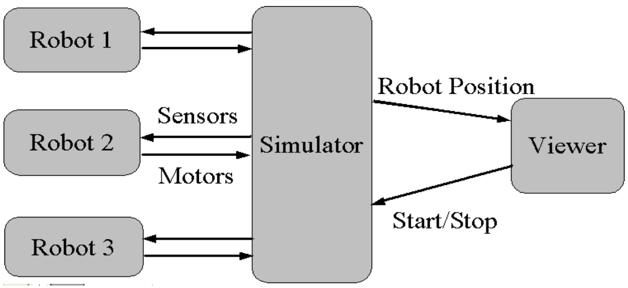

Fig. 3. Cyber-Mouse simulation architecture

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 robotic agents in test, the measures of its sensors, and to all viewers the positions and robots information. 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 same engines.

a) *Each robot (fig. 4) is equipped with the following sensors [13]:*

- 3 sensors of proximity guided to the front and 60º for each side.
- Beacon sensor that indicates which is the difference between robots direction and the beacon direction.

- Ground sensor, active when robot enters in the arrival zone.
- Compass sensor, that allows robot to know which its absolute orientation in the labyrinth is.
- Collision sensor, asset in the case of robot collision.
- Vision sensor, works by identifying other robots and their emotional state.

The measures of the sensors include some noise added for the shape simulator in order to simulate real sensors.

b) *In order to detect the beginning of the test and possible interruptions each robot has 2 buttons:*

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

c) *In terms of virtual engines robots is constituted by:*

- 2 wheels for 2 independent motors, one on the left and one on the right;
- LED of finishing, to light when reached the arrival zone.

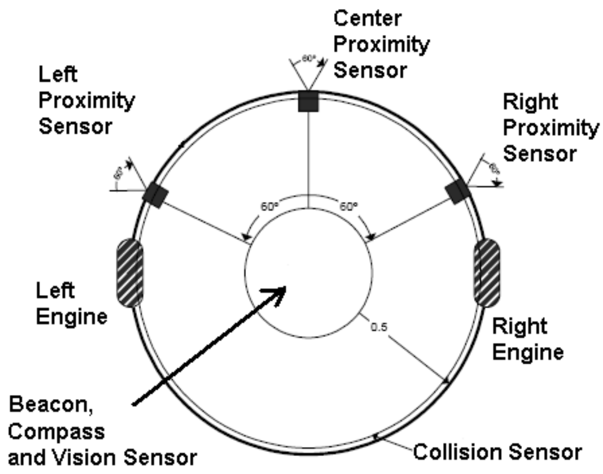

Fig. 4. Virtual robot diagram

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

4 EXPERIMENTAL ASSUMPTIONS

We assume a two layer architecture for our emotional model. One layer is physical and describe superior Nervous system from the Pavlov perspective. The other layer is psychical and work

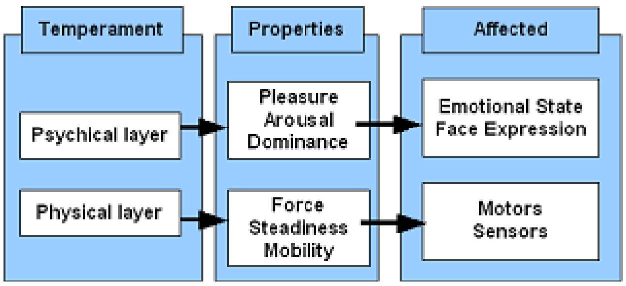

Fig. 5. Temperamental architecture.

with appraisal model created by Mehrabian.
In order to perform evaluation of agent needs, motivations and stimulus we will create appraisal bank [14] which will define the relationship between the constructed objects and subjective measures, called appraisal dimensions.

We choose Ciber-Mouse Simulation environment to implement and test our model because it offers an open, modular and flexible platform permitting unlimited applications and 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.

5 Implementation of Temperamental Model Using Fuzzy Logic and PAD Model.

Fuzzy logic was first developed by Zadeh [20] in the mid-1960s for representing uncertain and imprecise knowledge [17]. This method provides an approximate but effective means of describing the behaviour 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, the Pavlov's theory define the temperamental model based on characteristics of superior nervous system, but at the same time there are no pure temperamental type 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 type in different ratio. The different proportion of values: force, mobility and steadiness of processes of excitation and braking define the unique temperamental type for each person. Based on this uncertainty we use Fuzzy Logic for describe and monitorize the temperamental types in our project. Lets analyse most important variables for our model and their fuzzy interpretation.

4.1 Force

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. In the begin of the simulation we generate the variables values to determine the unique combination which will represent some temperamental type. Using fuzzy logic we can determinate which temperament we obtain for the agent. We define superior limit for the force value in order to obtain better simulation of real world.

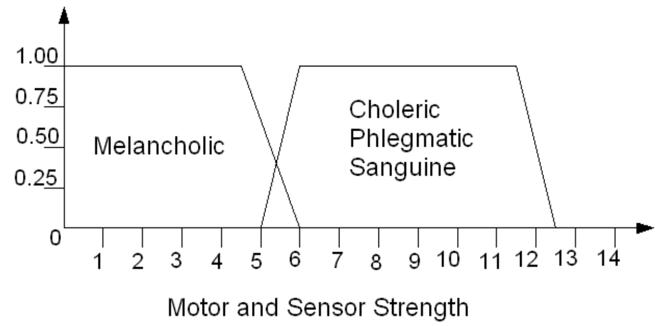

Fig. 6. Fuzzy representation of Temperament vs. Motor and Sensor Strength

4.2 Mobility

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 stop his motors and just stay in the same place until his emotional state change and force him to move. At the same time, one agent who have high mobility will search new places and new directories even if he is comfortable enough in some temporal phase.

4.3 Steadiness

The steadiness of the agent is the velocity of his emotional state variation. For example, more balanced agents have slow variation of emotional state. For this we introduce the variable called

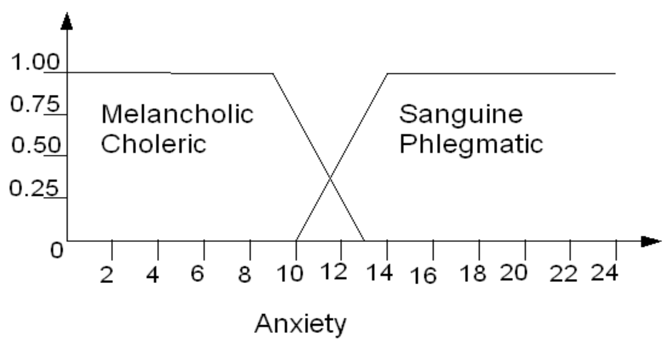

Fig.7.Fuzzy representation of Temperament vs. Anxiety

Anxiety which is used for 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.

4.4 Emotional Receptivity

This variables were based on Eysenck test described on second section. The Melancholic and Phlegmatic temperamental types are included in Introverts group and Sanguine and Choleric types are included in Extroverts group. We will evaluate they performance to reach the beacon, conditioned by they temperamental needs. Each agent possesses the property of Pleasure, Arousal and Dominance which describes its state in the temporal line. For instance the Pleasure depends of the proximity of the agent with other agents, and follows the next strategy:

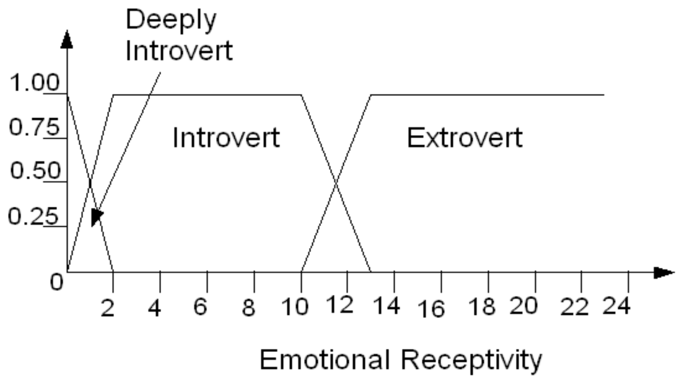

Fig. 8. Fuzzy representation of Temperament vs. Emotional Receptivity

For Extrovert agent Pleasure increase if he is near of other agent with high level of Pleasure. This increase is not a constant and depends on the value of Pleasure of the nearby agent.
If the Extrovert agent is near an agent with low (negative) Pleasure, his own Pleasure will decrease slowly. If the Extrovert agent is far from any agent in the space, his Pleasure decrease constantly.
Similar rules were implemented for Introvert agents, but with opposite effects. For Arousal and Dominance we implement different algorithms to evaluate the best strategy of emotional programming.

4.5 Pleasure, Arousal and Dominance

Analysis of emotional states leads to the conclusion that the human emotions such as anger, fear, depression, elation, etc. are discrete and we need to define some kind of measures to have a basic framework to describe each emotional state using the same scale. After studing the appraisal theory we find Mehrabian model 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 (Fig 9) gives an impression of the emotional meaning of combinations of Pleasure, Arousal and Dominance (PAD).

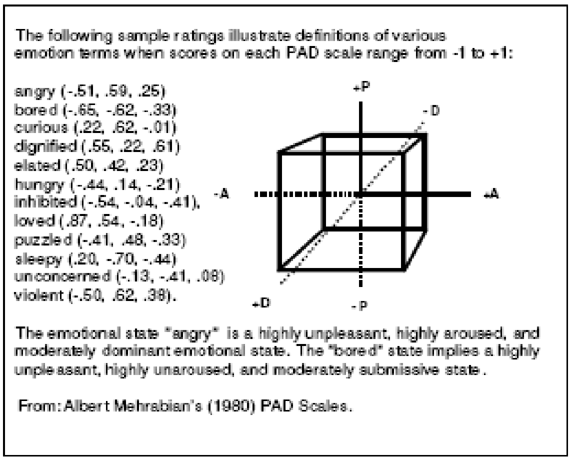

Fig. 9. Mehrabian PAD temperamental scale.

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 define them using the four diagonals in PAD space as follow:

- 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 Big-Five Personality factors in terms of PAD temperamental model [16] Mehrabian find the relationship between five temperamental types and the PAD scale. He describe this relationship using linear regressions. The resulting equations are given below for standardized variables with a 0.05 significant level:

Extraversion =	0.24P		+0.72D	(1)
Agreeableness =	0.76P	+0.17A	-0.19D	(2)
Conscientiousness =	0.29P		+0.28D	(3)
Emotional Stability =	0.50P	-0.55A		(4)
Sophistication =		+0.28A	+0.60D	(5)

Mehrabian also propose three linear regression Analysis to describe each of the PAD scales as function of this temperamental types with a 0.05 significant level:

Trait Pleasure =	0.59 agreeableness	+ 0.25 stability	+0.19 extraversion	(6)
Trait Arousability =	-0.65 stability	+ 0.42 agreeableness		(7)
Trait Dominance =	0.77 extraversion	-0.27 agreeableness	+0.21 sophistication	(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.

4.6 Instrumentation of Appraisal Banks

As we already refer, each temperamental type have it 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 psychical temperament layer for our model. The influence of each PAD component to the temperamental type is shown in (1)-(5) formulas, so using them we can distinct the different weight of the measures from Appraisal Bank and personalize them for each temperamental type. Lets define and describe the Appraisal Bank we use for our project.

Appraisal bank defines needs, motivations and stimulus of the agent as a set of subjective measures, called appraisal dimensions. We based our idea on Broekens and DeGroot [14] work that develop and test an appraisal model on PacMan experimental platform. Our appraisal bank describes needs, motivations and stimulus (NMS) of the agents in our simulation system:

- Needs: reach the beacon, satisfies personal (temperamental) characteristics like necessity of company of other agents or necessity of loneliness, avoid threats (angry agents).
- Motivations and stimulus: See or lose the goals or threats.

We describe this NMS system in order of PAD model. We define pleasure as conductance of the goal. For instance if the agent see the beacon and no obstacle are present his pleasure is high, while if he see the threat or lose the goal is highly unpleasant. Arousal is the amount of attention each event need, for instance avoid threat need the attention of the agent and lose it need no attention. Dominance is a measure that defines the amount of freedom of the agent. For example, see the wall decrease the dominance and see the no obstructed way to goal increase the dominance. The weight we attribute to each event differ on their importance and thus we divided them in three groups of importance: high, medium and low. We will define the importance of each events on simulation system, but each temperamental type has its own “value scale” for each need. We will define the “personality functions” which transform the importance of each event from appraisal bank in it personal importance for each agent depending on the agent temperamental type.

Table 1. Appraisal Bank

Event	Pleasure	Arousal	Dominance
See_Beacon	0,6	0,6	0,6
Near_Beacon	1,0	-1,0	1,0
Lose_Beacon	-0,6	0,6	-0,6
See_wall	-0,2	0,2	-0,2
Collide_wall	-0,6	0,6	-0,6
See_happy_agent	0,3	0,3	0,3
Near_happy_agent	0,5	-0,5	0,5
Lose_happy_agent	-0,3	0,3	-0,3
See_threat	-0,5	0,5	-0,5
Near_threat	-1,0	1,0	-1,0
Lose_threat	0,8	-0,8	0,8

So we define as very important agent's surviveness, which approach avoiding the threats. Medium importance is the performance of the agent in relation of the final goal of the simulation: reach the beacon. Low importance is the satisfaction of the temperamental needs of each agent: looks for a

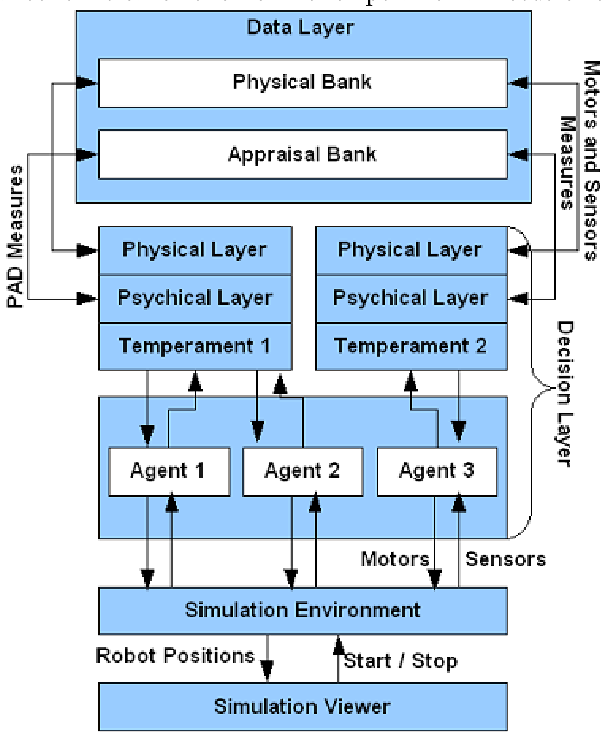

Fig. 10. Ciber-Mouse Simulation Architecture vs Appraisal Model and Central Nervous System

company or for isolation.

On the Fig. 10 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.

Lets analyze the relationship between the central nervous system defined temperaments and PAD dimensions using the information from Big-Five personality factors and Eysenck [8] theory. On the Fig. 11 we can see the intersection of different sets characterizing the temperamental types.

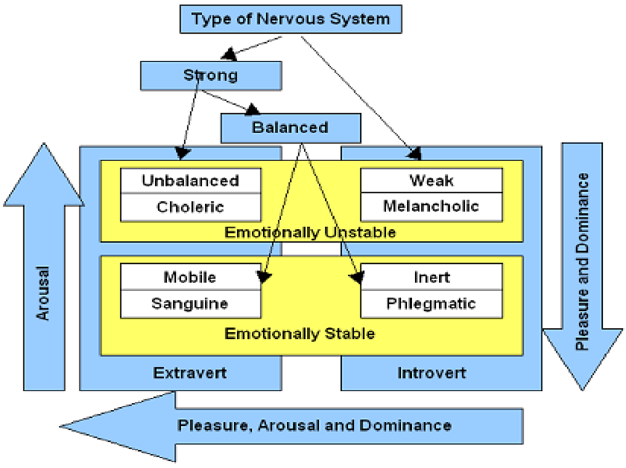

Figure 11. Central Nervous System vs PAD Dimensions

6 Evaluation

In this work we evaluate the group of 9 agents and their performance to reach the goal. In each evaluation we use different combination of temperamental configurations.

Fig. 12. Ciber-Mouse Simulation Environment. Example of experience.

There are different temperamental types of agents and their performance that we can observe on table 2 which represents means of some measures of the Physical temperamental type and Arousal measures.

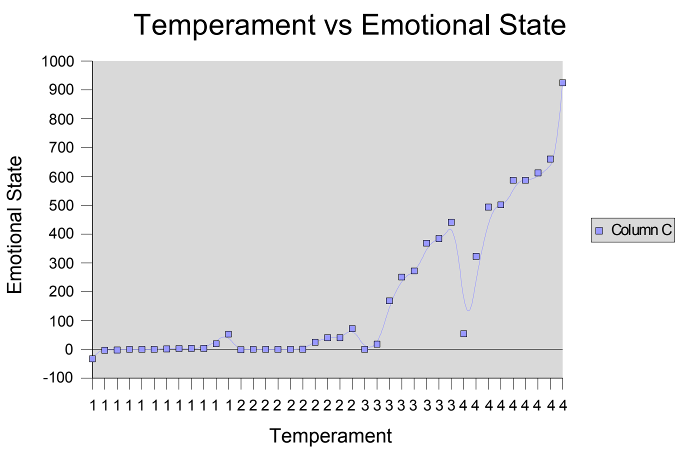

Fig. 13. Temperament vs Emotional State

1-Sanguine, 2- Choleric, 3- Phlegmatic and 4- Melancholic.

As we can observe from this table Melancholic temperament has better performance than other Physical temperamental types. It achieves better time performance on reaching the goal and better emotional state. On Fig. 13 we can observe the emotional state growing when the temperament changes.

Table 2. Experimental Results for Physical Measures vs Arousal

Temperament	Arousal	Emotional State	Sensor Strengt	Time (s)
Sanguine	0,50	0,00	10	1525
Choleric	1,00	0,10	10	1354
Phlegmatic	0,5	250,55	10	1800
Melancholic	**0,74**	**320,28**	**7**	**889**

We also want to show some curious result (Fig. 14) of the test in the empty space. Here we can see pure agent interaction without obstacles and free access to the beacon.

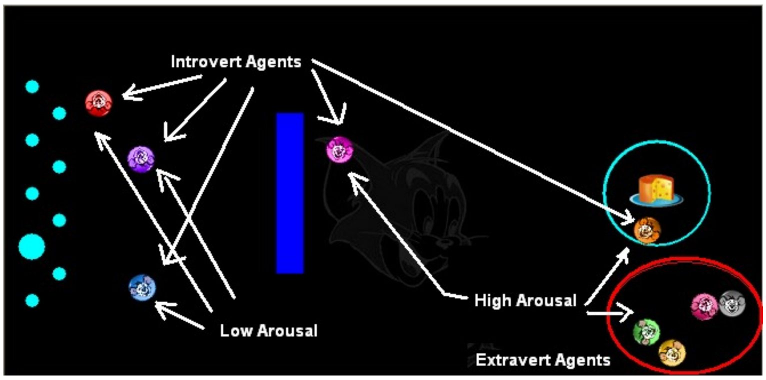

Fig. 14: Example of simulation environment during evaluation

As we see the agents with high arousal level come very closely to the beacon as well as extravert agents (rounded by the red circle) form the cluster near the beacon. In the example shown which is very usual to happen in the open simulation space we observe the optimal emotional values for each agent in accordance with each temperamental type.

7 Conclusion and Further Work

In this paper we have addressed the problem of multi-layer scalable emotional model which can be easily introduced in any non-emotional system. We presented the appraisal bank which can be easily adapted to most systems. We find that the runtime-scaling is very useful to describe the system in such uncertain area as emotional interaction of different agent with non-homogeneous characteristics and responses.

We compare the results of these evaluations with our previous results [21] and can conclude that there are significant improvement on the performance of the agents in simulation space, and with more flexible PAD model and fuzzy approach we can better describe different kind of emotions. As we already referred throughout the paper, there are many issues that need implementation to enable this study of temperamental Multi-Agent systems. One of these points is implementation of the different concurrent planning strategies for reaching the goal and their evaluation when applied to the different temperamental agents. Also we are planning to evaluate more emotional states from Mehrabian PAD scale and introduce some visual effect to the simulator with emotional icons which will represent the emotional state of each agent. We believe that this temperamental approach to the emotional multiagent system is the innovative way to implement emotional behaviours and develop new forms of collaborative strategies based on the temperamental algorithms.

8 Acknowledgements

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