Human Emotion Simulation in a Dynamic Environment

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Preface

The research conducted in this thesis was performed at the university of Northampton. I enjoyed working with the people of the Computing department. Particularly, I would like to thank my supervisory team: Prof Kamal Bechkoum for his help defining the theme, his incredible support and presence, his feedback and especially his empathy. I would like to thank my director of studies Prof Phil Picton for his availability and advices. I would like also to thank Dr Scott Turner for his meticulous reviews and advices.

Also, I thank all the persons who contributed to the evaluation in this work.

This work would not have been achieved without the moral support of my parents: Mohamed and Nacera and my amazing siblings: Samia, Naima and Kheireddine. I would like also to thank my extended family for their support and my dear friends.

Abstract

The aim of this work is to contribute to the believability of the simulated emotions for virtual entities to allow them display human like features. Endowing virtual entities with such features requires an appropriate architecture and model. For that, a study of emotional models from different perspective is undertaken. The fields include Psychology, Organic Components, Attention study and Computing. Two contributions are provided to reach the aim. The first one is a computational emotional model based on Scherer's theory (K. Scherer, 2001). This contribution allows to generate a series of modifications in the affective state from one event by contrast to the existing solutions where one emotion is mapped to one single event. Several theories are used to make the model concrete. The second contribution make use of attention theories to build a paradigm in the execution of tasks in parallel. An algorithm is proposed to assess the available resources and allocate them to tasks for their execution. The algorithm is based on the multiple resources theory by Wickens (Wickens, 2008). The two contributions are combined into one architecture to produce a dynamic emotional system that allows its components to work in parallel. The first contribution was evaluated using a questionnaire. The results showed that mapping one event into a series of modifications in the affective state can enhance the believability of the simulation. The results also showed that people who develop more variations in the affective state are more perceived to be feminine.

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1 Introduction

Early generations of computer systems including Artificial Intelligence systems (AI) have focused on providing logical solutions to the end users without taking into account the nature of users. For these systems, users are all similar and are supposed to interact with the system in a more or less similar way (like Chess programs or Expert Systems). These systems have provided many facilities to their users but had some limitations in their interaction. These limitations could clearly tell that the system is a machine and would certainly fail a Turing test. The following generation of systems offered more personalisation. Recommendation systems could estimate the needs and preferences of the end users and perform their operations based on these needs and preferences. Generally, these data are gathered from the interaction history with the end user. This behaviour seems more intelligent than the previous generation. However, it still cannot pass a Turing test due to the multifaceted nature of human intelligence. The Turing test is a way to assess whether a machine can think or not. A group of users spend five minutes dialoguing with a machine remotely (no direct physical contact). Then, the users assess whether the remote interlocutor was a machine or a human. If 30% of the users mistake the machine for a human then the test is considered to be a success. No machine was able to pass the Turing test until recently in 2014 where a program called *Eugene Goostman* simulating a 13 years old boy passed the test successfully with a score of 33% (Masnick, 2014). Still, many experts disputed the victory and the test since it did not include any personality on its own and only mimicking one (Masnick, 2014). These mentioned two generations fall under rational reasoning. However, humans have a limbic system that is specialised in what is called *emotional process*. This system alongside a cognitive system produce human experience. The previously mentioned systems do not include emotional models.

To allow a deeper interaction between users and machines, machines should be able to better understand the user. This cannot be achieved without endowing the machines with emotional capabilities. Such capabilities include understanding users' emotions and also communicating through emotions. Meaning, giving the machines the ability to display emotions. This is asserted by Picard's citation "A machine, even limited to text communication, will communicate more effectively with humans if it can perceive and express emotions." (Picard, 1997)

Endowing machines with emotions can be challenging. Cognition which is more deterministic has seen many successful applications. Emotion by contrast, has no deterministic model nor does it have a consensus over its definition.

1.1. Motivations of this Research

As seen in the previous section, modelling emotions can lead to a better human-machine interaction. However, this is not the only potential application of computational emotional systems. In (Marsella et al., 2010) the impact of computational emotional models can be divided in three categories:

- The impact on Psychological research on emotions.
- The impact on Artificial Intelligence and Robotics.
- The impact on human computer interaction.

In the Psychological theories, emotion simulation can provide a validation method. They can be simulated in a virtual environment and can offer more than what a testing laboratory would offer. Virtual characters allow more manipulation freedom than real subjects (Marsella et al., 2010). Both in terms of application and time. Furthermore, psychological theories are defined at a higher abstraction level (Marsella et al., 2010). This means that these theories are not formalised in a detailed level and therefore computational models enforce a more detailed definition of the process. This often leads to underlying hidden assumptions becoming a framework for theory construction (Marsella et al., 2010). Also, simulating virtual characters in a large scale with an emotional system requires integrating that system with other components such as cognition and body/facial expressions. This can engender new questions to research such as the relationship between emotion and the other components. In the field of AI and robotics, emotion is used to direct cognitive resources (by judging the importance) (Scheutz and Sloman, 2001). In (Damásio, 1994) Damasio argued that emotion is necessary for assigning priorities to tasks. Virtual games also benefit from emotional systems such as the *The Sims* video game where traditionally preprogramed emotional expressions where used. In this area, generating emotions on the fly (instead of preprogramed) can improve the impact of experience. In (Thomas et al., 1995) Thomas and Johnston demonstrated that using generated emotions can significantly contribute to the believability of interactions in virtual characters. Virtual companions and assistants also benefit from this technology. In the field of machine learning, emotions have been used to improve the algorithms (Stromfelt et al., 2017). In industry, products using these technologies like robots with personality are being introduced. Finally, in the field of Human Computer Interaction, several pieces of work took place demonstrating the impact of emotions in communication. Conati uses a Bayesian network to infer the emotion of a learner from their actions (Conati and Maclare, 2004). Other systems use facial expression or sensors to infer the emotional state (Haag et al., 2004) (Lisetti and Schiano, 2000). Another (social) impact, is that in the presence of lifelike characters, people can be more polite but also more nervous (Krämer et al., 2003). In (Cowell and Stanney, 2003) the authors state that people can trust more the recommendation of assistants if emotional characters are used. In (Mudrick et al., 2017) it was found that in online learning, tutors that display congruent emotions allowed learners to perform better than when tutors displayed non-congruent emotions.

1.2. Scope, objectives and contributions

This thesis' aim is to provide a framework for simulating human emotions in virtual characters/agents. The framework needs to be domain independent. Meaning that it can be used in multiple areas of application. The framework should contribute to the believability of the simulated emotions in their environment. The input to the framework is the external and internal environment of the agent/individual while the output is the emotions dynamics of the agent/individual. To reach our aim, the following objectives are dressed:

- Study of the current computational models, assess their architecture, their capabilities and limitations
- Study of the psychological theories to further understand the computational models. Several iterations on the first objective and the second one are necessary
- Identification and selection of areas of improvement to focus on
- Selection of the theoretical models that are going to be used in the final model based on the previous studies
- Modelling and implementing the final model
- Empirical evaluation of the final solution

Currently, most models work in a sequential way. The typical scenario is: a stimulus is picked by the organism. The stimulus is converted into a set of variables/dimensions. Then, the organism converts these variables into an emotion. Finally, a coping strategy is triggered according to the emotional state and the situation. A coping strategy is a response action to an emotional change such as replying back to an emotional message. These sequential models tend to ignore the parallel nature of human beings. They also assume that emotions are static by converting an ensemble of variables/dimensions into one discreet emotion. Variables/dimensions include (see chapter two and three): goal congruent event, dominance and pleasantness, and they may change from one model to another. These sequential models have many potential applications. However, they tend to fail in certain situations. As an example, the values of the variables/dimensions can change in the middle of executing a coping strategy. Alternatively, the individual might use only a subset of these variables/dimensions in a first place, then uses the other dimensions, which could also be referred to as progressive appraisal. In (Marsella and Gratch, 2009) a phase of using social norms variables/dimensions (after a first appraisal phase) to update the emotional state is shown to improve the possibilities of the model.

To reach the goal, two main contributions are realised and then combined. First, a computational model using Scherer's theory (K. R. Scherer, 2001) is developed . In this contribution, variables/dimensions are processed sequentially following Scherer's model to allow a continuous emotional change. Scherer's theory is at a high abstraction level and does not give details of how to derive an emotion from the variables/dimensions considered. For this, various theories and assumptions are used to allow such a transformation. Personality traits are also included in the set of variables/dimensions which are not included in Scherer's model. This progressive appraisal allowed us to generate an emotional curve instead of only a discreet emotion following any given event.

The second contribution deals with parallel execution of tasks by individuals. This contribution is based on Wicken's theory (Wickens, 2002) addressing the multiple resources model. This contribution uses the multiple resources available to an individual, such as cognition and body expressions/gestures, to predict whether two distinct tasks can be executed in parallel. It is not about picking the most appropriate task. It rather assesses whether a task can be executed when a person is in the middle of an action. This can happen frequently to living organisms endowed with multitasking capabilities such as humans. Actions can be internal and external as well. Like using cognition for an action while requiring to use bodily expressions for another goal. Scherer's emotional model is based on five components working in parallel and using a multiple resources paradigm can allow us to predict which component will be used at any given time by comparing what resources they need.

An algorithm is proposed to allocate the resources for tasks and releasing these resources as required. The algorithm is based on assessing the highest probability that two tasks being executed at the same time would interfere with each other. The combination of the two contributions allows a parallel processing of emotional episodes. The second contribution predicts whether two or more stimuli can be processed at the same time while the first contribution determines the emotional state after each appraisal of the variables/dimensions. This combination allows more possibilities, such as changing the coping strategy during its execution since the parallelism allows the modification of the variables/dimensions while doing any action (if the resources allow it). In this work, coping strategies are not in the focus. The main goal is emotion modelling.

1.3. Organisation of the thesis

In chapter 2, a literature review is provided. The review examines psychological theories of emotions. Mainly the appraisal family and dimensional family. It also explores the views from a neurologic point and the components used in such processes. Different representations of emotions and affects are dressed to allow us to make our design choices. In this chapter attention theories are studied to allow us to achieve one of our goal which is parallelism.

In Chapter 3, another type of literature review is conducted. A review from the point of view of affective computing. By contrast to the chapter 2 where the review is more general. In this chapter, different computational models are explored giving their different contributions and critics. It was observed that models differ greatly in their design as their aims and objectives are different. The reviewed models are FLAME by (El-Nasr et al., 2000), WASABI (Becker-Asano and Wachsmuth, 2009), Marinier and Lairds's model (Marinier et al., 2007), Emile (Gratch, 2000) and EMA (Marsella and Gratch, 2009). We consider that these models offer some of the most important contributions to the field.

In Chapter 4, The developed emotional computational model is introduced. This represents what we called previously the first contribution. The used theories and studies are provided to justify the choices of the model. A scenario using the model is provided as well. It ends with a discussion section.

In chapter 5, the second contribution detailed along few examples. It also provides the general architecture of the system and how both contributions are used to reach the aim of this work. It also ends with a conclusion.

In chapter 6, the evaluation procedure of the first contribution is given along with the results. Three different scenarios are used to evaluate the model. A group of users answered a set of questions relating to the experience. The results showed that progressive appraisals of variables/dimensions can improve the believability in certain cases. It also showed that some individual differences can be expressed by the progressive appraisal (sequential appraisal). Unfortunately and because of time, it was not possible to evaluate the second contribution and its combination with the first one. This will be done as a future work.

In chapter 7, a conclusion is given to the whole study. The potential applications and the shortcomings. The remaining of the work in to be undertaken in the future is dressed.

A conference paper has been published in Affective Computing and Intelligent Interactions conference (ACII 2015) addressing the work presented in chapter five. It is entitled "Multitasking in emotion modelling: Attention Control"

2 Emotions: Interdisciplinary Review

2.1. Emotion simulation

Emotions are recognised as a part of the human mind; involved in many of our daily activities. However, the effect of emotions on decision-making has often been misunderstood. According to Miranda (Miranda, 2011) in the past, emotions were seen as an undesirable product of the human mind. Therefore, the less the person is emotional the more intelligent and desirable he/she is. In an opposite view, researchers claim that emotions are part of life and are necessary in any intelligent behaviour (Damásio, 1994; Gray et al., 2002). To illustrate the importance of emotions in daily life, the researcher uses an example from (Damásio, 1994). A successful lawyer and client of Damásio, a neurologist, underwent a surgery to remove a tumour from his brain. The operation was successful, at least according to the initial goal. However, and unfortunately for the lawyer, the connections between his prefrontal lobes and his amygdala were cut. This made the lawyer incapable of managing his daily life priorities and then could not do any job properly despite not showing any cognitive problems. Damásio concluded that we are not information processors like computers "*Instead, the mind does something much more elegant: It weighs the emotional bottom line from those previous experiences and delivers the answer to us in a hunch, a gut feeling.*" (Damásio, 1994) *52*

"Just as there is a stream of thought, there is a parallel stream of feeling. The notion that there is "pure thought," rationality devoid of feeling, is a fiction, an illusion based on inattention to the subtle moods that follow us through the day." (Damásio, 1994)

This example strongly indicates that any intelligent behaviour mimicking humans has to involve emotions.

To simulate emotions a theoretical basis is needed. This basis is a sort of guidelines of a concrete realisation. Psychological models do not give us a full and extensive architecture of emotion mechanisms but rather a general understanding of the process (Marsella et al., 2010). The implementations need to make those theories concrete by finding ways of interpretation.

Among those theories, the appraisal theories are the most used in computational models (Marsella et al., 2010).

Although there are no agreements about the definition of emotions among the scientific community (Marsella et al., 2010), modelling emotions will follow a model and tend to respect its basic formalism.

2.2. Psychological theories of emotions

Psychological theories of emotions are needed as a basis for computational models. Actually, we have few theories in literature with different concepts. In order to model a computational emotional model, the designer needs to pick a psychological theory. Those theories differ in many ways and it is not easy to assess them in terms of their contribution towards computational modelling (Scherer et al., 2010) and thus make a choice for your emotional model. According to Scherer (Scherer, 2010) psychological theories of emotion differ with respect to their assumptions in the following aspects:

- How the emotion components — cognitive processes, peripheral physiological responses, motivational changes, motor expression, and subjective feeling are integrated,
- How different emotional states are to be differentiated,
- Their focus on specific stages of the process.

Despite the above differences, it is possible that many of them could converge towards a similarity if observed from a given angle Choosing a psychological model is not straightforward as it is hard to assess it against a set of goals. However, we can observe in the literature similar choices in given conditions that we will discuss in the next section.

Each psychological model belongs to a family of models. A family of models can be seen as a general approach or a tradition in defining the emotional process, the different stages as well as their order. We will explore the most influential models in each family and review them.

Computational models use psychological theories as a general guidance with some designer's choices and interpretations. We can find many computational models with differences and similarities and despite the number of those models and the related work, the field is far from mature and the goals they are trying to achieve are not clearly defined (Marsella et al., 2010).

Marsella (Marsella et al., 2010) also points out that research is rarely incremental but rather returns to motivational theories instead of extending existing computational models and those are rarely contrasted with each other against the set goals. Computational models address hidden assumptions in theories, they did extend them with formalisms like concepts, processes and metaphors (Marsella et al., 2010).

Among the emotional theories the appraisal theories and dimensional theories are most known. Many differences exist among those theories but the researcher believes that the distances between them could be reduced if we look at them through different perspectives. More details are given below.

2.2.1. Appraisal theories

According to (Moors et al., 2013) the basic rule of appraisal theories is that emotions are the reflection of the responses to the appraised features of the environment that are significant for the organism's well-being. It is also the most used in modelling emotions computationally as it shows the link between cognition and emotion (Marsella et al., 2010). Appraisal models view emotions as a set of subsystems or components. Appraisal is one component whose task is to evaluate the person-environment relationship (Moors et al., 2013). Other components are a motivational component with action tendencies, a somatic component with physiological responses, a motor component with expressive and instrumental behaviour and a feeling component with subjective experience or feelings (Moors et al., 2013).

Appraisal theories specify the variables involved in the emotional process. Those variables are used to differentiate between emotional states (Moors et al., 2013). They also specify goals or concerns of the person (Moors et al., 2013). Those variables and concerns are used to appraise a situation. There are a common number of variables in most appraisal models although the list of used variables may differ from one model to the other. According to Moors (Moors et al., 2013) the most common variables are *certainty*, *agency* (to whom the responsibility is claimed; oneself, someone else or impersonal), and *coping* potential or *control* (whether you have the control over the situation or not). Moors (Moors et al., 2013) also add that some authors propose that novelty, expectancy, urgency, intentionality, legitimacy, or fairness, and/or norm compatibility contribute to differences in emotions. Appraisal theories give details about how to compute and determine emotions using rule based like systems where the entries are the variables/dimensions. Among studies that examined the link between appraisal values to goals (Parkinson, 1997; Roseman and Evdokas, 2004) where goal-congruent and incongruent events lead to certain emotions.

Other emotional theories include an appraisal process; however appraisal theories assign a central role to the appraisal process in differentiating between emotional episodes and the changes in the other components (Moors et al., 2013). In (Clore and Ortony, 2000; Frijda, 2007; Reisenzein, 1994) it is stated that appraisal determines the intensity and quality of action tendencies, physiological responses, behaviour and feelings. This is the difference between theories belonging to the appraisal tradition and other theories that include the appraisal component but do not assign to it a central role.

Appraisal theories are criticised for being slow and non-automatic (Moors et al., 2013). However, many appraisal theorists accept that the appraisal process can be automatic or non-automatic (Moors et al., 2013). Moors (Moors et al., 2013) state that sometimes it can be non-automatic, for example in considering the possible actions in any particular event. Those possible actions can be used to appraise the situation. On the other hand, and often, appraisal can be automatic, fast and unconscious (Moors et al., 2013). As an example, let's consider a man facing a dangerous animal. If that man has a weapon strong enough to defend himself he will appraise the coping potential more favourable. If he doesn't have any mean to defend himself, coping potential won't be favourable thus the situation will be appraised differently. We can here observe that determining coping potential depended on cognition. Another example, let's consider the sight of a beautiful landscape, here the appraisal process is much faster and looks rather automatic. From the point of view of appraisal theorists, there is always an appraisal before triggering changes in the other components of the emotional process, whether those changes are fast or not.

Next, we will look at some specific appraisal models.

OCC Model

The OCC (Ortony, Clore and Collins) model (Clore and Ortony, 2000; Collins et al., 1988) is one of the most used in computing (Chaffar and Frasson, 2007). In OCC the authors define 22 types of emotions. Same types of emotions are triggered in similar situations. For every emotion is defined an opposite emotion. For example, sadness is the opposite of joy (Chaffar and Frasson, 2007). More recently, Ortony (one of the authors of the model) has simplified

OCC model by grouping types of emotions to finally define five types of positive emotions and six types of negative emotions (Ochs, 2007). According to (Ochs, 2007) in the OCC model, three classes are defined based on their triggering cause:

- The emotions triggered by an event affecting an object of the individual, such as joy, hope or fear.
- The emotions triggered by an event affecting a principle or standard, such as shame, pride or reproach.
- The emotions triggered by the perception of particular objects (animated or unanimated, concrete or abstract) such as love or hate.

The authors define global variables that determine the intensity of the emotions and local variables (specific to each of the above classes) that will determine both the type and intensity of the emotions of each class. This model is the most widely used model to simulate processes triggering emotions in computational systems (Ochs, 2007). Figure 2-1 represents the original structure of the OCC model.

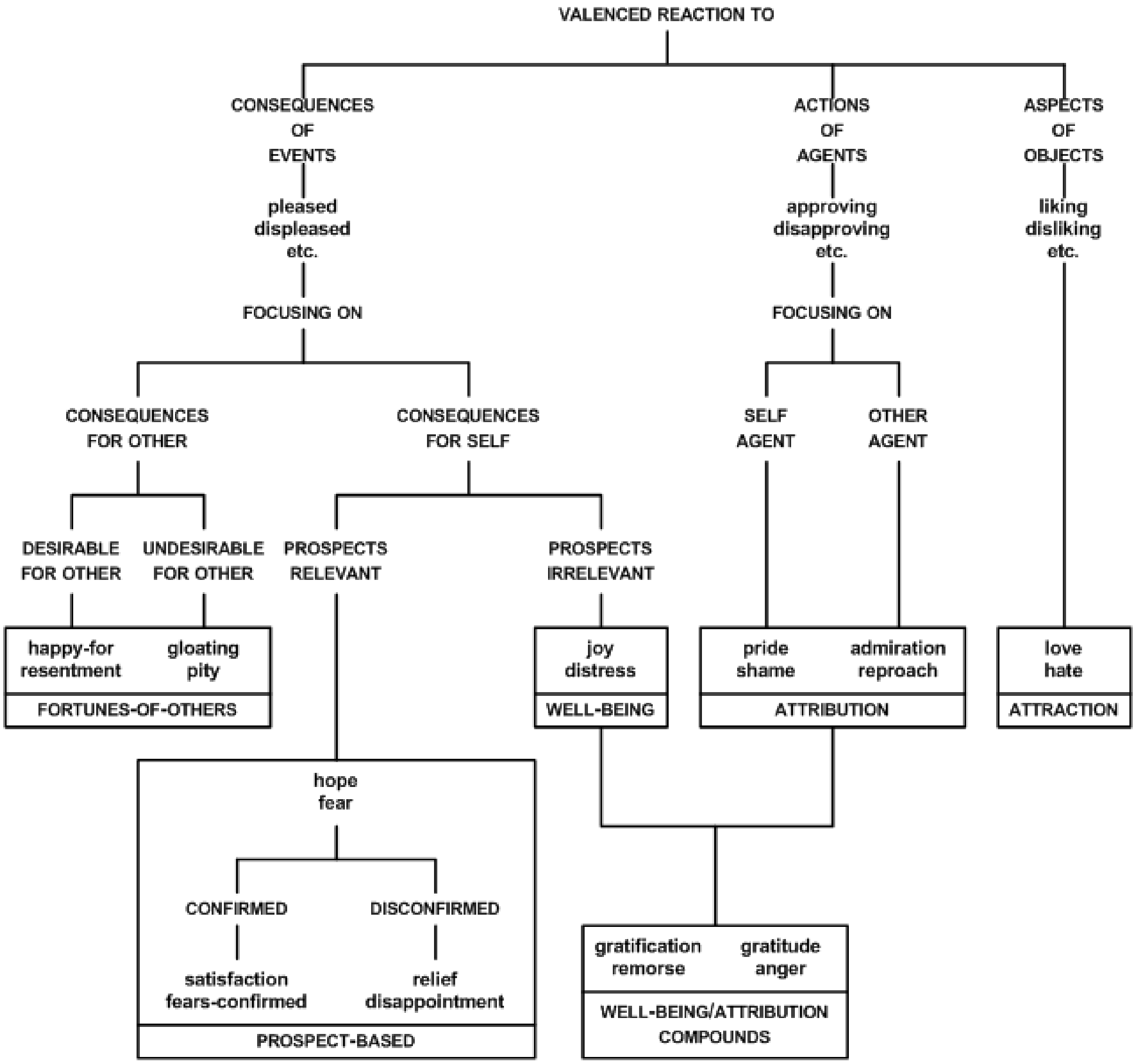

Figure 2-1 Structure of the OCC (Collins et al., 1988)

It is without a surprise that the OCC model is the most used one in computational modelling as we can see that it is clearly defined. We can see at the top three main branches. Those branches are consequences of event, action of agents and aspects of objects. They will interact respectively with goals, standards and attitudes then the selected branch will depend on this interaction. To make it clearer let us consider a person looking at the sky and suddenly a thunder flashes. If this Thunder is perceived as an event and it has some consequences on the goals of that person than we select the first branch and we will test the other variables.

Emotions' labels could have different meanings from one model to another. The OCC model gives a definition for each label. In (Collins et al., 1988) we can find those definitions. Here are some of them:

- Joy: (Please about) a desirable event.
- Distress: (Displeased about) an undesirable event.
- Happy for: (Pleased about) an event presumed to be desirable for someone else.

We can see that the OCC does not use the variable '*coping potential*' which is the ability of an individual to cope in a particular situation. This variable is used in other models.

Scherer's theory

Scherer's theory (K. R. Scherer, 2009, 2001; Klaus R. Scherer, 2009; Scherer, 2013) unlike the OCC describes the emotional process as a set of five components or processes:

- a cognitive component whose tasks are the evaluation of events and object,
- a peripheral efference component which acts as a system regulator,
- a motivational component prepares and directs actions,
- a motor expression component communicates reaction and behavioural intention,
- a subjective feeling component monitors the internal state and organism-environment interaction.

Scherer uses SECs (Stimulus Evaluation Check) to determine what type of emotion is experienced at a particular moment. He describes four types of SECs.

> *Relevance detection*: (K. R. Scherer, 2001) points out that the organism needs to scan the external and internal stimulus input constantly in order to check whether a particular situation requires deployment of attention, further information processing and adaptive reactions. This check will assess if a situation is relevant enough to require more attention and relevant processing. This check is composed of four sub-checks. The **novelty check**; considered the most primitive level of the sensory motor processing. Any event that can be qualified as sudden can be registered as novel. The second sub-check is **intrinsic pleasantness check**, it evaluates whether an event may result in pleasure or pain. Another sub-check is the **goal relevance check**. It

establishes the importance of a situation. The situation is considered important if it affects the individual's goals/concerns.

- *Implication assessment*: this check measures to what extent a situation can endanger an individual or meets his goals/needs. The checks involved in the implication assessment are the **causal attribution check;** this check detects the cause of an event/situation by discerning the agent responsible for the outcome. This check is important for the check that follows it. The next one is the **Outcome Probability Check;** it measures the likelihood of the occurrence of certain consequences of an event. This is an estimated probability. The **Discrepancy from expectation check**, here a given situation could be consistent or discrepant with an individual's expectations. Scherer(K. R. Scherer, 2001) (Scherer 02) gives an example where a student who failed in an exam and his father gives him a present will perceive the situation as discrepant. The **Goal/Need conduciveness check**. Finally, the **Urgency check** evaluates the urgency needed by a situation. Urgent outcomes involve both goals' importance and time constraints. An urgent event is considered important and needs a quick reaction because of the pressure of time.
- *Coping potential determination:* Coping is the ability of an individual to deal with a situation. Scherer (K. R. Scherer, 2001) implies that coping doesn't necessarily mean that the individual is able to reach his original goal but it is also possible for the individual to resign himself from a situation beyond his control. As an example, a student who fails his exam might feel able to cope with the situation because he thinks that changing his orientation will be more successful for him. This check is composed of three other checks. The **Control check**, it is to what extent an event could be influenced by an individual (directly or indirectly). Control involves predictability but the opposite is not true; we can predict the weather but we can't control it. The **Power check,** when we are able to control, we need power to exert the control (through direct power or indirect). In (K. R. Scherer, 2001) an example is given. A student is given a bad mark in a module at a university. The student can believe he is in a power state if he has an uncle who presides over the university's endowment fund and can use his relationships to modify the student's mark. There is a difference between Power and Control. Control is the probability that an event can be prevented or its consequences could be changed. Control is the ability of an individual to influence a controllable

event (directly or indirectly). Another sub-check of the Coping potential determination is the **Adjustment Check,** this checks the ability of an individual to cope with an incontrollable situation. If the control check and the power check yield to the conclusion that it is not possible to influence the outcome than this check examines the possibility for the individual to adjust himself to the outcome of the situation; accepting the outcome;

- *Normative significance evaluation:* This check is to measure how an action is evaluated against the social norms of an individual. Scherer (K. R. Scherer, 2001) uses two checks to produce the normative significance evaluation. The first check or sub-check is **the internal standards checks**, this check evaluates action using self-ideals or the internal moral code. It can be at variance with the group's moral code. The second check is **External standards check**. By contrast to the previous one, this check evaluates to what extent is an action compatible with the norms of a group. Scherer gives an example with the student who fails an exam. The student will appreciate things differently if he applies the norms of success of the university's football team or the norms of a group of junior scientists.

Emotion components and SECs

As we have previously seen Scherer defines five components that make up the emotional process. The modifications of these components are triggered by the SECs output. After each SEC evaluation, a change in different components occurs. Changes in one component can trigger changes in other components. Changes in feelings can lead to reappraisal. Those components are:

- **Cognitive component** its function is to evaluate objects and events.
- **Peripheral efference component** that regulates the system (Physiological).
- **Motivational component** whose task is to prepare and direct actions
- **Motor expression component** that communicates reaction and behavioural intention.
- **Subjective feeling component** (feeling state). The feeling state is the conscious part of the feeling.

The appraisal process is not only sequential. One event can lead to many cycles, sometimes to correct the appraisal values. The appraisal process starts with the relevance detection. This check (Relevance detection) evaluates whether an event deserves more attention and therefore perhaps more processing. The events which are not classified as relevant are ignored. The other checks, after the relevance detections, can start in parallel. However, a particular check cannot be completed without an outcome from the previous check. The order of checks is presented in figure 2-2.

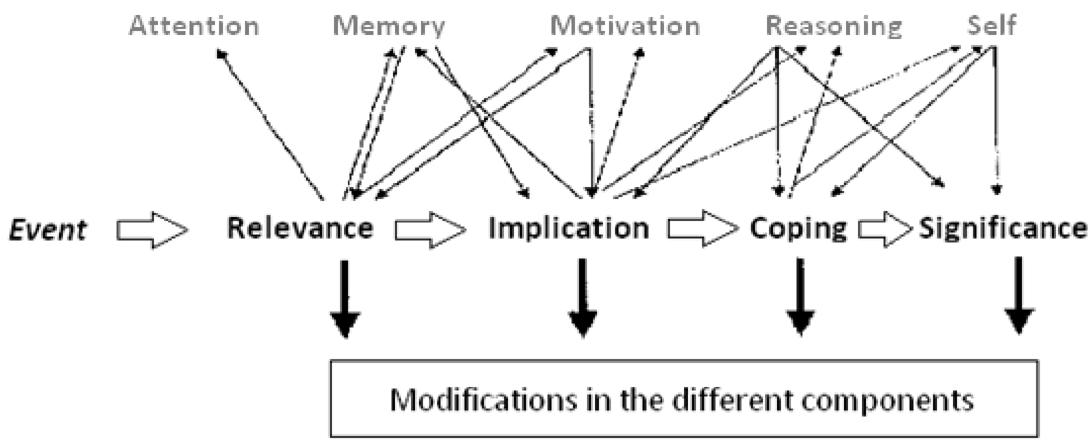

Figure 2-2 Scherer's checks sequence, adapted from (K. R. Scherer, 2001)

It is noted that the number of components involved in the emotional process has not reached a consensus (Moors, 2017). (Clore and Centerbar, 2004) includes all the components in the emotional process. (Frijda, 1986) includes a motivational and an experience component. (Lang, 1994) includes all components except the cognitive component. (Zeelenberg and Pieters, 2006) instead uses all components except the motor component. In many of these instances the same components are used, however, how they are defined can differ (Moors and Scherer, 2013). Some uses a single value to define its state while others use various values for a component thus making patterns for components (Moors and Scherer, 2013). Sherer does not define how these component should look like.

Roseman's theory

The first version of Roseman's theory was presented in 1979 and has been updated several times since. The latest versions (Roseman, 1996, 2013) includes the following factors:

- Unexpectedness, the author makes it different to novelty, unfamiliarity or uncertainty. This factor elicits surprise (the meaning of these terms might be different in other models).

- Situational state, motive consistent/inconsistent. The event is perceived as positive or negative; wanted or unwanted.
- Motivational state, aversive/appetitive. The event might be related to a desire. This desire might be wanting more of something or less of another thing.
- Probability, certain/uncertain.
- Agency, circumstances/other person/self. What or who caused the event with the presence of certainty and uncertainty.
- Control potential, low/high. Whether one can influence the outcome of the event.
- Problem type, instrumental/intrinsic. The event is unwanted because it obstructs the attainment of a goal or because of some of its own characteristics.

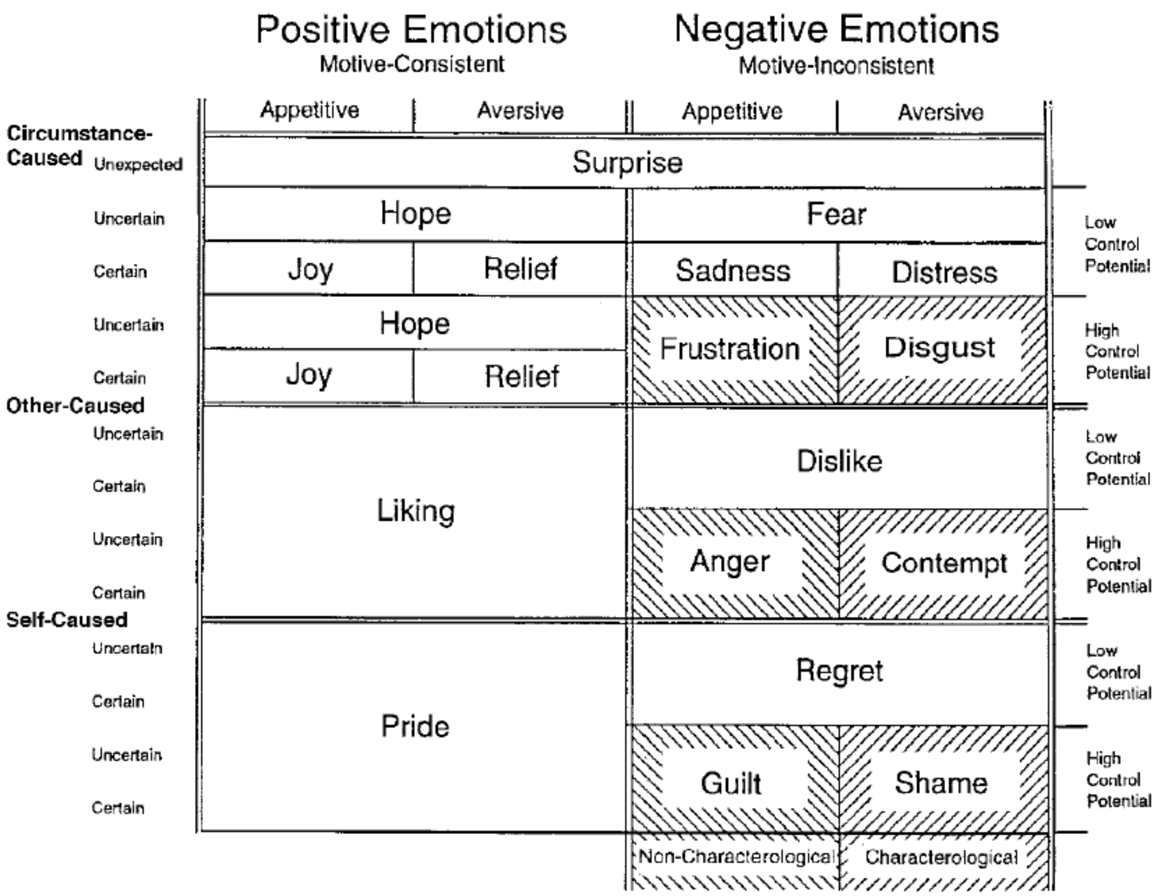

Figure 2-3 Hypothesised structure of the emotion system in Roseman's theory (Roseman, 1996)

Roseman's theory is structural and is comparable to the OCC with a few differences. It can predict emotion using the seven dimensions presented in Figure 2-3 to predict 17 types of emotions. However, it does not predict the development of emotions in time until a form of stability is reached.

Lazarus

Lazarus (Lazarus, 1991) proposes a two-stage cyclical process. The first stage is emotion production and the second stage is coping. After coping, re-appraisal follows and the process continues in a cyclic way. In this model, the cycles of appraisal-coping-reappraisal explain emotions' dynamic. In this model, appraisal occurs by checking if an external event is relevant and then congruent with the goals and concerns of an agent/being. During appraisal, four factors are evaluated, namely:

- Accountability: Who is accountable (to blame) for the negative outcome of the event?
- Expectancy: Is about the possibility of hope that the outcome will improve
- Problem-directed coping potential: is the ability of the agent to cope by changing the world
- Emotion-directed coping potential: coping potential by changing the internal world (Psychologically)

The appraisal process determines the emotional state. In (Smith and Lazarus, 1993) a two-process appraisal was identified; primary appraisal and secondary appraisal. Primary appraisal assesses motivational relevance and the motivational congruence of a given situation. Secondary appraisal evaluates coping related parameters. These parameters include accountability, future expectancy, problem-directed coping potential and emotion-directed coping potential. The combination of primary appraisal and secondary appraisal determines the emotional state.

This appraisal theory has been used by some computational models like EMA (Marsella and Gratch, 2009) and Thespian (Si et al., 2008). The strength of this theory is its ability to include coping in the emotional process, which leads to a dynamic appraisal. Its shortcomings lie in its inability to include the norms; a situation does not interact with the goals of an agent/being but interact with the norms of that agent/being. An example would be an adult hitting a kid. This situation does not interact with the agent/being's goals but it interacts with its norms which may lead to an emotional process.

Discussion

We can notice that appraisal theories are based on parameter evaluation followed by an emotional selection. The parameters more or less change from one model to the other. Some of these models are componential where each component can have its own process such as Scherer's model whereas others are structural like the OCC and Roseman's models. Structural models use focus only on appraisal while componential models make appraisal a central component that triggers the other components' processes. How the changes are triggered in other components remains vague. In the OCC, there are three types of events' elicitors; Object, Person and event (no agent). If an event occurs, it can be perceived as object-based, person-based or impersonal event-based. The order and circumstances in which the three cases appear are not detailed. However, in Scherer's model and if we examine it carefully we can see that the author has considered a particular order. The last stage, where an event has its normative significance checked (e.g. an inacceptable action) is comparable to the standards of the OCC model. In Scherer's model, an agent's goals are always evaluated before the norms. Re-appraisal is still possible. The equivalent of the OCC's attitude towards objects is not made explicit in Scherer's model**.**

Appraisal theories have been criticised for being slow in contrast to emotions that are generally fast. Appraisal protagonists argue that emotions can be fast or slow (K. R. Scherer, 2001). In the model used by EMA (Marsella and Gratch, 2009), appraisal processes are made separate thus making appraisal quick and independent of the task of gathering appraisal variables. Also, Scherer's model, unlike other appraisal models, emotion dynamics can be more emphasized because of the different checks and successive modifications of the different components. At the same time, it can be argued that the model does not predict emotions fast enough because of the volume of information processed.

2.2.2. Dimensional theories

The view of dimensional theories is that emotions should be conceptualized not as discreet but in a continuous space (Marsella et al., 2010). Generally, they use two or three dimensions. Such models include: Russell (Russell, 2003), Mehrabian and Russell, 1974 (Mehrabian and Russell, 1974), Barrett, 2006 (Barrett, 2006, 2014; Barrett and Bliss-Moreau, 2009) In these models a person is in an affective state at any given time (Russell, 2003) and they use terms such as core affect (Russell, 2003) instead of emotion. By contrast to emotions, *affect* is the component involved in feeling part of what is called 'emotion' while emotion from the point of view of appraisal is a process involving several components. Russel states in (Russell, 2003) "The concepts of emotion, fear, anger, and so forth are parts of a folk theory inherited from human shepherding and farming ancestors". Russell even states that the word emotion does not exist in every language (Russell, 1991). Mehrabian and Russell's (Mehrabian and Russell, 1974) model PAD (Pleasure, Arousal and Dominance) is a three dimensional model that maps any affective state to the PAD dimensions. The dimensions, unlike appraisal variables, are a component of the affective state and not necessarily linked to the external environment. In dimensional theories appraisal is viewed as a post explanation of the emotional process, by contrast to appraisal models where appraisal is a central component. The authors view is that emotions are a deliberate process and are not linked to cognition. Russell also points out that Core affect is primitive, universal, and simple and it can exist without being labelled, interpreted, or related to any cause (Russell, 2003). How the change in core affect is performed is not fully understood (Russell, 2003). The parameters that may influence core affects (its volatility and its responsiveness to types of stimuli) according to Russel (Russell, 2003) are: genetic differences, internal causes such as immune system's activity, diurnal rhythms and hormones change. The external causes on the other hand influence cognition, they can be based on real events or on virtual reality. Other causes might also influence the affective state such as drugs and cumulative stress (Russell, 2003). These changes in affective state might be untraceable to most people and they may attempt to find explanations that are not always obvious (Russell, 2003).

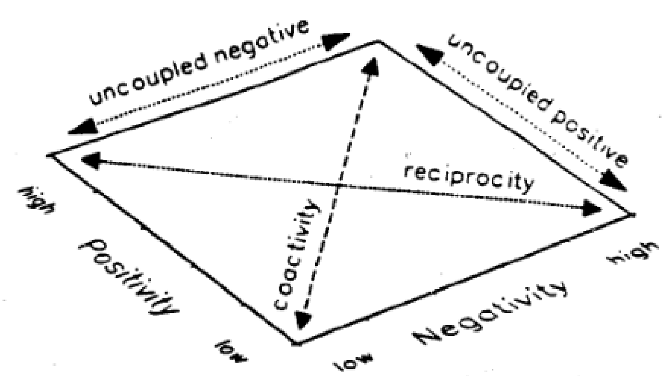

Figure 2-4 (Cacioppo and Berntson, 1994)

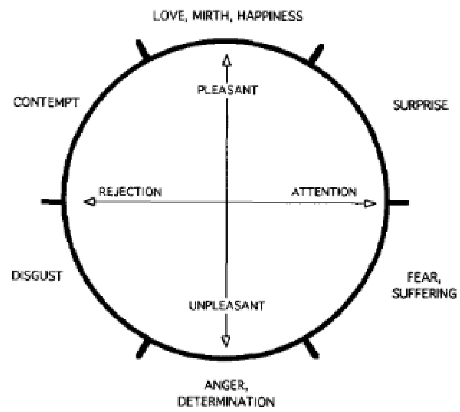

Figure 2-5 (Woodworth and Schlosberg, 1954)

Figure 2-6 (Russell, 1980)

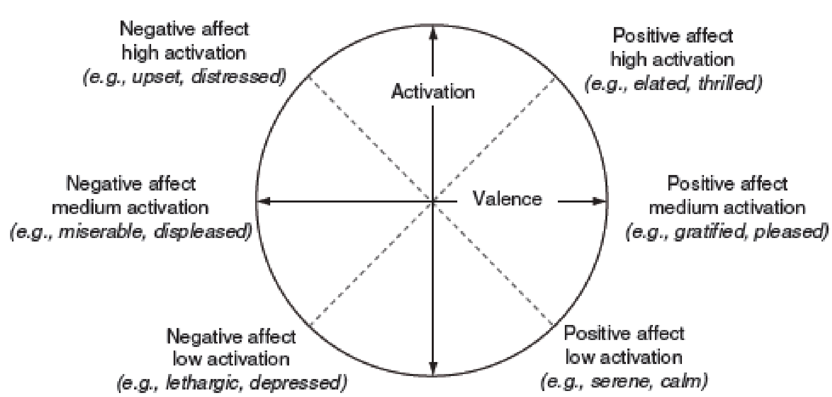

Figure 2-7 Circumplex (Barrett and Bliss-Moreau, 2009)

Figures 2-4, 2-5, 2-6 and 2-7 represent different dimensional representations of affective states. Most dimensional models use a 2D space representation such as the models presented in 2-4, 2-5, 2-6 and 2-7 where the two dimensions are Valence-Pleasure and Arousal-Activation. However, other studies have discussed the limitations of the two dimensional representations using data as in (Schimmack and Grob, 2000) where they use a three-dimensional model PAT (P=pleasure-displeasure, A=awake-sleepiness, T=tension-relaxation). In (Fontaine et al., 2007) a four-dimensional model is presented. The four dimensions accounted to explain and differentiate between the different affective states in (Fontaine et al., 2007) are Evaluation-Pleasantness, Potency-Control, Activation-Arousal and Unpredictability. The Unpredictability dimension was added to reflect the characteristics of Surprise/Novelty (Fontaine et al., 2007).

2.2.3. Moors' hybrid model

(Moors, 2017) introduced a 'reconciliation' model that combines a type of appraisal model and Russel's dimensional model (Russell, 2003) that uses the concept of components where affect is one of them. In this model the strong link between components' interinfluence such the links described in Scherer's model is retained while rejecting the concept of emotional episode. The author then moves from appraisal to information processing thus emphasizing a more general term instead of emotions.

2.2.4. Affect and Emotion

As mentioned above, dimensional theories goal is to define and formalize the *affect* and they do not attempt to describe emotions as such. Emotion is viewed as a phenomenon that is characterised by culture and accumulated knowledge of people (Barrett, 2014). Affect has components in a two, a three or a four-dimensional space. When an event occurs, a process triggers a modification in the affect; changing the values of one or more of the dimensions. The process itself is not part of the *affect*. The affect is also present in the case where no event has occurred. In the other hand, appraisal theories model the emotional process and an event is always required to trigger an emotional episode. That event, is then processed through cognition which will then trigger modifications on the feelings. One of the differences between appraisal and dimensional models is that if cognition is not involved then the phenomenon is not considered as an emotional episode. By contrast, dimensional models encompass all the modifications in the affective state (affect). For example, let's take the drug taking case. Drugs modify the affective component of the mind. However, appraisal theorists do not consider it as an emotion and classify it as a different phenomenon while dimensional theorists consider it as part of the phenomena that modify the affect. In other words, dimensional models include every phenomenon that modifies the affect while appraisal models study only those involving cognition.

Let's take an example where a person is feeling 'happy'. Is it considered as emotion from the point of view of appraisal? By providing only the label 'happy' is not enough to know. The question is what made that person happy? Was it an event that went through cognition or through a different component? If what made the person happy was some hormone alteration then this is not considered as an emotion as there is no cognition involved. If cognition was what triggered 'happiness', such as winning a national prize, then the process is considered as an emotional episode. From the point of view of dimensional theories feeling 'happy' is a change in *affect* and it is considered as an affective phenomenon regardless of the what triggered it.

2.2.5. Discussion: dimensional theories or appraisal theories?

By looking at the two families we can conclude that they are quite different. First, the appraisal family proposes that cognition is what triggers emotion. They model it as a central component. Dimensional theorists propose that cognition is not necessarily involved in emotion. They give examples like taking drugs that changes the affective state without any reasonable involvement of cognition. However, appraisal theorists do not consider changes in affective states without any involvement of cognition as emotion (K. R. Scherer, 2001). By contrast, dimensional theorists propose to model *affect* instead of *emotion* arguing that a being is always in an affective state. Furthermore, they see cognition as a mere explanation of the variation of the affective state and comes after it (Russell, 2003). This last point is what we believe to be the main discrepancy between the appraisal family and the dimensional family. Other discrepancies such as dimensional representations can be reconciled by used appraisal models that do not necessarily work with discreet emotions such as Scherer's model. Some theories argue that the affective process is itself a form of cognition (Duncan and Barrett, 2007) . An analogy would be that changes in affective states that do not involve cognition are like a hardware coded emotional system whereas the involvement of cognition in emotion is like a software process. In the model we propose, the first stage will not involve cognition but rather an affective evaluation. The following stages will use cognition and can correct the cognition-free previous affect generation.

From a computational perspective, the vast majority are using appraisal theories as their base models (Marsella et al., 2010).Not because they are more accurate, the main reason is that appraisal theories show a link between cognition and emotion and this renders them more simulation friendly. Dimensional theories rarely give an exhaustive picture of a whole scenario ranging from stimulus to change in affects. Also, most models that use dimensional theories tend to combine them with an appraisal phase (Marsella et al., 2010). Such models include WASABI (Becker-Asano and Wachsmuth, 2009, 2008) and ALMA (Gebhard, 2005) which uses the OCC model during an appraisal phase.

2.3. Are emotions discreet or dimensional?

As mentioned above, dimensional theories state that emotions are continuous in a 2D or 3D space. On the other hand, most appraisal theories use discreet labels for emotions where each label emotion has an intensity in the form of a decimal number, generally ranging from 0 to 1. Some theories have defines sets of basic emotions such as (Clore and Ortony, 2000; Ekman, 1999; Keltner et al., 2016) where these basic emotions can mix to form complex ones. Basic emotions are not to be confused with dimensions of affect, they are indeed discreet like the ones used in OCC. In appraisal theories, evaluation is a central component of any emotional episode but whether emotions are discreet or not has not reached a consensus even among appraisal advocates. Different empirical studies have backed both discreet and dimensional representations. However, the majority of these empirical studies have backed the dimensional representation: the weaknesses of the dimensional representations have been less recognised than the weaknesses of the discreet representations. Such studies include (Vytal and Hamann, 2010) and (Sylvia D Kreibig, 2010) who are in favour of discreet emotions. Other studies examined the link between appraisal values and the observations of certain types emotions creating an appraisal-emotion mapping such as (Cherek et al., 2003; Sylvia D. Kreibig, 2010; Lewis et al., 1990; Nummenmaa and Niemi, 2004; Smith and Kirby, 2009; C. Smith and Lazarus, 1990; Wiech et al., 2006). While (Mauss and Robinson, 2009), (Murphy et al., 2003) and (Watson and Clark, 1994) backed dimensional representations. Also, studies that suggested weak to non-existence evidences of primary emotions include (Cacioppo et al., 2000; Gendron et al., 2014; Larsen, J. T., Berntson, G. G., Poehlmann, K. M., Ito, T. A., &

Cacioppo, 2008; Nelson and Russell, 2013; Quigley and Barrett, 2014) while (Evers et al., 2014) and (Hollenstein and Lanteigne, 2014) put forward some discordance in this formalism (primary emotions).

We can see that the answer to the question of whether emotions are discreet or dimensional has not reached a consensus. However, empirical studies from the literature lean towards dimensional representations especially among the more recent studies where affect is a component thus in the model that is proposed on this thesis this kind of representation is used (dimensional).

2.4. Influence of *affect/emotion* on cognition

It is known that different affective states influence cognition. Previous studies have established that positive affective states broaden cognition and negative affective states narrow cognition. Such studies include (Easterbrook, 1959) and (Fredrickson, 2001). More recent studies postulated a different assertion. (Harmon-Jones and Gable, 2008) theorized that cognition broadening/narrowing depends on the intensity of the affective state rather than its direction (positive/negative). Thus, they postulated that affective states that have low intensity whether positive or negative broaden cognition while intense affective states narrow cognition. The reason for this is that low intensity affective states broaden cognition to look for new opportunities whereas more intense affective states narrow cognition to change the current state (Harmon-Jones et al., 2012).

A study by (Duncan and Barrett, 2007) suggested that emotion and cognition cannot be dissociated. In the same study, it is stated that *affect* appears to be necessary for normal conscious experience, language fluency, and memory. Before that it was considered that emotion and cognition are two separate processes (Lawson-Tancred, 1991). However, a neuroimaging literature review states that no brain areas can be designated specifically as "cognitive" or "affective" (Duncan and Barrett, 2007). Furthermore, what traditionally was referred to as "affective" brain areas (e.g., the amygdala and brainstem) are involved in sensory processing and consciousness in a way that cannot be dissociated from most of the definitions of "cognition".

The role of *core affects* is mainly to translate the acquired information from the external world into a meaningful representation to the internal processes (Duncan and Barrett, 2007). In the same research, it is also stated that the difference between *core affect* and *cognition* is not as traditionally understood and many phenomena that appear cognitive use *core affect*. However, because the experience that is labelled 'cognitive' does not show high affective states, *core affect* is shadowed while it participates in giving confidence in to the understanding of situations (Duncan and Barrett, 2007).

2.5. Attention theories

Attending to a situation requires allocating some resources to it. The previously discussed theories use cognition in appraising situations. Other theories add memory. In Scherer's theory relevance detection requires attention. Workload also requires attention and this resource can be divided among some tasks. Emotions will compete over attention.

In Scherer's model (Scherer, 2000) attention is required at the earliest stage of the emotional process. Attention is used to check whether a stimulus is relevant or not and then requires further processing. Directed attention allows us to attend to a relevant stimulus and by studying it and modelling it; it will be possible to create a more realistic artificial behaviour. As an example, you are talking on the phone to your boss and you received a promotion. At the same time, your kid dropped your cup of coffee. These two events will probably trigger two different emotions if they happened at two different moments but if they are happening at the same time the affective outcome might be different. In appraisal theories, this outcome will probably depend on the different stages and variables of the appraisal processes. The resources available for the emotional process will undoubtedly affect how a stimulus is appraised as those resources are limited and reasoning about two different concepts at the same time is not as easy as reasoning about only one per moment. When the available resources are not sufficient to deal with two tasks at the same time a mechanism is used to allocate more resources to a competing stimulus over another, details are given in (Knudsen, 2007). Another important aspect of attention in emotion is how attention is directed in an environment and how does that influence the affective state.

In most computational emotional models, components work sequentially, like a workflow. Generally, the process starts with attention, then an emotion is computed and finally an action is triggered. However, theories like Wicken's (Wickens, 2005) state that humans' mind can execute different tasks at the same time depending on the available resources. Thus, using such theories will allow us to simulate emotions related to events occurring at the same time according to the available resources during the appraisal processes. Those events will be appraised differently when occurring at the same time or when an organism is affecting some resources to other tasks. In this case the different modules will be able to work in parallel rather than in a sequential way.

Attention is directed either in top-down fashion or a bottom-up fashion (Buschman and Miller, 2007). A top-down approach is used when attention is directed by the goals and concerns or task demand. A bottom-up approach is used when an external stimulus takes the focus; salient stimuli, like hearing a loud sound will catch our attention. In our model, most resources are used for a top-down approach trying to fulfil the goal and concerns. Bottom-up will be also used to manage external events and some resources will be allocated to that task. A resources management paradigm will be used.

Early attention theories depict it as a single pool of resources like in (Kahneman, 1973) where it can be shared among different tasks. In those theories, the resources are similar and each task requires a certain amount of resources from that pool. More recent theories suggest that humans have multiple types of resources and allocate those resources according to the attended tasks. In other words, a person can attend successfully to two tasks at the same time if those two tasks use different types of resources or if they require the same resource and the amount required by each task can be satisfied at the same time. One of those theories is Wicken's, which is described in detail in (Wickens, 2005).

2.5.1. Multiple resources models

An organism can attend to different tasks at the same time provided that they do not interfere with each other. To simulate emotions accurately we propose to take into account how the body and mind handle many different tasks at the same time and how do we appraise situations in such cases. To attend to an event, we need to allocate certain resources to appraise that event as suggested by multiple resources theories. What happens if the needed resources are not available? How do we carry simulation in such cases? For this we will use a theory dealing with multiple resources and performance. Wicken's theory (Wickens, 2005) is one of the theories dealing with allocating multiple resources and predicting performance.

Wicken's theory (Wickens, 2005) considers that there are four dichotomous dimensions accounting for variance in time-sharing performance. Each dimension is divided into two levels. If two tasks require the same level they are more likely to interfere with each other than two tasks requiring two different levels. The four dimensions are processing stages, perceptual modalities, visual channels, and processing codes. According to Wicken, in processing stages the resources used by perception and cognition appear to be the same. The aspect that will be interesting in modelling human's behaviour is that Wicken states that the selection and execution of actions use different resources than perception and cognition. This suggests that perception/cognition and responses can be executed in parallel. Cognition and perception do share resources like working memory (Wickens, 2005) and therefore two simultaneous tasks, one involving cognition and the other involving perception, will interfere with each other.

The perceptual modalities dimension is divided into visual and auditory. Wicken states that dividing attention between the eye and the ear can be done better than dividing the attention between the tasks requiring the same modality at the same time. In (Wickens, 2005) it is stated that time sharing across modalities is better than time sharing intra-modalities. The reasons according to (Wickens, 2005) are that two intra-modalities channels may need masking if they are too close to focus on just one of them and they need scanning if they are far from each other. To model this, it is imperative to create a measurement method to compute how much two perceptual tasks are interfering with each other.

The visual channels dimension is divided into focal vision and ambient vision. These two modalities use separate resources (Wickens, 2005). The visual channels dimension is used only when perception is involved hence the nested representation in the figure 2-8. We will not use this dimension in our model for the sake of simplicity.

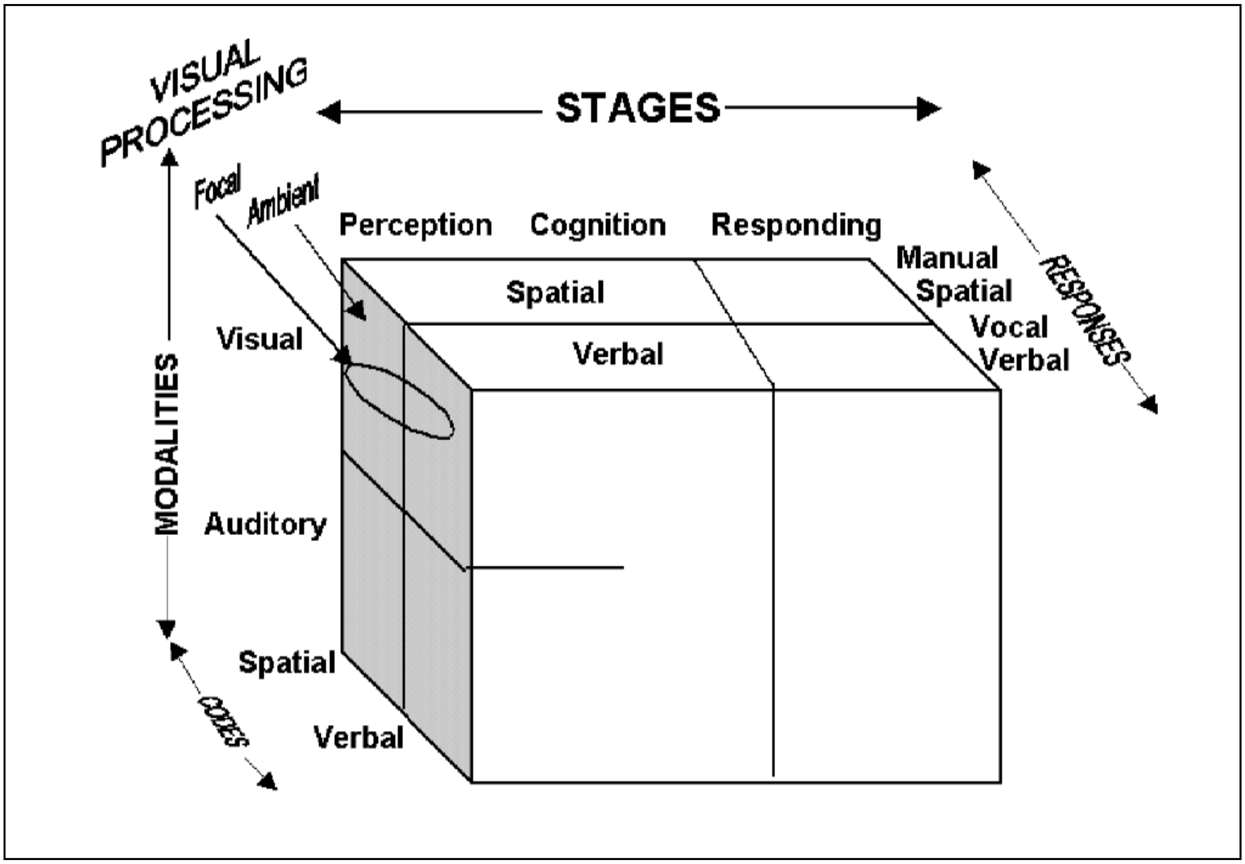

Figure 2-8 Three dimensional representation of the multiple resources model (Wickens, 2002)

Codes processing according to (Wickens, 2002) is a dimension that defines the distinction between analogue/spatial and categorical/symbolic processes. Spatial tasks involve different resources than verbal task, whether during perception, cognition or responses.

The figure 2-8 illustrates a three-dimensional representation of the multiple resources model. In this figure perception and cognition use the same resources (verbal or spatial). Responding on the other hand uses a different set of resources. The modalities dimension is a nested dimension within perception hence the distinction between visual modalities and auditory modalities only during the perception stage. The codes dimension suggests that spatial and verbal activities use different resources. The small cubes denote that spatial representation during perception and cognition shares similar resources and those resources will not be used elsewhere. Every other cube has a similar representation towards its coordinates. Table 1 represents the resources used in the three-dimensional representation without taking into account the visual channels dimension (Focal/Ambient).

Table 2-1 Resources needed according the three-dimensional representation

Representations	Resources
Perception, Spatial, Visual	Set 1, **Set 5**
Perception, Spatial, Auditory	Set 2, **Set 7**
Perception, Verbal, Visual	Set 3, **Set 6**
Perception, Verbal, Auditory	Set 4, **Set 8**
Cognition, Spatial	**Set 5, Set 7**
Cognition, Verbal	**Set 6, Set 8**
Manual/Spatial Response	Set 9
Vocal/Verbal Response	Set 10

In Table 2-1, the resources used during a cognition stage using spatial codes are shared with a perception stage using spatial codes whether the auditory or visual modalities are used during that perception stage. Because visual and auditory modalities do not appear to share resources the shared resources between (cognition, spatial) with (Perception, Spatial, Visual) and the shared resources between (cognition, spatial) and (Perception, Spatial, Auditory) are different, denoted respectively Set5 and Set7. The same rule applies to the shared resources of (Cognition, Verbal) and (Perception, Verbal, Visual) and the shared resources between (Cognition, Verbal) and (Perception, Verbal, Auditory).

Although responses and perception/cognition are not sharing resources, in (Wickens, 2002) a computational multiple resources model is presented by the author where he describes all the dimensions sharing a minimum of resources. From this computational model, it can be understood that although the author says that two channels appear not to share any resources this does not mean that a minimum of resources is not shared but rather interfere less with each other. Another aspect worth mentioning is that in addition to a minimum amount of resources shared among the different channels, other resources are shared between each added dimension of overlapping resources. For example (Cognition, Spatial) and (Manual, Spatial) will share another amount of resources although they belong to cognition and responses stages respectively.

2.6. Summary

Emotion research has not reached a consensus yet. This make it difficult for simulating them due to the deterministic nature of simulation models. Families of theories have emerged. The most notable ones are the dimensional family and the appraisal family. Theories within the same family have many similarities but also some divergences. Still, some aspects of different families can be combined together. Meaning that the divergence is not at every aspect. Dimensional theories are at a higher abstraction level than appraisal theories making them difficult to implement. By contrast, appraisal theories show the link between cognition and emotion making them appealing for simulation. However, the abstraction level of both families does not allow a straightforward implementation and a task of making the models concrete is necessary.

Appraisal families generally use discreet emotion (happy, sad…) as a representation. However, studies backing continuous representations instead of discreet ones are more prevalent. However, discreet emotions are not central to the appraisal families and using continuous dimensional representations does not contradict the formalism of these theories.

Dimensional theories model what is called affect instead of emotions which by contrast is a component. Emotions in the other hand in the appraisal theories are processes that may involve different components.

Attention theories which are linked to any process involving the mind have gone through many development stages. Currently, the multiple resources model is one of the prominent models of this field. In the upcoming chapters, the link between using attention and emotion is shown.

3 Literature Review: A Computational Perspective

3.1. Introduction

Theoretical models of emotions address the processes or the structure underlying emotions. Those psychological models can omit to give details about the whole emotional process and tend to focus on some parts with a varied level of concreteness. Computational models on the other hand need a full concrete formalism of what they are trying to model. By doing so, they are helping psychological models to address assumptions, which the authors might not have been aware of while modelling. Many aspects of the external and internal worlds are modelled when creating a computational model such as a person-environment relationship, appraisal computations, perception, attention, memory, planning, and coping responses (Marsella and Gratch, 2009). Furthermore, the computational model is used in simulation. It can be explored, modified and tweaked. It generates predictions that can be contrasted with real human subjects (Marsella and Gratch, 2009). In (Marsella and Gratch, 2009) it is assumed that computer simulation may be the only approach to evaluate the consequences of the psychological appraisal theories in a dynamic mode.

Several computational models can be found in the literature. However, their goals are different and they rarely build on top of other computational models. Their design can be quite different, influenced by what they want to achieve and the modeler's design. In the following sections, we will review some of the influencing computational models.

3.2. FLAME (Fuzzy Logic AdaptiveModel of Emotions)

FLAME by (El-Nasr et al., 2000) is an adaptive computational model of emotions. It is based on the OCC (Collins et al., 1988) model and Roseman's model (Roseman et al., 1990) both belonging to the appraisal family. The model uses fuzzy logic to represent the mapping of events and observations with the emotional states. Three components are included in the model, namely an emotional component, a learning component and a behavioural component.

The learning component is what mainly distinguishes this model from the others. The learning component allows an adaptation of emotions and behaviour over time and experience. FLAME uses a variety of types of adaptation. One of them is object adaptation where an object is associated with an emotion if the object is frequently observed along with it. Another type is the association of an event with an outcome. FLAME also builds dynamically a user model by observing sequences of events to allow an assessment of the likelihood of an event to occur. The number of events in a sequence is limited to three. These learning techniques create a dynamic representation of the knowledge of the agent or a pet in the case of FLAME. Figure 3-1 represents the modes of learning used in FLAME.

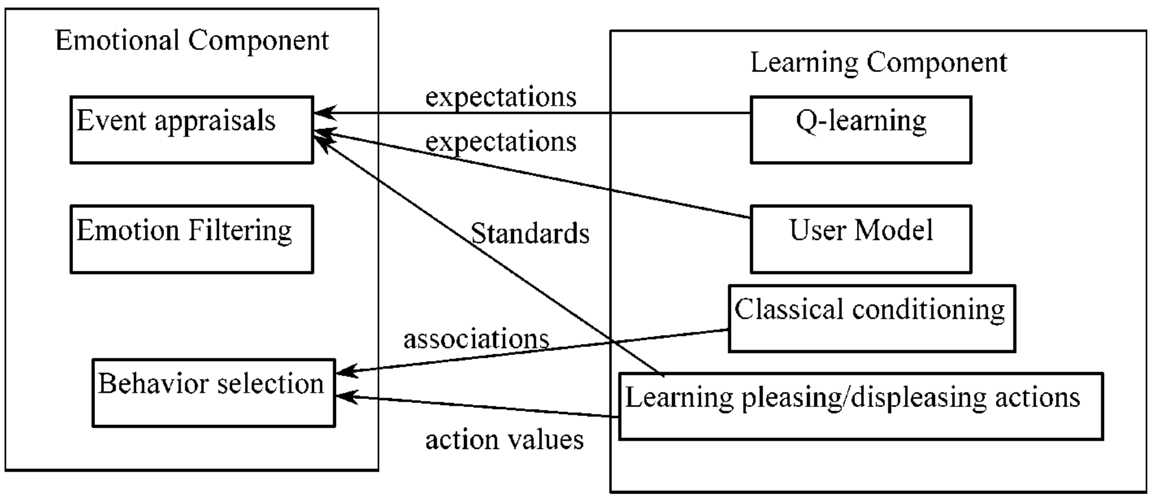

Figure 3-1 Modes of learning and their interactions with the emotional component (El-Nasr et al., 2000)

FLAME uses also filtering to produce a coherent emotional state. When two opposite emotions are triggered at the same time a filtering is applied. For that, FLAME uses an inhibition paradigm whereby emotions may inhibit motivational states (like hunger and thirst) and vice versa depending on their intensities. Opposite emotions will inhibit each other; the more intense emotion inhibits the opposite one. Another filtering technique used is through mood. In FLAME mood is calculated by the intensity of positive and negative emotions over the last n time periods. Mood will influence filtering by favouring the closer emotion to the actual mood. For example, if an agent is in a positive mood then a positive emotion will be favoured over a negative one.

Although FLAME is a decent contribution in this area, it is designed to simulate pet's emotions and does not include some influencing factors such as personality that is believed to influence emotions and behaviour. The authors of FLAME acknowledge that including personality in the model is difficult even though it is important (El-Nasr et al., 2000). FLAME also has a sequential process, as shown in figure 3-2, and cannot allow a parallel execution in its current form. Dividing attention and executing tasks in parallel could enhance the believability of the model since theories, such as the multiple resources theory(Wickens, 2002), have been formalized to study how successfully can an individual execute two tasks at the same time..

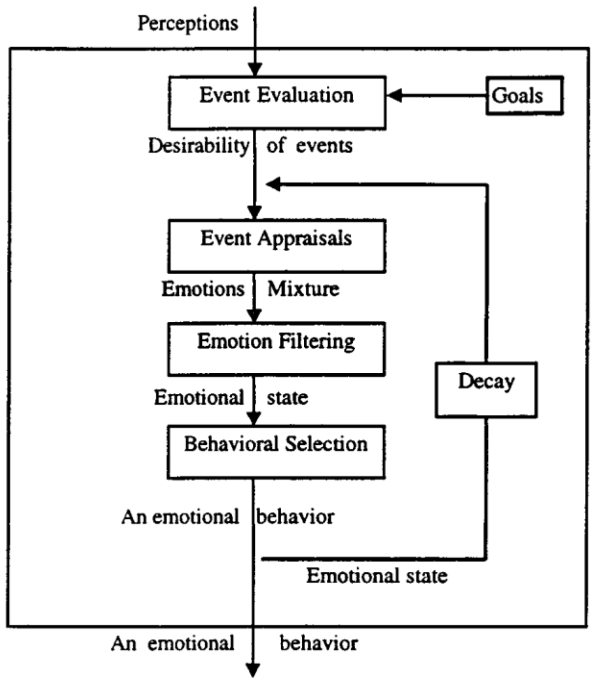

Figure 3-2 Emotional process component(El-Nasr et al., 2000)

3.3. WASABI

WASABI (Becker-Asano and Wachsmuth, 2009) is considered by (Lin et al., 2012) as one of the most general models to believably simulate affective agents. WASABI uses two types of emotions; primary emotions and secondary emotions. The primary emotions are similar to Damasio's model (Damasio, 1999) where no elaborate cognitive functions are required. The secondary emotions in WASABI depend on the cognitive ability of the agent and are related to a social context. They might be learnt from the memories associated with the primary emotions. Primary emotions are inborn affective states that arise during a situation involving for example danger (eat or be eaten). Those emotions are fast and involve fast reactive responses. WASABI uses nine types of primary emotions and three types of secondary ones.

Emotions are coded in a PAD; a three-dimensional space (Pleasantness, Arousal and Dominance). The affective state is also coded in a PAD. The secondary emotions are triggered via a more elaborate cognition. Those are the emotions in the group prospect based emotions in the OCC model (Collins et al., 1988) and are Hope, Fear Confirmed and Relived. Figure 3-3 illustrates the architecture of WASABI. The author states that only some aspects of secondary emotions are mapped into a PAD space.

In WASABI mood is represented as bipolar where only a positive mood or negative one are possible. Mood is defined before a PAD space representation and can influence emotions. Indeed, WASABI uses mood to ensure mood-congruency of emotion. A negative mood gives an advantage to negative emotions and a positive mood gives advantage to positive emotions. Mood's variation is much less fast than the variation of the emotional state.

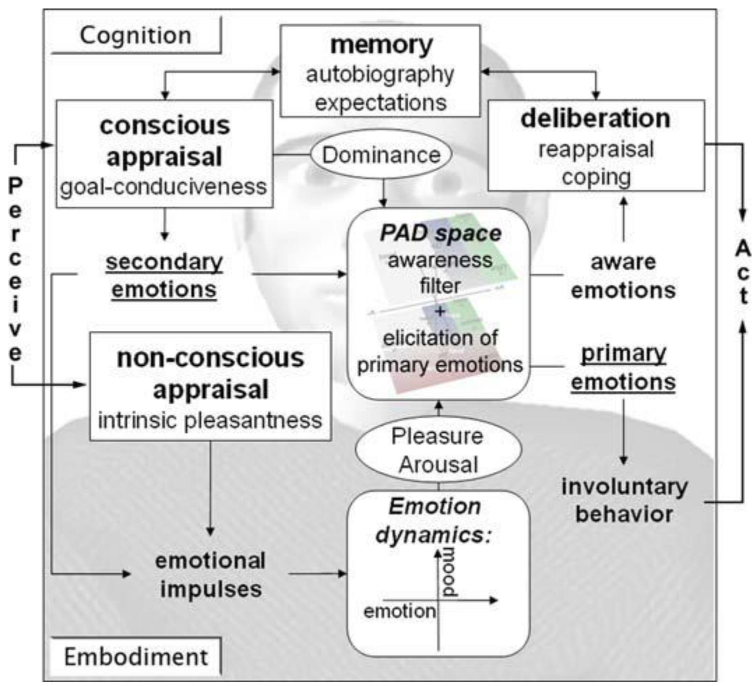

Figure 3-3 The conceptual distinction of cognition and embodiment in the WASABI architecture (Becker-Asano and Wachsmuth, 2009)

3.4. Marinier's model

Marinier and Lairds's model (Marinier et al., 2007) uses Scherer's theory. They use 11 variables out of the 16 in Scherer's variables/dimensions. The different variables/dimensions used are quantified using different scales. Some variables use a [0,1] scale, others use [-1,1] scale and some use discrete values. In this model mood and feelings are included and are coded using the same 11 variables used for emotions. Mood is influenced by emotions and a constant is defined as a mood's variation speed. The values of mood variables dragged to the values of emotions variables. Similarly, when no emotion is observed the values of mood variables are dragged towards their original value.

Emotions and mood are combined to create a coherent feeling. An intensity of the feelings is calculated based on the different variables. For that a formula is used where the variables of the formula are the 11 original ones of feeling. This model does not label emotions but rather describe them in frames containing the values of the different variables/dimension. Figure 3-4 illustrates an interaction between mood, emotion and feelings in this model.

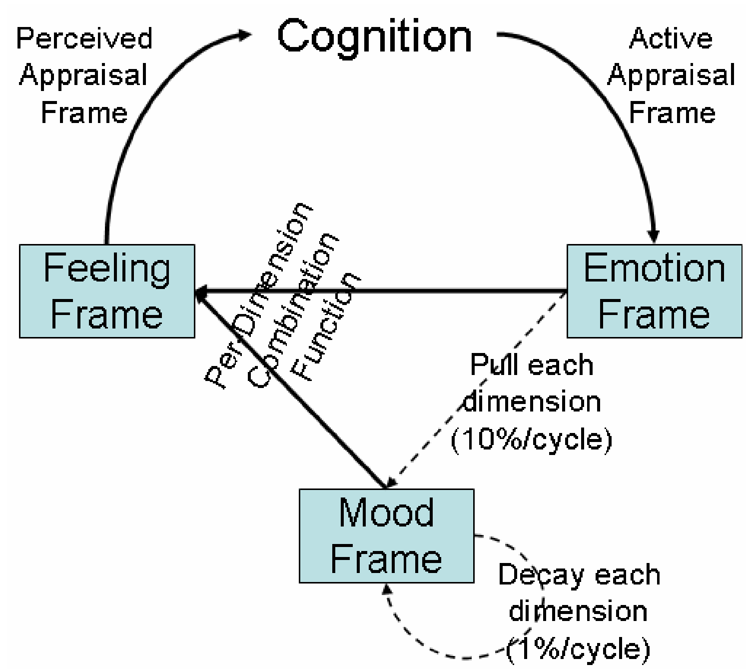

Figure 3-4 Influence of Mood and emotion on Feeling (Marinier et al., 2007)

3.5. Emile

Emile in (Gratch, 2000) is a computational model of emotions that uses the OCC model. Unlike other models where we need to evaluate manually every situation in terms of goal congruence, Emile builds this knowledge automatically through planning. Emile builds plans and by using probabilities and desirability of goals generates the emotional meaning of all of the other situations.

3.6. EMA (EMotion and Adaptation)

The authors of EMA (Marsella and Gratch, 2009) view that appraisal and inference are two different stages operating over the same mental representation. The speed of the whole process depends on the construction of the representation, which might be slow. EMA uses Smith and Lazarus's theory (C. A. Smith and Lazarus, 1990) which belongs to the appraisal family. They integrate appraisal and coping in a planning scenario. Appraisal allows a selection of paths of actions that the agent determines. This representation allows a powerful dynamics of action selection and appraisal sequences. It requires the modelling of basic operations and states appraisal for plans generation.

They use a BDI (**B**elief-**D**esire-**I**ntention) architecture to model the agent's reasoning. Concept such as likelihood and desirability of situations are used. From this an emotion is generated and is aggregated with the current emotional state to produce a mood. This strategy allowed them to produce a domain independent framework for conversational agents through the identification of the basic elements of an emotion enabled reasoning and coping system. This work is closely related to (Gratch, 1999) and (Gratch, 2000) where the first attempts of using planning in conjunction with appraisal has been made. Figure 3-5 illustrates the theoretical assumptions concerning the relationship between appraisal, emotion, coping and cognition, and the sources of dynamics that results in EMA.

This contribution distinguishes this model greatly from the existing ones. Indeed, in most existing models, domain specific knowledge is required to appraise an event. Using automatic planning can create that specific knowledge in different situations and domains, provided that situations definitions and evaluations are made and atomic operations of planning are elaborated. This contribution is the main that allowed EMA to be considered as a 'general framework'.

Despite EMA's important contribution, some limitations are identified. EMA's architecture is sequential in terms of appraisal. It does not allow appraisal at the same time of coping and thus changing an action in the middle of its course if there is a change in appraisal. Another limitation is the stochastic elements of appraisal. Appraisal can be done through many points of views (eg. the event's actor is perceived as event, as an agent or perceived as an object as mentioned in the OCC) where a situation can generate many variations of the emotional state.

This is because EMA relies on Smith's and Lazarus's theory where appraisal is a one-phase operation. Another critique given by the authors of EMA is its inability to predict empathetic emotions. However, this does not interfere with the general architecture in case the authors implement it.

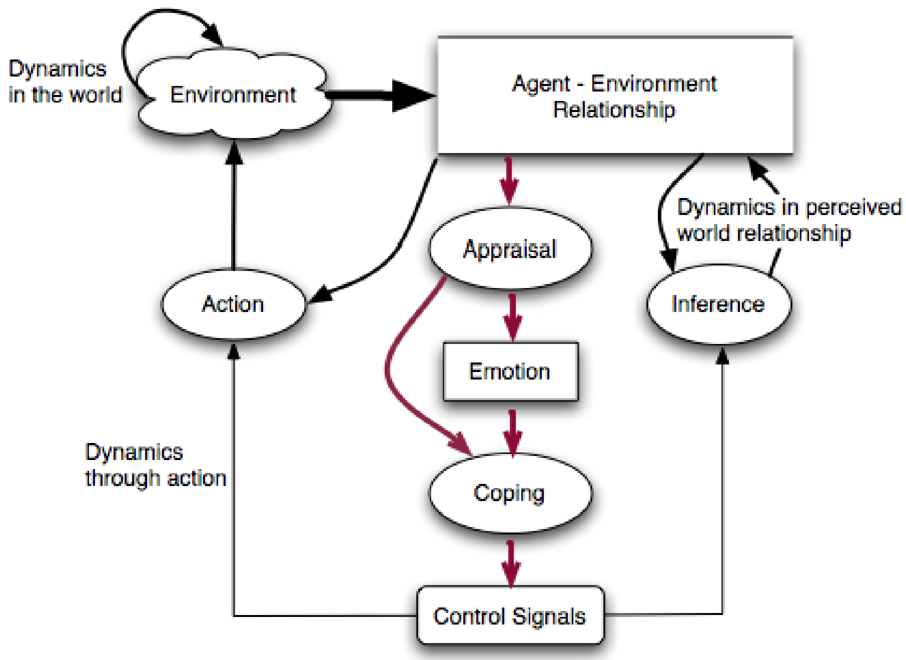

Figure 3-5 Theoretical assumptions concerning the relationship between appraisal, emotion, coping and cognition in EMA (Marsella and Gratch, 2009)

3.7. Other Models

Several models are present in the literature where the basics of the emotional theories are similar to the models presented above with the OCC being of the most used psychological theory. While the models' basics remain more or less similar, contributions can be observed on the way the computation of emotional states and their intensities are carried out. (Schneider and Adamy, 2014) have used fuzzy logic to link the external world to the affective state of the agent they simulated. The variables used that are inferred from the external world are rather simulation dependent and cannot be generalized to other cases. (Ojha and Williams, 2016) uses a multithreading paradigm to process several appraisals at the same time. The authors suggest that the human mind is capable of multitasking and unlike Scherer's sequential model, a multithreading paradigm is more adapted. However, in Scherer's model appraisals occurs simultaneously, the conclusion of each appraisal stage occurs only after the previous one concludes. Again, while multiprocessing can be true in some cases, in other cases a sequential processing is required, like evaluating the outcome of an event for the self and then later its outcome for others.

3.8. Discussion

Most computational models use appraisal theories (Marsella et al., 2010). Very few use dimensional theories but still rely on cognition like WASABI. We can also observe that the contributions follow different directions where some build on top of other contributions but many still take different directions. These different contributions can be quite challenging to harmonise. In term of contributions to the field, EMA's domain independent framework is one of the most important. The authors use a simple emotional model yet it allows a great expressiveness. One of the shortcomings admitted by the authors is the large number of rules generated. Marinier's model uses a large number of dimensions following Scherer's model but formalizing mood in the dimensions of appraisal has no theoretical background. FLAME's emotional conditioning method is a fine contribution in modelling the evolution of appraisal over time. Furthermore, it uses mood to build a bias towards positive or negative emotions. WASABI's uses an interesting approach in differentiating between primary and secondary emotions then mapping emotions in a PAD space. Thus, it enables a plausible interaction between mood and emotions.

We can observe that most computational models opted for discreet emotions. However, from the previous chapter we have seen that the number of theoretical studies backing this approach is limited compared to the dimensional representation. We can also observe that sometimes authors use assumptions without theoretical backgrounds in certain situations. This is understandable due to the nature of the work and for the sake of simplicity. Another reason is the absence of backed theories in certain cases.

In term of expressiveness power, the previous models have some limitations. As an example, parallel processing of all the sub-systems involved in the emotional process has not been fully addressed except while using mood to make a bias towards positive or negative emotions as done in FLAME. However, updating appraisal variables while coping has not been investigated. Indeed, coping and cognitive functions does not share a good deal of resources and thus can be executed in parallel (Wickens, 2002). Also, the different perceptions of one event and the order of appraisal if there is such an order may take place as mentioned in the OCC (Collins et al., 1988).

3.9. Conclusion

An effective computational emotional model is backed by a psychological theoretical model. Several psychological models have been used for the purpose of simulation. Thus, psychological theories present similarities and also divergences. They have different expressiveness power and unsurprisingly, the effectiveness of the computational model is dependent on the used psychological theories. The psychological theory used is not the only predictor of the expressiveness power of the implemented model. The way the psychological theory is implemented also accounts for this expressiveness power as degree of freedom is considerably large for the designer.

Throughout the literature, contributions have been observed at how a combination of psychological theories are used to achieve a certain expressiveness power such as in WASABI enabling the simulation of characters with different ages group while other contribution has been observed at level of the algorithm/techniques used in appraising the external events and future events such as in FLAME and EMA. This heterogeneity in contributions makes the different models hard to contrast and evaluate and can make the field less mature. One of the omitted area of contribution is how a single event effect can evolve over time triggering different variations in the affective state. In the next chapter, a contribution in this area is presented.

4 A Dynamic Emotional System

4.1. Introduction

Emotion simulation is a field of work that lies between Artificial Intelligence and Psychology. Its goal is to attempt to reproduce the same interactions that happen in human organisms during an emotional episode. This kind of simulation has many potential applications. It can enable virtual characters to go beyond preprogramed synthetic emotions towards dynamically generated emotions for more realism. This can be used in virtual learning environment and games. It can also allow testing psychological theories where evaluation is a sensitive part. Another potential area of application is robotics.

To create an implementable model an overview of the systems involved in the emotional process should be addressed. For this, studying different models explaining the emotion phenomenon is required. The next step is to convert these models into concrete models by exploring the abstract parts using assumptions and sometimes other theories.

We can find different models in the literature. Some are derived from psychology, others from neuroscience and physiology. In our study, we focus mainly on psychological models since they provide a link between the external world and the mind.

One of the obstacles we face when simulating emotions is selecting an appropriate model. Models can differ and sometimes contradict each other. However, looking at them from different perspectives can allow reconciliation between few models and allow a combination of models to achieve the required simulation.

4.2. Psychological families of emotions

We need to look at emotional psychological theories before modelling a computational emotional system since they constitute the basis of such a system. Previously, we have reviewed models belonging to two families: appraisal and dimensional families. The model that is introduced in the section below is a combination of models belonging to these two families. Although traditionally appraisal families and dimension families have been considered to contradict each other regarding the role of appraisal and cognition in the emotional process. Appraisal families as seen previously, tend to model the emotions as a process where different components contribute to this process. Dimensional theories on the other hand focus on modelling the *affect* or *affective states* which could be viewed more of an information representation rather than a process. Its modification is rather a black box where not many things are known. The proposed model combines aspects of both families in order to create a more general model in term of expressiveness yet keeping it as faithful as possible to reality.

4.3. A Dynamic emotional model

In the previous models, the possibility of parallelism between the different components of the body/mind is not considered. Human beings are able to multitask. For example, reading while drinking a coffee. Parallelism allows modifying coping strategies in the middle of their execution as appraisal changes. For example, a young person bumps into you causing some pain, a response would be to push him back but as soon as you realise he is so young you can cancel your action. Not every psychological model allows such a scenario to be modelled. In the models we reviewed, only Scherer's model is parallelism-enabled where appraisal can continue while executing an action. Lazarus's model (Lazarus, 1991) includes coping after appraisal. However, due to its sequential structure whereby appraisal is followed by coping then reappraisal, parallelism cannot be supported. In the larger scope of this work, parallelism of tasks is considered. However, in this chapter we will focus mainly on the implementation of appraisal.

In the OCC model (see chapter 2 section 2.1) when an event occurs, it can be perceived as an agentless event, an action (with an agent) or as an object (Collins et al., 1988). The type of the generated emotions depends on this perception. Sometimes, these perceptions occur in different orders, sometimes only one of them occurs. The OCC model does not tell how this sequence occurs. If a modeller would like to take this sequence into consideration, then assumptions have to be made in case other theories allowing its formalization are not present. In Scherer's model, we can observe a perceptive order. In the four stages of appraisal (Relevance detection, Implications, Coping, Normative significance) the sub-check intrinsic pleasantness of relevance detection could be associated to the OCC object perception. Normative significance could be associated with the OCC's 'agent perception' where the norms play an important role when judging the actions of others. The rest of the sub-checks (except agency) can be associated with ‘agentless event perception’. Scherer models the emotional episode in a parallel componential structure where each component can influence another one. Further influence can be expressed between components until stability is reached. Another particularity of Scherer’s model is that each sub check can trigger a modification in the affective state. This allows a dynamic affective state modification where one event can be associated with more than one variation of the affect (rather than triggering one discreet emotion). In our opinion, this allows more realism. For these reasons, in our model we use Scherer’s model to build the full emotional episode.

In the model developed in this research, instead of mapping the different parameters (sub-checks) into one affective state/emotion, a temporal mapping is used. This means that every check will trigger a modification in the affective state at different moments. In other words, the variables will be mapped onto a curve instead of one emotional label. The affective state is represented in a PDA space (Pleasure, Dominance, Arousal) (Mehrabian and Russell, 1974). The curve is then a four-dimensional curve (P, D, A, Time). Each check reaches a conclusion before the other checks following it. Figure 4-1 illustrates an example of the change in pleasure over time while experiencing an emotional episode. The different parameters/sub-checks are used to draw the curve. Furthermore, existing computational models tend to use fewer dimensions. Indeed, the larger number of dimensions, the less obvious it is to generate an emotion. In this work’s model, the dimensions are grouped in four groups and successive affective states modifications are derived.

For this part of the work the main theory used is Scherer’s (K. R. Scherer, 2001). However, Scherer’s theory presents only a guideline and it is far from being ready for implementation. There are no details on how appraisal variables affect the different components or how the different components affect each other. There are also no details on how the different processes evolve over time or the account of personality variables in the process. This is why other theories need to be used as well plus assumptions to make the model ready for implementation.

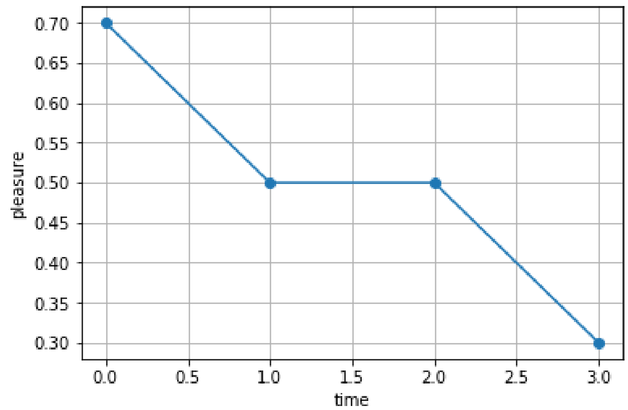

Figure 4-1 An example of pleasure variation during an emotional episode

4.3.1. General algorithm

The general algorithm to compute the variations of the affective states following one event is as follows:

1. Generate the 12 variables following an event
2. Compute the four points of the affective states pt1, pt2, pt3 and pt4 associated respectively with the four checks (described in the below formulas)
3. Compute the four points of inter-influence $PDA_{relevance}$, $PDA_{implication}$, PDA_{coping} and $PDA_{normative}$ (described in the below formulas)
4. Update the affective state with the values of $PDA_{relevance}$, $PDA_{implication}$, PDA_{coping} and $PDA_{normative}$ successively allowing a continuous change in values (derivable like curve).

Figure 4-2 describes how the process of modifying the affective state works starting from a stimulus picked from the external world.

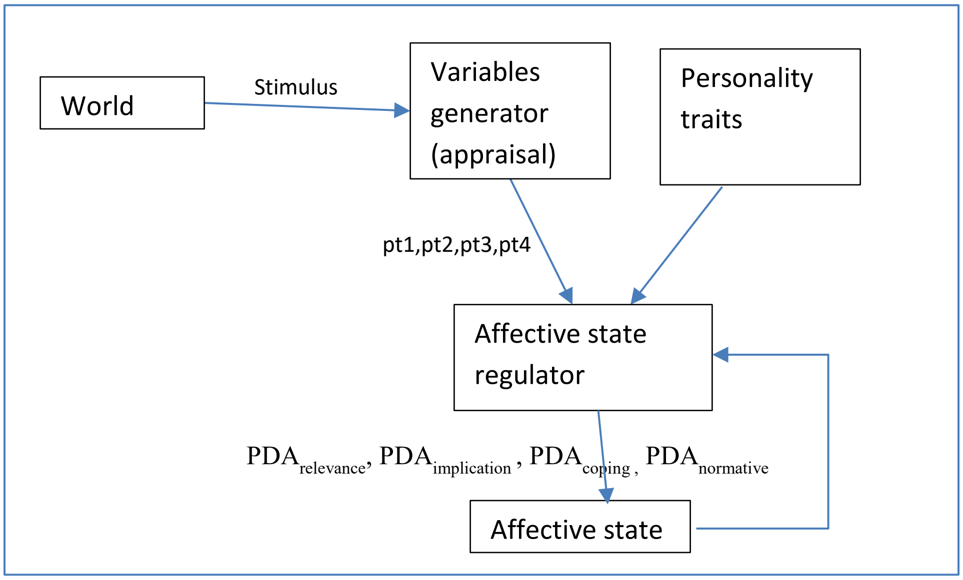

Figure 4-2 Description of the process

4.3.2. Computation of the four affective states (pt1, pt2, pt3 and pt4)

The variations in the affective state used in the present model during an emotional episode are faithful to Scherer's model since the modifications of the affective state are not applied simultaneously. To illustrate these modifications with a scenario: let's say that Bob has come across an old friend who makes him feel a positive emotion. However, Bob remembers that his old friend owes him some money, so he corrects his appraisal as seeing his old friend might obstruct one of his goals. In such a scenario Bob can experience a positive pleasantness then a less pleasant feeling. This is considered as one emotional episode in our model. To explain this in term of checks: the first check will perceive the friend as a pleasant object and generate a positive affective state from it. The next check can use cognition to infer that seeing that person might not be that pleasant after all. The appraisal variables are used to compute the four points of inter-influence (pt1, pt2, pt3 and pt4) and thus generate a succession in the variation of the affective state.

The different dimensions/variables used with their respective range values are as follows:

Table 4-1 Variables/dimensions and their respective range of values

Dimensions/Variables	Range of values
Novelty	[0,+1]

Intrinsic Pleasantness	[-1,+1]
Goal/Need Relevance	[0,+1]
Causality	0: Self, 1: Other, 2: Circumstances (impersonal)
Conduciveness	[-1,+1]
Outcome Probability	[0,+1]
Urgency	[-1,1]
Power	[-1,1]
adjustment	[-1,1]
internal standard compatibility	[-1,1]
external standard compatibility	[-1,1]

The four points of inter-influence are computed as follows:

Relevance detection point (pt1)

This check includes the novelty, intrinsic pleasantness and goal/need relevance sub-checks. We use these three parameters to compute the values of a PDA point. In the present model, we keep the same parameters as Scherer's. From these three parameters, we compute the values of Pleasantness, Dominance and Arousal as follows:

$$P_{relevance} = Pleasantness + sign(Pleasantness).(1 - |Pleasantness|)(1 - e^{-(\alpha.Novelty)}), \textbf{ where } \alpha > 0 \quad \textbf{(4.1)}$$

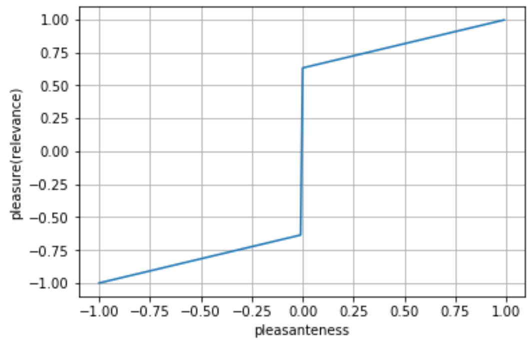

Figure 4-3 $P_{relevance}$ equation with α =1 and novelty=1

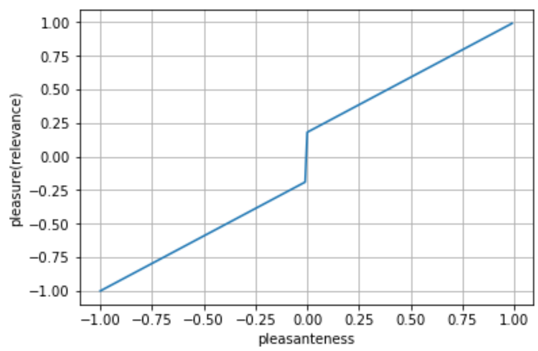

Figure 4-4 $P_{relevance}$ equation with α =1 and novelty=0.2

$$D_{relevance} = no\ variation \tag{4.2}$$

$$A_{relevance} = \left(1 - e^{-(\lambda.Novelty+\omega.Goalrelevance)}\right).2 - 1, \tag{4.3}$$

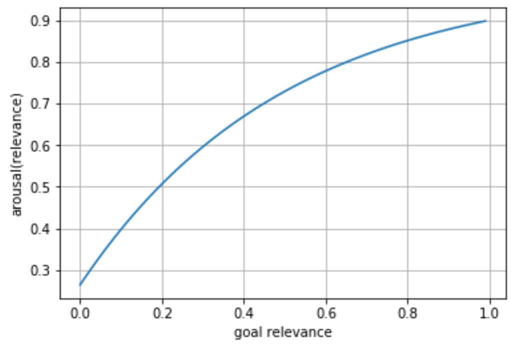

Figure 4-5 $A_{relevance}$ equation with λ =1, ω =2 and novelty=1

The function $1 - e^{-x}$ is used to ensure that the absolute values of Pleasure and Arousal are within the [0,1] interval. α is a coefficient that acts as a normalizer for the variable Novelty in the pleasantness formula ($P_{relevance}$). λ and ω coefficients and normalizers for the variables Pleasantness, Novelty in the Arousal' s formula.

These values of Pleasantness, Dominance and Arousal constitute the values of the first 3D point denoted pt1.

Implication point (pt2)

This check includes causality, outcome probability, expectations discrepancy, conduciveness and urgency sub-checks. In our model, we stick to the same parameters used by Scherer except for causality where we use only one type of causality instead of two for the sake of simplicity.

$$\boldsymbol{P_{implication}} = \begin{cases} \boldsymbol{sign(Conduciveness).\,(1 - e^{-\gamma.\rho.|Outcomeprob.Conduciveness|})} \\ \boldsymbol{if\ causality = 1\ and\ Conduciveness < 0\ then\ \rho = 2\ else\ \rho = 1} \end{cases} \quad \textbf{(4.4)}$$

$$\boldsymbol{D_{implication} = no\ variation} \quad \textbf{(4.5)}$$

$$\boldsymbol{A_{implication} = urgency\ .\ c,} \quad \textbf{(4.6)}$$

$$c = \begin{cases} \mathbf{0.5} & \boldsymbol{if\ causality\ = 0\ and\ Conduciveness < 0} \\ \mathbf{1} & \boldsymbol{otherwise} \end{cases}$$

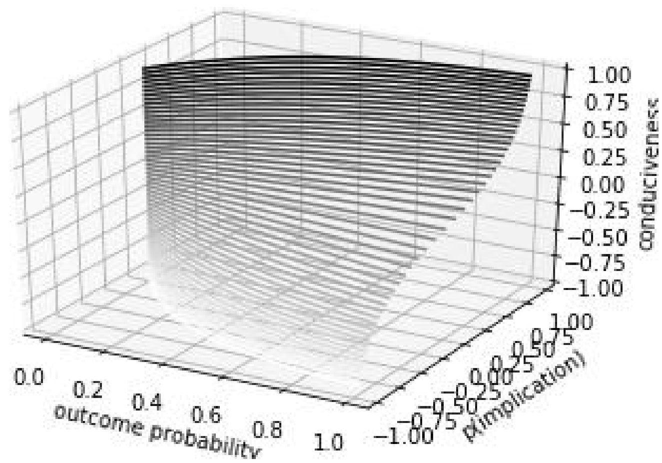

Figure 4-6 $P_{implication}$ equation with ρ =1, γ =3

γ is a normalizer >0. Outcomeprob and Conduciveness are multiplied to compute how close an individual is to his goals or how far he/she/it is from his concerns. If $causality = 1$ and $Conduciveness < 0$ then ρ=2. This part of the formula is used to amplify the absolute value of pleasure if conduciveness is negative and the cause of the event is another agent. The assumption behind it is that if a negative event happens and that event can be attributed to an agent, then the pain associated with it is amplified. Again, giving only three possible values to causality might not be faithful to reality. There are cases where causality is shared between a personal and impersonal causes. There are also cases where causality is shared between the members of a group. Real life cases make causality a complex attribute. For the sake of simplicity, we have considered only three possible values for this attribute.

Causality influence arousal as well. In (Neumann, 2000) the presence of a personal cause (agent) for a negative event triggers anger, while when the cause is the self, the emotion triggered is guilt. In many models such as the Circumflex (Barrett and Bliss-Moreau, 2009) anger is associated with a higher arousal whereas guilt/shame is associated with a lower arousal. For this, we add the coefficient ‘c’ to the arousal formula above.

In the previous formula Arousal is synonymous to urgency. The point generated is denoted pt2.

Coping potential point (pt3)

In the original model it Includes control, power and adjustment. In the formula below, we use only power and adjustment as we combine control and power into one variable.

$$D_{coping} = \max(Power, Adjustment) \qquad \textbf{(4. 7)}$$

To compute dominance, we simply take the maximum between power and adjustment. Arousal and Pleasure are not modified. This point is denoted pt3.

Normative significance point (pt4)

Internal standard compatibility and external standard compatibility are used in Scherer's model we kept the same parameters in our model. These two parameters only affect pleasure in our model as they are perceived as evaluating whether the event is acceptable/non-acceptable from standards point of view. Pleasure is calculated as follows:

$$P_{normative} = \frac{\delta.Internalstd + \theta.Externalstd}{\delta + \theta} \qquad \textbf{(4.8)}$$

δ *and* θ are coefficients to give different weights to the internal standards and external standards. The can be equal or they can be linked to other parameters such as the personality.

The fourth point is denoted as pt4.

We need to give a more precise meaning to the 11 dimensions used to compute pt1, pt2, pt3, pt4. These dimensions represent a vector. The values of this vector are appraisal values. One question is what should the vector's values be? Are they general appraisal values? Or the agent's appraisal values. If the latter, we need to know at what moment. Since an individual might appraise events differently depending on his/hers/its affective state, parameters and other components. To simplify things at this level, we stipulate that the appraisal values are the agent's appraisals in a neutral affective state. This might not reflect the reality. However, this will allow us to simplify the process since we cannot know how the other components such as the affective state will influence appraisal.

4.3.3. Progression over time

Accurately simulating the timing of the different changes on the affective state during an emotional episode can be a real challenge since the process of acquiring appraisal values is not entirely defined. Therefore, we assume that appraisal values are determined instantly in the sequential way defined in Scherer's model. However, for the sake of realism, the change in the affective state is not instantaneous. It converges from the initial affective state to the new affective state gradually over time. In other words, the curve representing the modifications in the affective state have to be pseudo-continues. This method is not necessarily faithful to reality where we suspect that new changes in the affective states can start before the conclusion of the previous one. This limitation is due to the absence of a method to compute the moments of determination of appraisal variables/dimensions.

4.3.4. The four points of inter-influence

After computing the four points of affective states, we do not modify the values of the affective state directly to match the points' values successively. In other words, these four points act like vectors trying to drive the values of the affective state towards their values. Using the current affective state (CAS) and these four points (pt1, pt2, pt3 and pt4) we compute the new four successive values of the affective state. We name them $PDA_{relevance}$, $PDA_{implication}$, PDA_{coping} , $PDA_{normative}$.

Personality traits can affect the affective state. A personality trait can make a person favour positive or negative affective states. Extraversion and Neuroticism are known for influencing positive and negative affective states respectively while other personality traits have less influence in the same pleasure/displeasure axe (Zhang and Tsingan, 2014). Personality traits are used to filter certain affective states. For example, Extraversion is known for favouring positive affects over negative ones. Because of that, an agent/person scoring high on Extraversion will give a lesser weight to negative affects if the previous affective state is positive. In our model, we do not only use personality to filter affects. The current affective state also plays a role. The used weights depend on the current affective state (the affective state preceding the event) and personality traits. Mood is simply the affective state after stabilisation (in our model).

To update the affective state, we adopt the following rules:

- The more the distance between the values of the current affective state (CAS) and the values of the new point (pt1, pt2, pt3, pt4), the more difficult it is to update the affective state to closer values to the new point's values.
- Each point can be related to one or more personality traits. Normative significance is related to agreeableness and consciousness. Extraversion and Conscientiousness predicts more problem-solving and cognition usage, Neuroticism less (Connor-Smith and Flachsbart, n.d.). In Scherer's model, all the stages except relevance detection use cognition. Implication and Coping seem to use cognition more than Normative Significance. From these finding, people who score high in Extraversion and Conscientiousness should favour more the phases Implication and Coping. Normative significance will also be favoured but to a lesser extent. Neuroticism also favours negative emotions (Tong, 2010)
- Attention bias studies have shown that anxious individuals tend to focus more on negative events (MacLeod et al., 1986). Anxious people score high on negative pleasure. Similar studies have shown that depressed individuals have difficulties getting out of their affective state. Depressed people score high on negative arousal. From these studies, we postulate that if the sign of one of the components of the affective state is different from its counterpart component on the computed point then the component of the computed point will have a lower weight. This postulate is not necessarily 100% accurate and the reason for this bias might be more than a particular affective state. However, because a lack of extensive information, we simplify the explanation of these studies by this postulate.
- We assume that empathy allow the use of the normative significance phase more ie. The more empathic you are the more weight you give to that phase. Empathy is characterized by the Agreeableness trait of personality. Conscientiousness also favours social norms (Roberts BW, Jackson JJ, Fayard JV, Edmonds G, 2009).

The above rules are translated into the following formulas:

We denote the current affective state values by CAP, CAD, and CAA respectively: current affective state pleasure, current affective state dominance and current affective state arousal.

The initial values of CAP, CAD, CAA depend on the previous affective state triggered by a previous event. In case of no event has been observed and for the purpose of simulation, it can be initialised to 0. The function that updates the affective state is 'update'. The following formula updates affective state's pleasure, dominance and arousal using respectively pleasure, dominance and arousal of the calculated points (pt1, pt2, pt3 and pt4). This is not necessarily accurate. For example, Arousal of pt1 might influence Pleasure of the affective state. However, for the sake of simplicity and in the absence of studies allowing us to draw such formulas, we will assume that each component of the points influences its respective component on the affective state i.e Pleasure influences only Pleasure, Dominance influences only dominance and Arousal influences only Arousal.

To include personality traits in the affective state's modifications, we define six variables that we will call 'personality filter variables'. These variables are paf+, paf-, daf+, daf-, aaf+, aaf- they respectively denote pleasure affect factor, dominance affect factor and arousal affect factor. They act as coefficients to respectively positive pleasure, negative pleasure, positive dominance, negative dominance, positive arousal and negative arousal. These variables formulas are:

$$\mathbf{pafp=((E+1.5A)+2.5)/5} \quad \mathbf{(4.9)}$$

$$\text{pafn}=((N-1.5(A+C))+4)/8 \quad (4.10)$$

$$\text{dafp}=(2/3E+2/3)/(4/3) \quad (4.11)$$

$$\text{dafn}= (1/4(N+E)+0.5) \quad (4.12)$$

$$\text{aafp}=((1/3E+1/4C)+7/12)/(7/6) \quad (4.13)$$

$$\text{aafn}=(-1/3N+1/3)/(2/3) \quad (4.14)$$

The formulas above are derived from studies dealing with the correlation of affective states and personality traits (Yik and Russell, 2001) (Zhang and Tsingan, 2014) (Mehrabian, 1996). These variables show how a person/agent has a personality inclined to a certain affective state. A denotes Agreeableness, it scales between friendly/compassionate and challenging/detached, E denotes Extraversion which reflects energy and positive emotions, C denotes Conscientiousness which is correlated with self-discipline and dutiful, and N denotes

Neuroticism. It identifies people who tend to feel psychological stress more than the others. These parameters are personality traits that are found in OCEAN model (John, 1990). Their values are between 0 and 1. 0 means the individual scores low on these values while 1 means he scores high.

As described in (John, 1990), If a person scores 1 in A (agreeableness), it means that he is highly compassionate and friendly. If he scores 0, it means he is very challenging and emotionally detached. Most people are in the grey area between 0 and 1. Scoring 1 in E (extraversion) means that that person is extrovert, full of energy and tend to feel positive emotions intensely. In the other hand, scoring 0 means that the person is highly introvert. A score of 1 in C (conscientiousness) denotes that the person is very dutiful, very responsible and reliable. A 0 in C means that the person is easy going and careless. Unlike the other three variables, a high score in N (neuroticism) is rather perceived negative. A score of 1 in N means that the person is highly neurotic and tend to feel stress and negative emotions more intensely while a score close to 0 in N means that the person is secure and confident.

A personality alone will not explain the inclination of a person/agent to a certain affective state since this inclination might change over time while personality is more or less stable. For this, we mix the 'personality filter variables' with the current affective state to produce the ready to be used variables. We call these variables 'final filter variables'. They are computed as follows:

$$\mathbf{fpafp = (pafp + CAP)/2 \quad if\ fpafp<0\ then\ fpafp=0} \qquad \mathbf{(4.15)}$$

$$fpafn = -(-pafn + CAP)/2 \quad if\ fpaf<0\ then\ fpafn=0 \qquad (4.16)$$

$$fdafp = (dafp + CAD)/2 \quad if\ fdafp<0\ then\ fdafp=0 \qquad (4.17)$$

$$fdafn = -(-dafn + CAD)/2 \quad if\ fdafn<0\ then\ fdafn=0 \qquad (4.18)$$

$$faafp = (aafp + CAA)/2 \quad if\ faafp<0\ then\ faafp=0 \qquad (4.19)$$

$$faafn = -(-aafn + CAA)/2 \quad if\ faafn<0\ then\ faafn=0 \qquad (4.20)$$

These six coefficients are respectively associated with final positive pleasure, final negative pleasure, final positive dominance, final negative dominance, final positive arousal and negative arousal. These coefficients are the one that are going to be used in the formulas bellow that updates the affective states.

The following formulas are as follows:

Point 1 ($PDA_{relevance}$):

$$CAP = update(CAP, \mathrm{P}_{\mathrm{relevance}}) = \frac{(\alpha_{p1}.CAP + \beta_{p1}.\mathrm{P}_{\mathrm{relevance}})}{\alpha_{p1} + \beta_{p1}} \qquad \textbf{(4.21)}$$

$$CAD = update(CAD, \mathrm{D}_{\mathrm{relevance}}) = \frac{(\alpha_{d1}.CAD + \beta_{d1}.\mathrm{D}_{\mathrm{relevance}})}{\alpha_{d1} + \beta_{d1}} \qquad (4.22)$$

$$CAA = update(CAA, \mathrm{A}_{\mathrm{relevance}}) = \frac{(\alpha_{a1}.CAA + \beta_{a1}.\mathrm{A}_{\mathrm{relevance}})}{\alpha_{a1} + \beta_{a1}} \qquad (4.23)$$

$$\alpha_{p1} = \begin{cases} fpafp & if\ CAP \geq 0 \\ fpafn & Otherwise \end{cases}$$

$$\beta_{p1} = \begin{cases} fpafp & if\ \mathrm{P}_{\mathrm{relevance}} \geq 0 \\ fpafn & Otherwise \end{cases}$$

$$\alpha_{d1} = \begin{cases} fdafp & if\ CAD \geq 0 \\ fdafn & Otherwise \end{cases}$$

$$\beta_{d1} = \begin{cases} fdafp & if\ \mathrm{D}_{\mathrm{relevance}} \geq 0 \\ fdafn & Otherwise \end{cases}$$

$$\alpha_{a1} = \begin{cases} faafp & if\ CAA \geq 0 \\ faafn & Otherwise \end{cases}$$

$$\beta_{a1} = \begin{cases} faafp & if\ \mathrm{A}_{\mathrm{relevance}} \geq 0 \\ faafn & Otherwise \end{cases}$$

Point 2 ($PDA_{implication}$):

This level is favoured by a high Conscientiousness, a low Neuroticism and a less intensive affective state (near zero). The justification for that is that this level relies heavily on cognition. Intense affective states tend to lower the use of cognition. Similarly, Conscientiousness is known to favour calm analysis.

ifp=C-N-|CAP| if ifp<0 then ifp=0 (4.24)

ifa=C-N-|CAA| if ifa<0 then ifa=0 (4.25)

$$CAP = update(CAP, \mathrm{P}_{\mathrm{implication}}) = \frac{(\alpha_{p2}.CAP + \beta_{p2}.\mathrm{P}_{\mathrm{implication}})}{\alpha_{p2} + \beta_{p2}} \tag{4.26}$$

$$CAA = update(CAA, \mathrm{A}_{\mathrm{implication}}) = \frac{(\alpha_{a2}.CAD + \beta_{a2}.\mathrm{A}_{\mathrm{implication}})}{\alpha_{a2} + \beta_{a2}} \tag{4.27}$$

$$\alpha_{p2} = \begin{cases} fpafp & if\ CAP \geq 0 \\ fpafn & Otherwise \end{cases}$$

$$\beta_{p2} = \begin{cases} fpafp + ifp & if\ CAP \geq 0 \\ fpafn + ifp & Otherwise \end{cases}$$

$$\alpha_{a2} = \begin{cases} faafp & if\ CAA \geq 0 \\ faafn & Otherwise \end{cases}$$

$$\beta_{a2} = \begin{cases} faafp + ifa & if\ CAA \geq 0 \\ faafn + ifa & Otherwise \end{cases}$$

Point 3 (PDA_{coping}):

This level uses similar resources as the previous one. Therefore, a high Conscientiousness, a low Neuroticism and a less intensive affective state (near zero) favour this level.

$$\mathbf{ifd=C-N-|CAP| \quad if\ ifd<0\ then\ ifd=0} \qquad \textbf{(4.28)}$$

$$CAD = update\big(CAD, \mathrm{D_{coping}}\big) = \frac{(\alpha_{d3}.CAD + \beta_{d3}.\mathrm{D_{coping}})}{\alpha_{d3} + \beta_{d3}} \qquad (4.29)$$

$$\alpha_{d3} = \begin{cases} fdafp & if\ CAD \geq 0 \\ fdafn & Otherwise \end{cases}$$

$$\beta_{a2} = \begin{cases} faafp\ + ifd & if\ CAD \geq 0 \\ faafn + ifd & Otherwise \end{cases}$$

Point 4 ($PDA_{normative}$):

In this level, we use Conscientiousness and Agreeableness as catalysers whereas an intense affective state decreases its coefficient. The justification for that is that Conscientiousness favours social norms while Agreeableness favours empathy and can make the agent look for justifications for another agent.

$$\mathbf{nf=C+A-|CAP|} \qquad \textbf{(4.30)}$$

$$update(CAP, \mathrm{P_{norm}}) = \frac{(\alpha_{p4}.CAP + \beta_{p4}.\mathrm{P_{norm}})}{\alpha_{p4} + \beta_{p4}} \qquad (4.31)$$

$$\alpha_{p4} = \begin{cases} fpafp & if\ CAP \geq 0 \\ fpafn & Otherwise \end{cases}$$

$$\beta_{p4} = \begin{cases} faafp\ + nf & if\ CAP \geq 0 \\ faafn + nf & Otherwise \end{cases}$$

α_{p4} *and* β_{p4} are coefficients related to Agreeableness and Conscientiousness personality traits. The more conscientious and agreeable the person the more he will try to look at the event from different perspectives.

The four new PDA values of the affective states (CAP, CAD, CAA) represents the actual values that update the affective state sequentially starting from point 1 to point 4. After computing the four positions of the affective state, we precede to the creation of the adequate facial representations.

Example:

A car driver is aiming to arrive to his destination on time. On the road an event occurs that will delay his arrival. The event's vector is coded as follows (Novelty=0.5, Intrinsic_pleasantness=0.8, Goal/Need Relevance=0.6, Causality=1, Conduciveness=0.3, Outcome Probability=0.6, Urgency=0.5, power=0.2, adjustment=0, internal standard compatibility=0, external standard compatibility=0.2)

To predict the emotional status of the driver the following calculations are carried out (according to the method presented on this chapter).

First the four points need to be computed (pt1,pt2,pt3,pt4):

pt1: We take α=1, $\lambda = 1$ and ω=1 for the sake of simplicity

$$P_{relevance} = 0.8 + (0.2)(0.4) = 0.88$$

$$D_{relevance} = no\ variation$$

$$A_{relevance} = 0.66 \,.\, 2 - 1 = 0.32$$

pt2: we take $\gamma = 1$ again for the sake of simplicity

$$P_{implication} = 0.31 \begin{cases} sign(Conduciveness).\,(1 - e^{-1.\ 2\ .|0.18|}) \\ if\ causality = 1\ and\ Conduciveness < 0\ then\ \rho = 2\ else\ \rho = 1 \end{cases}$$

$$D_{implication} = no\ variation$$

$$A_{implication} = 0.5$$

pt3:

$D_{coping} = \max(Power, Adjustment)$=0.2

$P_{coping} = no\ change$

$A_{coping} = no\ change$

pt4: $we\ take\ \delta = 0.5,\ \theta = 0.5$ again for the sake of simplicity

$P_{normative} = \frac{\delta.Internalstd+\theta.Externalstd}{\delta+\theta}$ =0.1

After computing the four points associated with the four appraisal checks, we proceed to compute the four variations of the affective state. The initial values of the affective state are chosen to be (just before the current event happened) P=0.2, D=0.3, A=-0.1. Personality traits values are: C=0.5, E=0.1, A=0.3, N=-0.5. For the sake of simplicity, we take all the coefficients $\alpha_{p1} = \alpha_{d1} = \alpha_{a1} = \alpha_{p2} = \alpha_{d2} = \alpha_{a2} = \alpha_{p3} = \alpha_{d3} = \alpha_{a3} = \alpha_{p4} = \alpha_{d4} = \alpha_{a4} = \beta_{p1} = \beta_{d1} = \beta_{a1} = \beta_{p2} = \beta_{d2} = \beta_{a2} = \beta_{p3} = \beta_{d3} = \beta_{a3} = \beta_{p4} = \beta_{d4} = \beta_{a4} = 1$,

Personality coefficient are computed as follows:
pafp=((E+1.5A)+2.5)/5=0.61
pafn=((N-1.5(A+C))+4)/8=0.3
dafp=(2/3E+2/3)/(4/3)=0.54
dafn= (1/4(N+E)+0.5)=0.4
aafp=((1/3E+1/4C)+7/12)/(7/6)=0.64
aafn=(-1/3N+1/3)/(2/3)=0.75

First modification of the affective state following pt1 along with the required coefficients:
fpafp= (pafp + CAP)/2   if fpafp<0 then fpafp=0
=0.41
fpafn= -(-pafn + CAP)/2   if fpaf<0 then fpafn=0

=0.05

fdafp= (dafp + CAD)/2   if fdafp<0 then fdafp=0

=0.42

fdafn= -(-dafn + CAD)/2   if fdafn<0 then fdafn=0

=0.05

faafp= (aafp + CAA)/2   if faafp<0 then faafp=0

=0.27

faafn= -(-aafn + CAA)/2   if faafn<0 then faafn=0

=0.42

The first point: pt1=(P=0.88,D=-,A=0.32)

The first variations values are:

$$CAP = \frac{0.41\ .\ 0.20 + 0.41\ .0.88}{0.41 + 0.41} = 0.54$$

$$CAD = 0.3$$

$$CAA = \frac{0.42\ .-0.1 + 0.27.0.32}{0.42 + 0.27} = 0.064$$

Second modification of the affective state along with its coefficients:

pt2=(P=0.31,D=-,A=0.5)

fpafp= (pafp + CAP)/2   if fpafp<0 then fpafp=0

=0.575

fpafn= -(-pafn + CAP)/2   if fpaf<0 then fpafn=0

=0

fdafp= (dafp + CAD)/2   if fdafp<0 then fdafp=0

=0.42

fdafn= -(-dafn + CAD)/2   if fdafn<0 then fdafn=0

=0.05

faafp= (aafp + CAA)/2   if faafp<0 then faafp=0

=0.352

faafn= -(-aafn + CAA)/2   if faafn<0 then faafn=0

=0.343

Affective state values after the second modification:

$$CAP = 0.39$$

$$CAD = 0.3$$

$$CAA = 0.372$$

Third modification of the affective state along with its coefficients:

pt3=(P=-, D=0.2, A=-)

fdafp= (dafp + CAD)/2   if fdafp<0 then fdafp=0

=0.42

fdafn= -(-dafn + CAD)/2   if fdafn<0 then fdafn=0

=0.05

During this modification, only *dominance* is affected:

$$CAD = 0.23$$

Fourth modification of the affective state along its coefficients:

pt4(P=0.1, D=-, A=-)

fpafp= (pafp + CAP)/2   if fpafp<0 then fpafp=0

fpafp =0.5

fpafn= -(-pafn + CAP)/2   if fpaf<0 then fpafn=0

fpafn =0

During this modification, only *pleasure* is affected:

$$CAP = 0.2$$

To summarize the results these are the successive values of the affective state:

- t_0 (before the event occurs): P=0.2, D=0.3, A=-0.1
- t_1 (after the first check): P=0.54, D=0.3, A=0.064
- t_2 (after the second check): P=0.39, D=0.3, A=0.372
- t_3 (after the third check): P=0.39, D=0.23, A=0.372
- t_4 (after the fourth check): P=0.2, D=0.23, A=0.372

Figure 4-7, figure 4-8 and figure 4-9 denotes the variation of pleasure, dominance and arousal over time respectively during the experience of the previous event. It is considered as one emotional episode. These figures show how the experience of the event presented in this example modified the affective state in a continuous way until stability is reached. The four values are plotted to draw this curve along with the initial values.

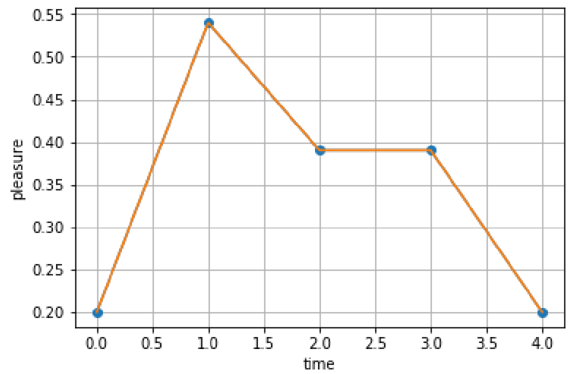

Figure 4-7 Pleasure variation over time

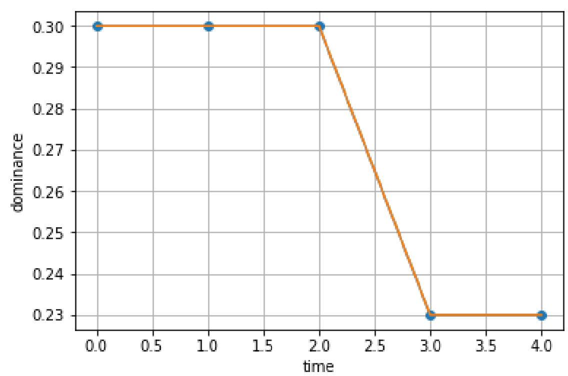

Figure 4-8 Dominance variation over time

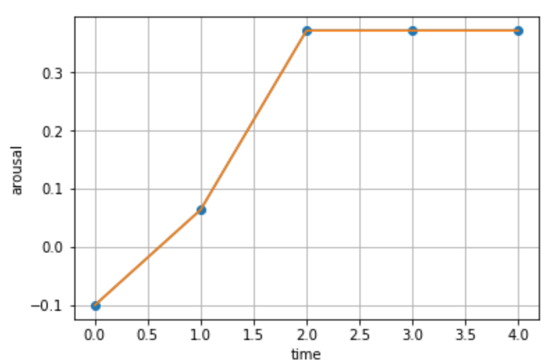

Figure 4-9 Arousal variation over time

4.4. Conclusion

In this chapter, we introduced a computational emotional model based on Scherer' theory. Despite the theory being highly elaborate, it is at a high abstraction level and implementing it requires a concrete definition of every aspect. This theory allows every event to trigger a gradual modification of the affective state instead of a single emotion being triggered. The theory also does not articulate how the different variables/dimensions are coded and how do they modify the affective state. For this, we proposed a series of formulas and coding to concretely implement this theory. Many of the formulas are based on different studies. We used assumptions where studies are absent. The different components used in Scherer's theory are also very abstract. For the sake of simplicity, we only used two components, namely cognition/appraisal and the affective state. The different formulas of computing pt1, pt2, pt3 and pt4 and the coding used of dimensions/variables are a representation of the appraisal component. However, this representation could be more complex as it used different resources. Affect is represented in a PDA space, which is derived from a competing theory belonging to the dimensional theories. However, the 3D space representation of the affective state (P, D, A) does not contradict Scherer's theory. In the literature review, we have seen different studies showing either a single representation of affect or emotion using simple labels or dimensional representations. We also found that more studies are backing the dimensional representation.

We also introduced personality traits in computing the effect of pt1, pt2, pt3 and pt4 generating four other points that will represent the actual values of the affective states. These points are $PDA_{relevance}$, $PDA_{implication}$, PDA_{coping} , $PDA_{normative}$. The current affective state also influences the computation of these points. Different studies and assumptions were used to compute these points the represents the real variations of the affective state. Using all of these studies and theories, we were able to produce a dynamic variation of the affective state instead of what is currently used which is a single emotional label. In The next chapter, a formalism of another component will take place. This component is motor expression which will use a theory from another area (the multiple resources theory). Using the motor expression component will allow us to extend the possibilities of the model developed in this chapter.

5 Multitasking in Emotion Modelling: Attention Control

5.1. Introduction

Existing computational emotional models rarely address the multitasking nature of the human body and mind. When an organism experiences an emotional episode, it may trigger a coping action. During the execution of this action, its perceptions and cognition can still take part in other activities in parallel. As an example, a driver is listening to the radio while driving. At the same time, the driver hears a piece of news that may affect one of his goals. A coping strategy is to park and call a friend. While the driver is parking, he witnesses a crash. Executing the coping strategy does not prevent the driver from experiencing the emotion associated with witnessing the crash. Attention, cognition and actions can be executed in parallel (Wickens, 2002). Attention and cognition are included in the emotional process by theories such as Scherer's (Scherer, 2010).

In this chapter, the possibility and ability to attend to more than one event at the same time and executing more than one action simultaneously is examined. An algorithm based on the multiple resources model (Wickens, 2002) is implemented to direct the attention according to the goals and resources. The algorithm is then combined with the emotional model previously described to produce a multitasking behaviour that includes emotions.

The presented algorithm in this chapter constitute the second contribution of this thesis. It is based on Wicken's theory where it uses its conflict matrix presented in table 5-1 below. Wicken's theory provide a mean to predict whether two tasks can be executed at the same time successfully. The proposed algorithm (Allocation algorithm) estimates the used and available resources during the execution of many tasks at the same time, making it fitter for simulation purposes. The main contribution of this chapter cab be found in (Sidoumou et al., 2015).

5.2. Attention theories

Attention theories, as described previously, deal with how the focus is directed. Selecting a subset of concurrent tasks to execute requires understanding how this process works. For this, the theory must be able to handle and combine multiple resources. Such a theory is formalized by Wickens (Wickens, 2002). Wickens decomposes resources required for any given task into categories. Each task requires a certain amount of each category to be executed appropriately. The work presented in this chapter is based on this theory.

5.3. A general emotional model using attention theory

Most computational emotional models use a sequential paradigm in processing the information flow between the different components of the model. In other words, each stimulus triggers one emotion, which in turns triggers a coping strategy. This scenario might not be a fair representation of real world situations where competing stimuli take place simultaneously.

The idea behind using Wicken's theory is to allow a parallel processing of the information. Each component of the model can be active at any time and does not need to block any other component from being active before completing a task. Such an architecture is justified by the previously introduced multiple resources theory (Wickens, 2002) where the prediction of workload (tasks involving internal resources) success is emphasized. In this theory, perception, cognition and responses can be shared among tasks. It is therefore possible to assign them to a number of concurrent tasks in parallel. The model proposed here is built with the aim of simulating emotions associated with simultaneous events which might need many cognition and action phases. Each component of the model can have its own required resources. The architecture of the model is presented in figure 5-1. The different components of the architecture are described as follows:

A. **Perceptions**

The perception component is responsible for transforming events from the external environment into information that can be stored in the *working memory* (short term memory). Perception is controlled by the *attention regulator*. Two senses are associated with perceptions; the sight and the audition. Information is continuously acquired and, depending on the *attention regulator*, is stored in the *working memory*. The perception is controlled using either a top down or a bottom-down approach. A top-down perception is triggered when a concern requires attention such as goals or avoiding an outcome. A bottom-up perception is triggered when an event with a high valence is observed in the external environment such as hearing a loud sound.

B. **Appraisal**

The appraisal component is responsible for evaluating an external event. The psychological model used in this study is the one described in Scherer's model. Variables are determined in an environment. Those variables are converted into a series of points in a three-dimensional space (PDA) successively **as described in the previous chapter.**

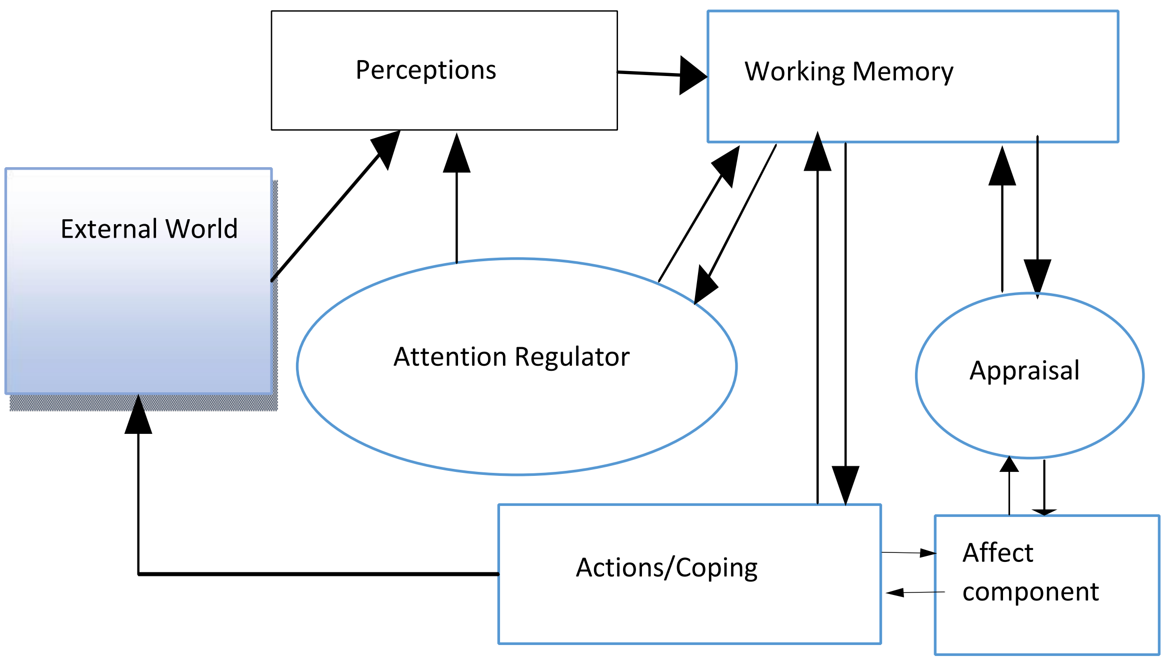

Figure 5-1 Architecture of the general emotional model

C. **Working memory**

Working memory is a type of memory associated with short term memory. Attending to a situation requires the working memory to build a mental representation of this situation.

D. **Attention regulator**

The *attention regulator* is the coordinator of the system. It assigns the different resources to tasks depending on the situation and the importance of tasks. Multiple resources theory is used to determine conflicting tasks. Resources are allocated on demand by tasks that are related to the concerns of an individual. The considered resources are derived from table 1. These common resources are used in (Wickens, 2002).

The *attention regulator* selects the potential tasks and computes their urgency/importance according to the associated goals/concerns. A sorted list of urgent/important tasks is produced. The *attention regulator* will then load the most urgent/important task in the *working memory* and allocate the required resources to it. If there are enough available resources, other tasks might be loaded to be executed. The resources could be at any level (perception, cognition and responses). As an example, a person driving a car wants to arrive on time to watch his favourite TV program. This goal is the most urgent amongst the other goals. Visual/spatial resources and manual/spatial response resources will be allocated to meet this goal (driving efficiently to arrive on time). Other tasks interfering with this one, in terms of resources, will be ignored if their urgency/importance is not comparable to the attended task and the available resources do not allow their execution. If another task more urgent/important as the attended ones is considered then a resource sharing policy is activated whereby less important tasks will have their resources freed if required. During the execution of tasks related to a goal involving resources allocation, a bottom-up scanning of the environment needs to be performed to detect external events. If the processed stimulus can make a task more urgent/important, then this task is brought into attention and can have resources allocated to it.

Let us consider the previous example of the driver. While driving an accident occurs in front of the driver. The driver is now facing a threat of getting caught in the accident. An important goal which is the safety of the organism arises and at the same time this goal is more urgent/important than the attended one. If the available resources will not satisfy attending to both tasks then the *attention regulator* will allocate all the required resources to the later task (the resources of the former task will be freed).

E. **Action/Coping**

Actions and *coping* are modifications to the environment, which are executed by an individual to meet one of his/her goals or to avoid a particular situation. *Actions* cannot generally be executed simultaneously if they involve the same type of resources (Manual/Spatial or Vocal/Verbal). Wicken's theory also tells us that perception/cognition can be executed at the same time with a response thus we will be able to execute responses and tasks based on perception/cognition at the same time. A conflict management strategy will be discussed in the following section. Although action/coping is presented on the above diagram, the contribution of this chapter does not select what action to execute. The present work only check whether a particular action can be executed at a particular time.

5.3.1. Resources allocation strategy

Resources are limited and any living being cannot attend to too many situations at the same time. A simulation needs to know to what extent two situations can be attended to simultaneously. Besides that, it is not easy to determine all the types of resources involved. Current studies only tell us if two tasks executed at the same time they may or may not interfere with each other. These studies do not specify the types and exact amount of resources needed by each task.

If an individual requires attending to two situations because they involve the same level of urgency a computation conflict mechanism is triggered. The conflict management can determine two cases defined as follows:

- The two situations have a low level of conflict, which suggests that the two situations can be attended to at the same time.
- The two situations have a high level of conflict. In such a case, only one situation can be attended to at a time. The situation associated with the more important goal and more urgent will be prioritised. Abandoning the lower priority goal may trigger an emotion.

To determine whether or not two situations can be attended to at the same time, a conflict matrix from (Wickens, 2002) is used. This matrix addresses the conflict in resources' demand by the elements of the three primary dimensions of the multiple resources model. Table 2 gives an illustration of the 'conflict matrix'.

In the conflict matrix, conflict values are assigned to resource allocations if different phases of two tasks (Task A and Task B) are executed at the same time. If both Task A and Task B require a visual spatial perception at the same time, then during that phase the conflict value is

0.8 (from the matrix). If both tasks require at the same time a verbal response then the conflict value is 1.0, which means that we cannot produce two different verbal responses at the same time. Those values may not be the same in all cases; for example, performing a visual-spatial operation on two distinct

Table 5-1 Conflict matrix (Wickens, 2008)

		Task A Resources							
		Perceptual				Cognitive		Response	
		VS	VV	AS	AV	CS	CV	RS	RV
	VS	0.8	0.6	0.6	0.4	0.7	0.5	0.4	0.2
	VV		0.8	0.4	0.6	0.5	0.7	0.2	0.4
	AS			0.8	0.4	0.7	0.5	0.4	0.2
Task B Resources	AV				0.8	0.5	0.7	0.2	0.4
	CS					0.8	0.6	0.6	0.4
	CV						0.8	0.4	0.6
	RS							0.8	0.6
	R V								1.0

objects that are close to each other may require less effort and interference than if they were far from each other (Wickens, 2002).

The different labels in Table 5-1 are VS (Visual Spatial), VV (Visual Verbal), AS (Auditory Spatial), AV (Auditory Verbal), CS (Cognitive Spatial), CV (Cognitive Verbal), RS (Response Spatial), and RV (Response Verbal). Because the exact body/mind resources involved in each stage are not known, the 'Conflict Matrix' will be used to determine whether two situations can be attended to at the same time or not.

The 'Conflict Matrix' gives us how much two tasks can interfere with each other if two phases of those tasks are executed at the same time. However, to compute the interference, it is useful to include in the computation the amount of resources needed in each phase by the tasks.

A vector representing the resources available is used. This vector named 'AR' vector is an eight-dimensional vector. Each cell of the vector represents the initial availability of the resources involved by one of the eight elements (VS,VV,AS,AV,CS,CV,RS,RV). A task will be represented by a similar eight-dimensional vector TR_{Task}, describing the resources needed for its correct execution. Since most elements within a task do not interfere with each other in most cases, because of their sequential requirement (Wickens, 2002), we assume that there is no interference between elements within a particular task. When a new task T1 requires attention, the AR vector will be updated according to the following formula:

$$AR[i] = AR[i] - MAX_{j=1}^{8}\left(shr(i,j).TR_{T1}[j] + intr(i,j)\right),\ \ i \in [1,8]$$

where $intr(i,j)$ is the interference between the element at the position i and the element at the position j, taken from Table 2 and $shr(i,j)$ is the sharing coefficient; it determines the shared resources between the element at position i and the

element at position j. $shr(i,j) = \begin{cases} intr(i,j) + 0.2 & if\ i = j \\ intr(i,j) & otherwise \end{cases}$

The formula used to update the vector AR is explained by calculating the shared resources required by an element of the vector and an element of the AR vector. This is determined by $shr(i,j).TR_{T1}[j]$. Then $intr(i,j)$ is added to include the interference. Each cell of AR represents how much resources are available for each associated element. The maximum is taken in order to take only into account the worst cases.

Allocation algorithm:

```
AR available resources vector, TR the resources vector of a task R,    ARtmp
Vector, float max=0;
Copy AR values into ARtmp
For i=1..8
  For j=1..8
    If max< shr(i,j) · tr[j]+intr(I,j)
    max= shr(i,j) · tr[j]+intr(I,j)
  End for
  ARtmp[i]=ARtmp[i]-max
  max=0;
  If ARtmp[i]<0 return false
End for
Copy ARtmp values into AR
Return true
```

Note: intr(i,j)=0 if there is no task intended when the task R is examined

If a task causes $AR\ [i]$<0, $i \in [1,8]$ then the task is not executed and will go to a waiting list. The tasks in the waiting list will have their urgency and goal importance updated constantly.

De-allocation algorithm:

1. *AR available resources vector, TR the resources vector of a task R to free, ARtmp Vector, float max=0;*
2. ***For** i=1..8*
3. * **For** j=1..8*
4. *   If max< shr(i,j) · tr[j]+intr(I,j)*
5. *   max= shr(i,j) · tr[j]+intr(I,j)*
6. * **End for***
7. * ARtmp[i]=ARtmp[i]+max*
8. * max=0;*
9. * If ARtmp[i]<0 return false*
10. ***End for***
11. *Copy **ARtmp** values into **AR***
12. *Return true*

The following is an example showing a scenario:

T1 is driving a car from point A to point B. This is a task defined by the vector (2,0.5,0,0,0,0,0,1.5). This task needs to be attended to by a person whose AR vector is

(3,3,2.5,3,3,3,2.5,2). The person is attending to task T1. Applying the allocation algorithm updates AR to (1,1.8,1.3,2.2,1.6,2,1,1.1). This means that T1 can be attended to by that person. After that, a task T2, which is listening to the radio, defined as (0,0,0,1,0,0,0,0) needs to be attended to. The Allocation algorithm updates AR to (0.2,0.6,0.5,0.4,0.6,0.6,0.2,0.1), which means that T2 can be attended to while attending to T1.

The driver switches off the radio and T2 resources are freed. AR is updated to (1,1.8,1.3,2.2,1.6,2,1,1.1) and another task T3 is brought into attention. T3 is to make a phone call. It is defined by the vector (0,0,0,1.5,0,0,1,1.5). If the driver attempts to execute T3 while executing T1, which is illegal, the allocation algorithm will update the vector AR to (0,0.3,0.3,-0.1,0.35,0.25,-0.8,-1.4). Several values of the AR vector are negative; this means that T1 and T3 cannot be executed at the same time. While the direct link to emotion was not shown in this example, T1, T2 and T3 can either be related to a goal to reach/avoid an emotional state or to emotional coping strategies.

5.3.2. New bottom-up tasks

If a bottom-up task arises (like a light flashing suddenly or upon the hearing of a loud sound), the attention is directed to it. Those tasks are mainly perceptive and will interrupt attention and take the required perceptive resources then their urgency and goal importance will be evaluated. After that, this task will be treated like any other task.

5.3.3. Complex tasks

Some tasks require two or more phases in parallel to be executed. Like taking notes while a presenter is giving a talk. In one phase, the user is required to attend to the speech and in another phase, he/she is required to write down his/her interpretation of the speech. This kind of composed tasks can be coded in two ways. The first way is to create two eight-dimensional vectors similar to a regular tasks vector and take them like two concurrent tasks being executed at the same time. This way is suggested because there is some interference between those two tasks unlike a standard task where there is no interference in between its elements. In case of two subtasks with no interference between them or the user knows how to execute them without any interference, then it is better to represent them as a single task with only one vector of resources.

Some tasks require more than one phase. Each phase may involve different resources. Those types of tasks can be represented by a chain of resource vectors. The vectors do not interfere between each other since they are executed sequentially. Combining sequential sub-tasks and parallel subtasks in one task is possible.

5.3.4. Scenarios

To understand more about the proposed algorithm, a few scenarios are provided below.

Scenario 1:

In the first scenario Bob is trying to take notes during a lecture. Bob's AR vector is (2,2,2,3,3,3,2,2). The first task which is listening to the lecture is represented by a vector T1 (1,1,1.5,1.5,0.2,0.2,1,0). During the listening task, Bob does not use a lot of cognition as he will be trying to take notes instead of carrying out an analysis of the lecture. First let us see if according to the proposed algorithm and settings, Bob will be able to perform T1. After running the allocation algorithm, the new AR vector is updated to (1,1,0.5,1.5,1.95,1.95,1,1.4). By Looking at the new values of AR, Bob is able to execute task T1 as there is no negative value. Let us now modify T1 by making listening, writing and using some cognition. T1 would be (1,1,1.5,1.5,1,1,1,0). After executing the allocation algorithm, AR new values are (1,1,0.5,1.5,1.95,1.95,1,1.4). As we can see AR does not change by modifying T1, the sub-tasks of one task are not considered to be competing against each other. In other words, the sub-tasks are not executed at the same time. In cases where there is some interference between the sub-tasks it would be better to treat that task as a complex task and decompose it into smaller tasks.

Another complicated case is when two tasks share some of the coding (coding are the information related to the task. It can be visual spatial, auditory spatial, visual verbal or auditory verbal. Sharing the coding means that the same information will be used by two different tasks). This means that their respective subtasks compete against each other partially. In this case, merging the two tasks would lose the competitive aspect and separating them will not capture their non-competitive aspect. This special case has not been considered in this study. An example of such a task is what is described in the previous scenario where Bob needs to listen and watch the lecture, take notes and use some cognition. If using the cognition is going to interfere with the other tasks then coding it as a subtask of T1, like we did, would be wrong since it would be considered as not being executed at the same time with the other tasks.

Now let us make T1 as listening and watching the lecture and taking notes and T2 as using cognition. T1 will be represented by the vector (1,1,1.5,1.5,0,0,1,0) and T2 would be represented by the vector (0,0,0,0,1,1,0,0). AR is represented by (2,2,2,3,3,3,2,2). Let us execute the allocation algorithm for T1. AR updated values will be (1,1,0.5,1.5,1.95,1.95,1,1.4). Now, allocating T2 would lead to (-0.4,-0.4,-0.9,0.1,0.15,0.15,-

0.2,0.2). We can observe that executing T1 and T2 at the same time is not possible whereas combining their values, like we have seen before, is possible. This is explained by the interference caused while executing two different tasks.

In reality using cognition while writing and listening can have some level of interference but not full interference. For the coding is the same (same data) and it also produces some new data, which can interfere with acquiring other data through listening. This is a limitation of Wicken's model and the allocation algorithm as well. However, there is one way to implement this scenario. This is achieved by dividing T2 into two tasks T2-1 and T2-2. Ti is then combined with T2-1 and T2-2 is kept as a competitive task. T2-1 will thus not compete with T1 and therefore such a scenario can be simulated.

Another limitation is that in this case T2-1 would compete with T2-2, which might not be matching a real-world scenario.

Scenario 2:

Let us now consider another scenario. A military pilot needs to complete a mission of landing his/her airplane at a specific destination while collaborating with other pilots who are doing the same activity in their respective airplane. Let us consider the pilot resources as being represented by the vector AR=(2,2,2,3,3,3,2,2). The vector of the activity commanding the airplane is defined by T1= (1.5,1,0.2,0.5,0.2,0.2,1.5,0.5). The execution of task T1 will affect the values of AR. The updated values of AR after applying the allocation algorithm are (0.5,1,1.09,2.4,1.95,2.25,0.5,1.09). T1 can be executed. We note that T1's values can be different from one person to another, even though representing the same task. The next task, T2, is the coordination of the activity and information sharing with the other pilots. T2 is represented by the vector AR (0,0.5,1,1.5,0.6,0.6,1,1). When attempting to execute T2 the updated AR corresponds to (-0.7,-0.5,-0.7,0.1,0.55,0.5,-1.3,-0.9). The resources are not enough to execute T2 at the same time with T1. The pilot needs to be a little more experienced so that he/she can automate more tasks and then require less resources for T1 and T2. An acceptable vector of T1 and T2 would be (0.9,0.9,0.2,0.5,0.2,0.2,1,0.4) and (0,0.3,0.5,0.5,0.5,0.5,0,0.4) respectively.

5.4. Analysis

Based on Wickens's theory an algorithm is designed to allocate the required resources to each task depending on the situation. Originally Wickens proposed this theory to predict whether or not two tasks can be executed at the same time. The algorithm proposed in this work used the same theory extending its capabilities to simulate the execution of two or more tasks at the same time.

The effectiveness of the algorithm is not easy to assess. One of the potential shortcomings of the algorithm is that it is not associative. In other words, executing T1 then T2 is not the same as executing T2 then T1, as far as resource allocation is concerned. Yet, the associative nature of this phenomenon has yet to be established.

The goal of introducing the allocation/deallocation algorithms in the larger scope of the work is to allow an implementable model of Scherer's theory (K. Scherer, 2001). Scherer's theory introduces components working in parallel. However, it does not specify how these components will work. Each component requires a number of resources and as the resources are limited, components should have a working policy that allow them to be consistent with the available resources.

5.5. Combination with Scherer's model

The main goal of the introduction of the multiple resources theory in this work is to allow a more realistic emotional simulation. As mentioned above, Scherer's theory does not offer a mechanism on how the different components will dynamically interact. It only provides a high-level abstraction. A question that can be asked is: When can the appraisal values be updated? Is it after executing coping, as is the case in circular models? Is it in parallel while other components are working?

From Scherer's definition they should be working in parallel (K. Scherer, 2001). To illustrate, let us consider the example of a kid bumping into Bob and examine the different possibilities and how would they be implemented. First scenario, Bob pushes the kid back. This scenario can be implemented by most models since there is a reaction (coping) after appraisal. Bob can do other appraisals and copings after that. Second scenario, Bob only looks at the kid expecting an apology. Again, in this scenario although the appraisal and coping could be different from the first scenario, this case can be implemented by most models since it is appraisal followed by coping. The third scenario is: when Bob tries to push back the kid, he stops in the middle of the action. This scenario is more complex. How would stopping the action midcourse be modelled? This scenario involves appraisal at the same time while executing coping. Meaning that initially, Bob uses a first appraisal then launches the action of pushing the kid back. While pushing back is being executed another appraisal takes place, realizing that it is a kid, which corrects few values of the first appraisal. From the new values Bob coping strategy changes from what happens in the first scenario to what happened in the second one. This scenario clearly requires parallel processing of the different components.

To decide whether Bob is going to stop his action midcourse, the multiple resources model is used. The algorithm decides whether there is room for resources for parallel appraisal while the action of pushing back the kid is executed. Still, one problem occurs, it is whether further processing for appraisal to cancel the action will be considered as a separate task or not. However, such decisions are beyond the scope of this work.

5.6. Evaluation

To evaluate the proposed algorithms, three scenarios are considered. These scenarios are well known in the literature and have been analyzed by many studies. The first scenario is driving while using a cell phone. In (Hancock et al., 2006) it is mentioned that the inability to use a cell phone while driving is due to the use of hands and thus sharing this resource with driving activity. This means that using a hand free phone is more usable than a standard one while driving. Let's examine how to model this scenario with the proposed algorithm.

First, let's assume the initial resources vector AR as follows: (3,3,3.5,2.5,3,3,2.5,3). The driver starts driving, the vector representing this task will be T1= (1,1,0,0,0,0,1,0). After that the driver tries to use the cell phone. This task is represented by the vector: T2= (0,0,0,1,0,0,1,1).

The values of the AR will be:

- Initially AR= (3,3,3.5,2.5,3,3,2,2)
- After executing T1, TR= (2.0,2.0,2.9,1.9,2.3,2.3,1.5,2.4)
- After executing T2, TR= (1.2,0.79999995,2.1000001,0.100000024,1.0999999,0.9,-0.29999995,0.4000001)

As it can be observed after an attempt of executing T2, one of the resources values is negative which means that T2 cannot be executed in its current form.

Now let's see if using a hand free phone instead of a standard one can change the outcome. T2 will be substituted by T'2= (0,0,0,1,0,0,0.1,1). The only difference between T2 and T'2 is the resource required from a Spatial Response which is substituted from 1 to 0.1 (a hand free phone does not require any special response). In this case the outcome will be:

- AR= (3,3,3.5,2.5,3,3,2,2)
- After executing T1, TR= (2.0,2.0,2.9,1.9,2.3,2.3,1.5,2.4)
- After executing T'2, TR= (,1.2,0.79999995,2.1000001,0.100000024,1.3,0.9,0.29999995,0.4000001)

TR's values are still all positive which means that T'2 can be executing along with T1. This first scenario has shown the possibility to simulate two linked scenarios with different outcomes. It should be noted that the effectiveness of the algorithm also depends on how the resources and tasks are being coded and how the values are selected. The algorithm can give results depending of the resources and tasks vectors. Still, it is worth to recall that being able to execute both tasks depend also on the individual and how much resources are required for both. An experienced person may need less overall resources to drive than another person. Also, if the values of the available resources AR at the end of both scenarios are examined, the second scenario seems barely feasible since some resources types are close to 0.

The second scenario is the case of multimodal interfaces in the cockpit of modern cars. This kind of interfaces has been successfully implemented (Kramer et al., 2005). In this scenario auditory navigation information are communicated to the pilot whereas sensory cues are used to warn the pilot about some critical events like the presence of an obstacle in the blind spot (Hancock et al., 2006). This implies that using these three channels of communicating three different event has better chance of succeeding than using only one or two channels. Let's consider the resources vector AR= (3,3,3.5,2.5,3,3,2,2), T1=(1,1,0,0,0,0,1,0) which is the driving task, T2=(0,0,0,1,0,0,0,0) which is using auditory channels and T3=(0,0,0,0,0,0,0.3,0) which is sensing touch events. Executing them at the same time implies:

- AR= (3,3,3,3,3,3,2,2)
- After executing T1, TR= (2.0,2.0,2.4,2.4,2.3,2.3,1.5,2.4)
- After executing T2, TR= (1.2,0.79999995,1.6000001,0.60000014,1.3,0.9,1.1,1.6000001)
- Then after T3, (0.68000007,0.53999996,1.0800002,0.34000015,0.5199999,0.38,0.0,0.8200001)

From these results the algorithm predicts a success with this configuration. Let's see if we change one of the modalities from auditory to visual with the same quantity of required resources. T2 will be replace with T'2= (0,1,0,0,0,0,0,0) which uses the visual-verbal modality instead of the auditory-verbal one with the same quantity. The results are as follows:

- AR= (3,3,3,3,3,3,2,2)
- After executing T1, TR= (2.0,2.0,2.4,2.4,2.3,2.3,1.5,2.4)
- After executing T'2, TR= (0.79999995,0.20000005,1.6000001,1.2,1.3,0.9,1.1,1.6000001)
- Then after T3, (,0.27999997,-0.059999943,1.0800002,0.94000006,0.5199999,0.38,0.0,0.8200001)

This configuration is not predicted to succeed, although the first two tasks are predicted to succeed in parallel, adding the third one will drain the resources. These predictions seem to be in line with the current applications of using the three different modalities to communicate information successfully to the pilot instead of using less channels to communicate what is required.

The third and last scenario that will be examined deals with resources within a single task. By contrast, the previous two scenarios examined the predictions of the presented algorithm with concurrent tasks and seemed to have a good level of accuracy. However, how the algorithm performs in predicting the behavior under resources used by one single task could be different. (Spence and Driver, 1996) demonstrated that directing attention to a spatial location, improved both visual and auditory discrimination. This suggest that intra-task resources sharing is not only the sum of the required resources but can be less than the sum. Studies by (Vroomen and Gelder, 2000), (Ernst and Banks, 2002) and (Duncan et al., 1997) also states that using auditory channels improve visual perceptions within the same task. The task that will be evaluated reflects the findings of the previous studies. A person trying to understand a talk while listening to and watching the interlocutor. Using both channels improves the understanding. This means that using auditory and visual channels adds very little or no workload on the other channel. Let's AR= (3,3,3,3,3,3,2,2) and T= (0,1,0,1,0,0,0,0) which is the vector representing the task of watching and listening to an interlocutor. After executing T, TR= (2.4,2.0,2.6,2.0,2.5,2.3,2.3,2.6). Unsurprisingly, T can be executed without any problem. However, the previously mentioned studies suggest that there is no visible interference between modalities by predicting better performance. This can be explained by some of the resources used by the visual channels like the executive control resources are the same that are used for the auditory channels. This can be seen by the algorithm's result on the updated TR where for example the first value VS has been updated yet no direct resources on T1 is using VS. This is due to the shared resources between VS and VV and AV which include the executive control resources. The algorithm is faithful to Wicken's theory where there is no interference between the resources of a single task. The given justification in the theory is that the different resources within a single task will be used sequentially in most of the time. In the above scenario, both resources *auditory* and *visual* are being used at the same time yet very little to no interference is observed. The algorithm is performing reasonably well in its prediction. However, further investigations need to be carried-out to determine whether this improvement on performance reduces the resources required or is related to a different concept. Another task where intra-task resources can interfere is taking notes (Wickens, 2008). This task requires writing and listening at the same time. Yet, unlike the previous task the interference is clearly there. A preliminary explanation, is that what is being listened to can be different than what is being written at a particular moment (writing can be delayed while other auditory information is being received). In this case the algorithm will perform poorly as it supposes that there is no interference unless the task is divided into subtasks.

The algorithm performed reasonably well on the three scenarios. However, three scenarios are not enough to assess its validity in every scenario. Moreover, the performance of the algorithm is highly related to how good is the coding of the available resources (TR) and tasks vectors. For example, on the last scenario presented although the results seem satisfactory, the studies do not say that there is no interreference at all. There might be some interreference between the resources within the same task even if it is very little (or the opposite). Also, the task of taking notes seems very challenging for the algorithm unless it is presented in a different way. This suggests that tasks can be related in some way and the degree of the link between tasks can also influence the level of interference. For example, if the task of taking note while listening is separated into two tasks T1 (taking notes) and T2 (listening). T1 and T2 are related in a way. The level of the relationship between T1 and T2 may influence the level of interference i.e. highly related tasks interfere less with each other with no interference to very little interference in fully related tasks like listening and watching an interlocutor. While unrelated tasks may observe a very high interreference. This introduces the concept of distance between tasks which can add more accuracy to the algorithm if implemented.

5.7. Conclusion

In this chapter, a technique is presented that allows multitasking when simulating emotions by directing attention. The emotional model used is that of Scherer's where attention is required at the earliest stages. Using Wickens' multiple resources model allowed the researcher to implement a mechanism to control attention in a dynamic environment. The vector representing tasks is simple enough for the designer as it does not represent tasks by precise body and mind resources but it rather uses elements representing groups of resources involved by the tasks (VS,VV,AS,AV,CS,CV,RS,RV). This representation is able to give a correct enough tasks coding. It is therefore the researcher's opinion that this coding gives an acceptable compromise between tasks representation and simplicity. From the work reviewed as part of this research, it is still unknown what are the exact elementary resources and their quantifications involved when performing tasks. Thus, an approximation is necessary.

Although the original aim is emotion simulation, the method developed as part of this study and presented in this chapter can be used for other types of simulation involving multitasking and cognition.

In this method, the maximum interference was taken as suggested by the formula but taking into account that, in reality, individual differences matter when executing two concurrent tasks. For example, an experienced driver might share resources between two tasks better than an inexperienced one. This means that not in every case the maximum interference is the one that applies. However, for the sake of simplicity and generalisation this assumption had to be made. Another potential problem may occur with the proposed algorithm which is the level of relationships between tasks and how can it influence the interference. This possibility has not been studied in Wicken's theory and deserves proper investigations. The interaction between the affective state and the available resources should be examined more. This is particularly the case when experiencing some types of emotions can reduce the amount of resources available (arousal influence is an example). Does experiencing a particular affective state use the same resources as the other eight elements? Does it involve other types of resources? A study of changes in subjective feelings, their resource requirements and their interference with other tasks is required. Another potential application of the multiple resources modelling is its use in motivational states. Motivational states are states that can trigger an action such as hanger or fear, can interact with emotion or with the affective state. An example can be found in the work of Bolles and Fanslow who proposed a model (Bolles and Fanselow, 1980) of interaction between emotion and affective states. The multiple resources model can play a role in this kind of simulation making it more accurate. For this, the resources required by motivational states need to be determined and compared to the resources required by affective states and tasks. Inhibition takes place when a more urgent task, including affective state modification and motivational states, requires more resources to be executing. Another less important task can be cancelled to free the required resources. This method will be a generalisation of tasks' simulation including the internal ones such as motivational states. However, this requires a study of the resources involved and their interaction in the motivational and affective states. Finally, the concept of distance between tasks is introduced during the evaluation.

6 Evaluation

The goal of this computational emotional model is to allow software agents (an intelligent software entity) to simulate emotions more realistically. For that, a continuous appraisal process is adopted. At each stage, a different set of variables are checked and the affective state is modified accordingly. Thus, each event is susceptible to produce a series of affective state variations.

In this evaluation, the researcher assesses the believability of the produced emotions in different scenarios using the described model (chapter four). The hypothesis that is subject to evaluation is the following:

"The way sequential checks are conducted can account for individual differences and therefore make the simulation more realistic for certain profiles". E.g. some people give more weight to one of the checks over the others. This hypothesis means that if it is true, sequential check (progressive appraisal) can be more appropriate for certain profiles. Meaning that some profiles shows in a clearer way that they evaluate the situation progressively. Other profiles may not display that they conduct a sequential check to the events happening to them. However, they may apply the sequential check very quickly or they may not.

6.1. Solution Design

A framework has been developed to implement the proposed architecture. Using that framework three scenarios were implemented. Each scenario with the possibility to use the emotional model proposed, a basic model that generates one affective state from an event and randomly generated affective states from events. Each agent is represented by its own thread. An agent has an emotional module, a resources module and a facial expression generator module.

Java 7 has been used to develop the framework and the three simulations. All the modules has been coded from scratch except for the facial generator module where the AffectButton tool (Broekens and Brinkman, 2013) has been adapted to produce the animated faces of the agents.

As it can be seen in figure 6-1, an agent has a reference to an Emotional Module interface. This is the implementation of the Bridge design pattern (Gamma et al., 2002). It allows to decouple an abstraction from its implmentation. In our case emotional modules can be plugged thus allowing the agent to be decoupled from its emotional implementation. Using the bridge design pattern allowed a flexibility in the modification of the different emotional modules while evaluating the contribution since three types of models were used at different moments.

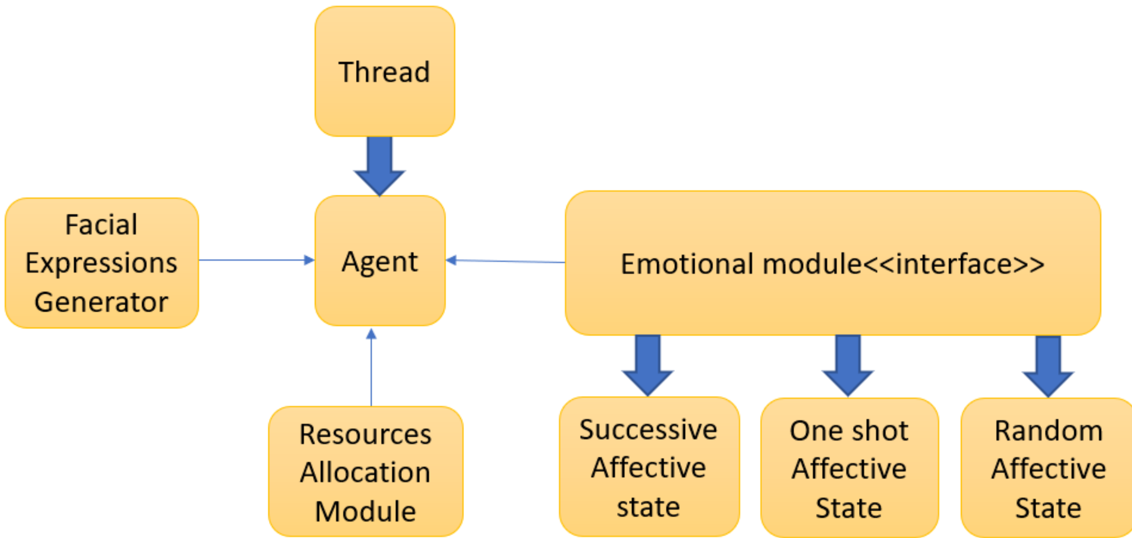

Figure 6-1 Software Architecture of the Framework from an agent point of view (UML style)

As shown in figure 6-1 the three emotional modules that are developed implement (inherit) the emotional module interface and are pushed into their respective agent. Thus, an agent will use the emotional module assigned to it without modifying its internal structure yet behaving accordingly.

Figure 6-2 shows the diagram of the environment with its agents and events.

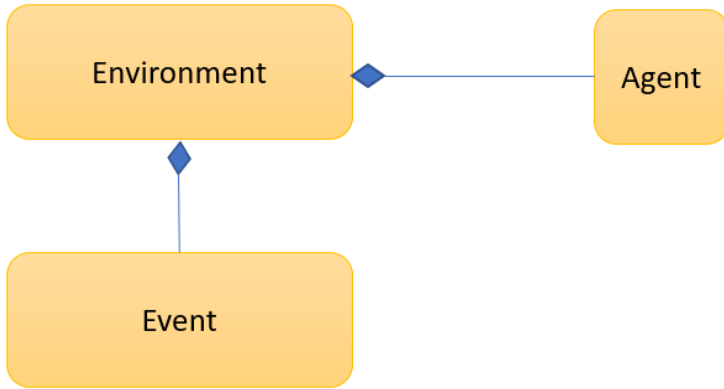

Figure 6-2 Composition relationships between the Environment. Agents and Events

6.2. The Participants

Nineteen volunteers were selected to take part in this evaluation. All of them are students at the University of Northampton and come from different backgrounds. Their age ranged from 19 to 33. The participants evaluated the simulations separately to prevent them from influencing each other in case they express a view or ask a question.

6.3. The Process

Three different scenarios were shown to the participants, each one in three different settings. The settings are:

- Randomly generated affective states whereby each event generates one variation in the affective state randomly. This is used it to set a baseline between rational emotions and non-rational ones. Only two values "below settings" are taken into consideration, if they significantly differ from the random setting.
- Fixed point generated affective states. In this setting, each event can trigger only one modification of the affective state using all of the variables at once (instead of a curve). We use the average values of the four calculated points described in chapter four to produce only one PDA point (averaging the four points into one point).
- Dynamic emotions using the model described in this work (using the four points as described in chapter 4).

The three different scenarios are described as follows:

1. The first scenario is to test how an agent would react to a complex event. In this scenario, a present is given to a virtual agent. The gift instantaneously turns into a pumpkin. This scenario is used to simulate a dynamic event where a succession of appraisals may take place. Table 6.1 shows the events happening during this scenario:

Table 6.1 Scenario 1 events

Event Vector	Moment(s)	Description
1f, 0.7F, 1f,1.0f, 0.2f, 0f, 1f,-0f, -0.2f,0.7f, 0.7f, -0.9f,-0.9f	2s	A present is giving to the agent that turns instantaneously into a pumpkin (like a bad surprise)

2. The second scenario is to simulate a prolonged fear. In this scenario, an agent is facing a bear that is going to attack it. After few seconds, the bear is neutralized. Sharp fear and relief are simulated using the three different settings to compare how they perform. Table 6.2 shows the events happening:

Table 6.2 Scenario 2 events

Event Vector	Moment(s)	Description
0.4f, -0.4F, 1f,1.0f, 0.8f, -0.9f, 1f,-0.7f, -1f,-0.9f, -0.9f, -0.5f,0.2f	5s	A bear appears threatening the agent
0.7f, 0.4F, 0.8f,1.0f, 0.8f, 0.9f, 1f,0.9f, 1f,0.0f, 0.0f, 0.5f, 0.5f	10s	The bear is neutralized

3. In the last scenario, a driver is driving a car while listening to the radio. The driver listens to a number of sequential news and also experience two events. The first one a bird flies in front of the driver. The second one a school bus blocks the road to the driver causing traffic congestions. In this scenario, different kind of events take place allowing the participants to give a general judgement for a multitude of events. The list of events that happen to the agent are described on table 6.3:

Table 6.3 Scenario 3 events

Event Vector	Moment(s)	Description
0.3F, 0.9F, 0.8F,0.9F, 0.4F, 0.6F, 0.7f,0.6F,0.5f, 0.8F, 0.8F, 0.8F,0.8f	3s	Favourite Football team scored (news on radio)
0, -1F, 0,-1, 0, 0, 0.8f,-1F, 0.2f, 0.1F, 0.1F, 0.1F, 0.1f	18s	Favourite Football team lost! (news on radio)
0, 1, 1,1, 0, 0, 1,1, 1 , 1, 1, 1, 1,	32s	It will be sunny all day! (news on radio)
0, -1, 0,-1, 0, 0, 1,-1, 1, 1, 1, 0, 0	47s	The radio stops working
-0.8f, 0.1F, 0.7f, -1f, 0.5f, -0.5f, 1f, -0.5f,-0.5f,-0.8f, -0.8f, 0.5f,0.5f	60s	Bird appears in front of the car
0.3f, 0.0F, 0.3f, 1.0f, -0.0f, 0.5f, -0.0f,0.0f, -0f, -0.0f, -0.0f, 0.3f,0.4f	70s	The bird disappears
0.3f, 0.7F, 0.3f, 1.0f, -0.5f, 0.5f, -0.7f,0.7f, -1f, -0.9f, -0.9f, 0.3f,0.4f	80s	Traffic jam starts

The face of the driver is constructed using AffectButton tool (Broekens and Brinkman, 2013). This tool has originally been developed to allow an affective state self-report. We have adapted this tool to make it synchronized with our emotional model and produce an animated face from the PDA values.

6.4. Simulations results

After conducting the three scenarios in the three different settings the PDA values of the agent are as follows (table 6.4, table 6.5 and table 6.6 shows the appraisal values of scenario 1, 2 and 3 respectively):

Table 6.4 Scenario 1 appraisal values

Event	Time	PDA (Scenario fixed value)	PDA (setting: random)	PDA (setting: successive variations)
1f, 0.7F, 1f,1.0f,	2s	-0.04726261,	0.9819369,	• Initial values=

0.2f, 0f, 1f,-0f, -0.2f,0.7f, 0.7f, -0.9f,-0.9f		0.28, 0.79267377	0.25318345, -0.36875567	(0.0, 0.0, 0.0) • Pt1= (0.47969967, 0.0, 0.4816844) • Pt2= (0.29007843, 0.0, 0.64418685) • Pt3= (0.29007843, 0.24386728, 0.64418685) • Pt4= (-0.29117, 0.24386728, 0.64418685)

Table 6.5 Scenario 2 appraisal values

Event	Time	PDA (setting: fixed value)	PDA (setting: random)	PDA (setting: successive variations)
0.4, -0.4, 1,1.0, 0.8, -0.9, 1, -0.7, -1, -0.9, -0.9, -0.5, 0.2	5s	-0.5597757, -0.35999998, 0.77567595	-0.48058194 -,0.27031878 -,0.2983938	• Initial values= (0.0, 0.0, 0.0) • Pt1= (-0.36765477, 0.0,0.43918994), • Pt2= (-0.56639093, 0.0, 0.6191535) • Pt3= (-0.56639093, -0.278666, 0.6191535) • Pt4= (-0.37407282, -0.278666, 0.6191535)
0.7, 0.4, 0.8,1.0, 0.8, 0.9, 1,0.9, 1,0.0, 0.0, 0.5, 0.5	10s	0.5896498, 0.0 ,0.7800852	-0.29387552, 0.16673884, 0.88005644	• Initial values= (-0.37407282, -0.278666, 0.6191535) • Pt1= (0.22573614, -0.278666, 0.75978976) • Pt2= (0.4295117, -0.278666, 0.8226463) • Pt3= (0.4295117, -0.19306162, 0.8226463) • Pt4= (0.46308675, -0.19306162, 0.8226463)

Table 6.6 Scenario 3 appraisal values

Event	Time	PDA (Scenario fixed value)	PDA (setting: random)	PDA (setting: successive variations)
0.3F, 0.9F, 0.8F,0.9F, 0.4F, 0.6F, 0.7f,0.6F,0.5f, 0.8F, 0.8F, 0.8F,0.8f 0.6F,0.5f, 0.8F, 0.8F, 0.8F,0.8f	3s	0.48089576, 0.32, 0.7556788	-0.31800476, 0.840521, 0.4697968	• Initial values= (0.0, 0.0, 0.0) • Pt1= (0.4725594, 0.0, 0.38919687) • Pt2= (0.42753577, 0.0, 0.59040153) • Pt3= (0.42753577, 0.26130024, 0.59040153) • Pt4= (0.60502726, 0.26130024, 0.59040153)
0, -1F, 0,-1, 0, 0, 0.8f,-1F, 0.2f, 0.1F, 0.1F, 0.1F, 0.1f	18s	-0.17999999, 0.04, 0.4	0.8738164, 0.80067015, 0.1015725	• Initial values= (0.60502726, 0.26130024, 0.59040153) • Pt1= (-0.18354784, 0.26130024, -0.12722078) • Pt2= (-0.11865269, 0.26130024, 0.34575358) • Pt3= (-0.11865269, 0.20203172, 0.34575358) • Pt4= (-0.008815232, 0.20203172, 0.34575358)
0, 1, 1,1, 0, 0, 1,1, 1 , 1, 1, 1, 1,	32s	0.4, 0.4, 0.74586594	0.4192756, 0.7673738, 0.9500062	• Initial values= (-0.008815232, 0.20203172, 0.34575358) • Pt1= (0.4920267, 0.20203172, 0.5375415) • Pt2= (0.33866, 0.20203172, 0.6779498) • Pt3= (0.33866, 0.4725791, 0.6779498) • Pt4= (0.66000897, 0.4725791, 0.6779498)
0, -1, 0,-1, 0, 0, 1,-1, 1, 1, 1, 0, 0	47s	-0.2, 0.4, 0.4	-0.17888081, -0.6420951, -0.35877606	• Initial values= (0.66000897, 0.4725791, 0.6779498) • Pt1= (-0.15376273, 0.4725791, -0.077754565) • Pt2= (-0.098537296, 0.4725791, 0.3847773) • Pt3= (-0.098537296, 0.6671918,

				0.3847773) • Pt4= (-0.048807178, 0.6671918, 0.3847773)
-0.8f, 0.1F, 0.7f, -1f, 0.5f, -0.5f, 1f, -0.5f,-0.5f,-0.8f, -0.8f, 0.5f,0.5f	60s	-0.1856282, -0.35999998, 0.67952234	0.30136177, 0.8892487, -0.07293518	• Initial values= (-0.048807178, 0.6671918, 0.3847773) • Pt1= (0.19902533, 0.6671918, 0.39119446) • Pt2= (-0.18306868, 0.6671918, 0.5915362) • Pt3= (-0.18306868, 0.097267106, 0.5915362) • Pt4= (0.08064036, 0.097267106, 0.5915362)
0.3f, 0.0F, 0.3f, 1.0f, -0.0f, 0.5f, -0.0f,0.0f, -0f, -0.0f, -0.0f, 0.3f,0.4f	70s	0.16023768, 0.0, 0.67952234	0.38586015, 0.8681886, 0.029871026	• Initial values= (0.08064036, 0.097267106, 0.5915362) • Pt1= (0.26591438, 0.097267106, 0.49457392) • Pt2= (0.1729381, 0.097267106, 0.65189046) • Pt3= (0.1729381, 0.061770394, 0.65189046) • Pt4= (0.2619433, 0.061770394, 0.65189046)
0.3f, 0.7F, 0.3f, 1.0f, -0.5f, 0.5f, -0.7f,0.7f, -1f, -0.9f, -0.9f, 0.3f,0.4f	80s	-0.108794585, -0.35999998, 0.67952234	0.7314166, -0.9024376, -0.7638558	• Initial values= (0.2619433, 0.061770394, 0.65189046) • Pt1= (0.5486499, 0.061770394, 0.52475107) • Pt2= (0.14335223, 0.061770394, 0.670131) • Pt3= (0.14335223, -0.2944076, 0.670131) • Pt4= (0.24782938, -0.2944076, 0.670131)

6.5. Findings

First, we will analyse the findings of each scenario and then make a synthesis of all of them. What follows are the findings for each scenario:

Scenario 1

Within the questionnaire (see Appendix 1) the focus is on questions 7, 8, 12, 14 and 15. These questions are respectively:

7 - is that person a human being?

8- are that person's emotional responses expected?

12- how realistic was the emotional transitions of that person

14- let's assume that person is a real human being how old do you think she/he is

15 - what is the gender of that person.

Participants had to answer by values from 0 to 10 to question 7, 8, and 12. Table 6.7 shows the participants' answers.

Table 6.7 Participants answers to the questions about scenario 1

Questions	Multiple variations	Single variation	Random case
	Mean	Mean	Mean
7	7.78	7.52	6.10
8	8.21	6.15	5.57
12	8.39	5.44	5.07
14	21.42	27.49	19.89
15	10:F, 7:M, 2:Both	5:F, 14:M	6:F, 10:M, 2: Both, 1: Trans

Question 7 deals with how likely the virtual character could be a real human being. The participants mean estimations was very close in multiple affective state variations and single affective state variation. Question 8 goes further by checking whether the agent's emotional responses were expected by the participants. The differences are important for this question. Multiple variations made more sense for the participants. Question 12 is about the emotional transitions. This question places more emphasis more on the variations instead of just the expectedness. The differences are significant here as well. The mean of age estimations was 21.42, 27.49 and 19.89 respectively in multiple variations, single variation and random case. As expected, the mean age of the single variation case is higher than the mean age of multiple variations. This can be explained by older people can control their emotions more and then display them less. Question 15 deals with the gender of the agent. Similarly to the previous question, the agent that displayed more variations in its affective state was more perceived as more feminine.

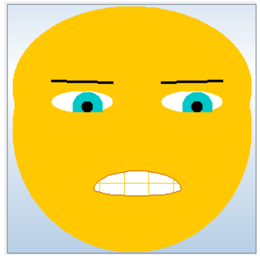

Figure 6-3 Example of a simulated face

Scenario 2

In this scenario, fear is simulated followed by relief. The difference between the multiple variations and single variation settings are not important for all of the questions. This is translated by the type of the event happening. The first event is a bear appearing and then second one is the bear being neutralized. In both situations (fixed and multiple variations) we treated what is happening as two different events. If we follow Scherer's theory we should have treated the whole experience as one single event. By gathering the feedback of the participants who judged the single variation as more realistic, we concluded that the primary reason was during the first event where there shouldn't be a normative significance phase. In the other hand, the participants who judged the multiple variation setting as more realistic was because of the second event where relief can be expressed better during the normative significance via a more dynamic face rather than a simple expression. From this finding, we can postulate that for some people some emotions can be more complex than a single state. Not as a combination of basic emotions but rather as a succession of variations in the affective state. In this case relief is expressed via phases. However, this still require more research. Also, attributing a higher age for the multiple variations settings is also due to the normative significance phase where there is an attenuation of intense affective states. Table 6.8 shows the participants' answers.

Table 6.8 Participants answers to the questions about scenario 2

Questions	Multiple variations	Single variation	Random case
	Mean	Mean	Mean
7	7.63	7.47	4.32

8	8.21	8.02	4.34
12	7.92	7.24	4.55
14	25.73	22.05	26.31
15	3:F, 14:M, 2:Both	3:F, 14:M, 2:Both	5:F, 13:M, 2: Both, 1: Trans

Scenario 3

In this scenario, the differences between the participants' judgements of the realism between the multiple variations setting and the single variation setting are not visible enough. However, the multiple variation setting is clearly perceived to be more feminine than the single variation setting. This is due to the different types of events happening where some generates successive different variations while others generate successive variations that are not too different. Successive different variations in the affective states can lead to perceive the agent as more feminine. Table 6.9 shows the participants' answers.

Table 6.9 Participants answers to the questions about scenario 3

Questions	Multiple variations	Single variation	Random case
	Mean	Mean	Mean
7	8.52	8.05	5.42
8	8.39	7.78	4.36
12	7.97	7.15	4.42
14	28.84	31.47	22.84
15	8:F, 9:M, 2:Both	2:F, 15:M, 1:Both	5:F, 12:M, 2: Both

6.6. Discussion

From analysing the three scenarios, we can observe that the first scenario was the most influenced by the multiple variation settings. The difference in realism in scenario 2 and scenario 3 evaluated through question 7, 8 and 12 is not strongly visible if we compare setting 2 and 3 (multiple variations and single variation). This is explained by the fact that some events may require less variations in the affective state than others. The presence of the normative significance phase was correlated with maturity when acting as a curve to some intense events while successive high changes in the affective states was correlated with feminine traits.

From these findings, we conclude that the sequential check can improve the realism in certain situations. In other situations, it does not contribute to improve it significantly. For scenario 2 and 3 the improvement was minor. Situations where realism improved are those involving complex events where all the variables/dimensions are relevant as seen in scenario 1.

This framework can be improved by defining where an event starts and ends and link it to a full cognitive reasoning system. The affective states variation will be linked to the speed of appraisal and actions. We also noticed that sequential check also allows larger possibilities in simulation where we have seen the possibility of perceiving a more feminine emotional display. Confirming theories stating that men tend to inhibit more emotions than women such as in (Jansz, 2000). As expected by the hypothesis.

We also observed that certain experiences where successive variations in the affective state was given one label for the whole experience by participants, such as in the first scenario where we had a positive reaction followed by a negative one. Many participants estimated it as surprise. This suggest that emotions can be a process as defined by appraisal theories rather than a single state.

Personality facets were not apparent enough to participants. This may be enhanced by including personality in the process of appraisal itself rather than only in its effect on the affective states. This can be done by including personality facets in the formulas of the four points of the affective state (pt1, pt2, pt3 and pt4).

Through this evaluation, only the general aspect of the model was assessed. Many sub aspects need to be evaluated such as the bias coefficients of the used formulas.

Comparing computational emotional models is quite challenging since their goals differ. For example FLAME's (El-Nasr et al., 2000) contribution is in creating dynamic conditioning where appraisal of events change over time depending on the experiences. EMA's (Marsella and Gratch, 2009) idea was in creating a dynamic appraisal and action selection through planning. WASABI (Becker-Asano and Wachsmuth, 2009) uses two level of emotions: primary and secondary emotions. Adding secondary emotions seems to make the simulate characters appear older. Each model is susceptible of having the edge in the area where it has contributed.

6.7. Conclusion

In this framework, we have developed a dynamic emotional model based on Scherer's model. Using sequential checks was as good as one appraisal check in some cases whereas in other cases sequential checks had the edge. Maturity and emotional stability were well represented via the normative significance check. However, the absence of a cognition model that can take time into consideration was the drawback of our method. Indeed, for checks to be realistic, time need to be taken into account. In our model, checks required more or less the same amount of time. Another area where our model can be improved is to determine where an event starts and when it ends. The bear scenario is the best example showing this point where in our opinion the whole scenario should have been considered as one event with checks keeping appraisal values updated.

Sequential checks also allowed the possibility of showing more feminine affective states.

An interesting observation was when participants judge multiple affective state transitions by one label. This was done during the first scenario where a positive affective state was quickly followed by a negative one. However, this could be the affective state they expected.

Finally, although Scherer's model is sequential, it does not exclude a parallel processing of information and appraisal. The sequence only means that the next stage will not conclude before the end of the previous one. Our model does not support parallel processing. Our next stage is to model parallelism where actions can be executed at the same time with appraisal and then change it at the same time.

7 Conclusion

In this work, a literature review from a computational perspective and a psychological perspective is done. Studying the problem from different point of views, allows a better understanding of the possibilities and the shortcoming of the available methods. It also allows to determine the different understandings of the researchers contributing in the field. Psychological models operate at a higher abstraction level and by looking at the computational models, we can find many different assumptions depending on how the psychological theories and the problems were understood by the authors even among researchers belonging to the same views. For example, in the appraisal families of emotional models, some view appraisal as the emotions themselves whereas others view appraisal only as a part of the emotional process (Scherer, 2000). Understanding all of these differences is a real challenge. Also, some differences can be subtle.

After studying the different theories, a model based on Scherer's theory was developed and implemented. This model used initially two of the five components from Scherer's theory. The appraisal component and the affect component. The appraisal component used sequential checks to produce a succession of variations in the affective state. Thus, each event is mapped in a continuous space producing a curve instead of one discreet emotion. To create the different values of the affective state from appraisal's variables/dimensions several theories and assumptions have been used (detailed in chapter 4). The second component is the affective state. A PAD space is used to represent it (Pleasure, Dominance, Arousal). This is by contrast to discreet emotions since the PAD space is a part of the dimensional theories and are generally viewed as competitors to appraisal theories. However, in our opinion there is no contradiction between using a dimensional representation of the affective state and Scherer's theory as in this theory affect is a component in its own and is open to any configuration. Appraisal (along with internal parameters) cause the PAD values to move continuously. The successive variations of the affective state allowed a greater expressiveness of the model. For example, the usage of social norms phase to conclude an emotional episode and then correcting appraisal from a wider point of view. The successive appraisal also allowed to account for differences in personalities in certain scenarios. However, it was noted that it should be correlated to the individual's traits/attributes. Results showed that activating the successive appraisal and disactivating it highlighted differences in the perceived gender of the simulated character by the respondents with high statistical significance. In the future, an analysis between the time allowed between the successive checks needs to be examined to determine if this is the main influence of the perceived gender of the character.

To allow a parallel execution of tasks, attention theories were investigated. An algorithm to allocate and free the resources was developed to predict and simulate the execution of several tasks at the same time. The expressiveness power of this method was discussed from different perspectives. Evaluation of this contribution showed a realistic simulation in certain cases whereas in other cases such as taking notes while listening to an interlocutor needs to be refined. The concept of tasks interdependence was introduced to be examined in the future. As expected, the proposed formula carries the strength and weaknesses of Wicken's model. This contribution was added as a component of Scherer's model to the whole developed model i.e. the motor expression component. This allowed the possibility of parallel execution of the different components during one or more emotional episode. The developed algorithm of the multiple resources model determines when a component can fully work depending on the available resources and the other tasks being executed. For example, after some appraisal values are determined following a stimulus, an action can be triggered (a coping strategy). If the resources allow it, appraisal can still continue while executing the action and then can trigger an action modification or even a cancellation. This allows the simulation of a wider range of scenarios. The algorithm assumes that sub tasks within the same task will be executed sequentially instead of in parallel. A full integration with the emotional model needs to be carried-out. This full integration requires three questions to be answered:

- How can a cognitive system be implemented to select the required coping strategies and directing actions based on goals?
- How the availability of resources affects appraisal and the other components?
- What resources are involved during an emotional episode (including affective resources) and how do they interfere with the other resources presented in chapter 2 and 5? Answering this question allows more possibilities for simulation such as reducing the possible coping strategies depending on particular emotional state. For

example, someone under intense fear and low dominance may not be able to execute certain actions like fighting.

7.1. Perspectives and future work

A list of possibilities of using the multiple resources algorithm was dressed at the end of chapter 5. Among them using the algorithm in the case of coding motivational states. Like the resources required for hunger and how it may inhibit tasks that shares the same resources but are less urgent. For example, fear can inhibit hunger. This possibility is worth being examined and thus provides a framework for simulating motivational states and tendencies more accurately. Also, the multiple resources algorithm is not associative nor commutative. This needs to be addressed and eventually corrected. Emotional resources need to be studied in order to accurately predict the interference between emotion related processes the other processes for a better simulation. The actual model only uses eight dimensions representing eight types of resources.

As far as the emotional model is concerned, personality traits variables are used only during the second phase which is generating the final values of the affective state. Appraisal is not influenced by the personality traits. In reality, this link may or may not exist and requires an investigation. Also, the influence of personality traits as shown during the evaluation can be improved.

Scherer's theory gives a particular order to the four checks. After their execution, these checks can reoccur updating the appraisal values. The policy of doing these new updates remains unclear and require a study to identify the process. During the evaluation, the successive checks have proven to be useful in certain cases and less useful in others. However, this might be due to the timing required for each check to take place. Indeed, this timing is very important for the believability of the scenarios. However, it is linked to the part of the process in other components, mainly the cognitive component and the speed at what the variables/dimensions are inferred from the stimulus and context.

The influence of two other components is yet to be determined: The *Action Tendencies* component and the *Autonomic Physiology* component.

The evaluation of the multiple resources algorithm and its combination with the whole model need an appropriate strategy that will require more scenarios and metrics.

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Appendix 1

Questionnaire for simulation 1 ☐ 2 ☐ 3 ☐

Please watch the simulation till the end then answer the questions below. The full simulation takes less than 10 minutes.

1. In which country did you live most of your life?			
2. How long have you been driving?	.....Years		
3. Did you like the simulation? (0: you did not like it at all, 10: you were very delighted with it)	/10		
4. Do you think the driver is sympathetic? (0: very non-sympathetic, 10: very sympathetic)	/10		
5. Do you think the driver is empathic? (0: very non-empathic, 10: very empathic)	/10		
6. Is the driver's behaviour natural? (0: very non-natural, 10: very natural)	/10		
7. Is the driver a human being? (0: very unlikely, 10: very likely)	/10		
8. Are the driver's emotional responses expected? (0: very unexpected, 10: very expected)	/10		
9. Would you take a ride with the driver? (0: never, 10: definitely yes)	/10		
10. Is the driver neurotic? (0: very neurotic, 10: very non-neurotic)	/10		
11. Was the driver more emotional or more rational? (0: very emotional, 10: very rational)	/10		
12. How realistic was the emotional transitions of the driver? (0: non-realistic at all, 10: very realistic)	/10		
13. How would you rate the driver's conscientiousness? (0: very low conscientiousness, 10: very high conscientiousness)	/10		
14. Let's assume the driver is a real human. How old do you think he/she is?	.....		
15. What gender would you attribute to the driver?	. ....		
16. Would you like to watch a longer scenario involving the same driver (0: never, 10: yes, definitely)?	/10		

Appendix 2

Information Sheet for participants

Title: Evaluation of the Framework for modelling emotions

My name is Mohamed Redha Sidoumou. I am a PhD student within the School of Science and Technology, at University of Northampton. I am working on a piece of software that can simulate emotions in a virtual environment. To evaluate how good our software is in term of the simulated emotions by a virtual character, I would like to invite you to take part in the evaluation process.

This software represents an emotional model we have developed and we would like to compare it to other models. For this, you will watch three different simulations, each representing a different model then you will rate each one of them by answering a questionnaire (if you accept to take part in this evaluation process).

The team conducting this study is composed of:

Mohamed Redha Sidoumou	Research Student
Scott Turner Phil Picton Kamal Bechkoum	Supervisory Team

There are no risks involved with the participation in this evaluation.

The information given (by you) will be stored in my laptop and will be password protected. Your identity will remain anonymous throughout the process. A code will be assigned for each participant and you will be only known by your code. Once the research is completed, the information you provided will be destroyed. After writing the results of the study you will not be able to withdraw the information you have provided. The results shall be written within two months after data collection. This means you have two months to withdraw from the process if you wish.

You have the right not to participate. You can stop at any time if you do not want to finish the questionnaire. We advise you to stop any time if you feel any distress caused by the questionnaire. If you choose not to participate, everything will be as fine.

Thank you for your consideration.

If you would like to participate, please complete the consent form.

Appendix 3

Consent letter for participants

Dear Participant,

My name is Mohamed Redha Sidoumou. I am a student at the University of Northampton at the Department of Computing and Immersive Technologies. My supervisors are Dr Scott Turner, Prof Phil Picton and Prof Kamal Bechkoum.

You are invited to participate in a research whose aim is to model a Framework for modelling emotion for characters in virtual worlds. This research has been approved by the University of Northampton Research Degrees Board.

This questionnaire was developed to evaluate how good our Framework is in simulating emotions. There are no identified risks from participating in this evaluation. All data collected from this evaluation will be strictly confidential and you will not be directly referenced in any report.

Participation in this research is completely voluntary. The data collected from this study will be password protected in a secure laptop until the end of the research.

For any further information please contact me at mohamed.sidoumou@northampton.ac.uk

Thank you for your consideration.

Please sign if you have read the information above, you approve it and you are at least 18 years old.

I confirm that:

- I have read the letter
- I know I can leave the project at any time if I change my mind.

and I would like to take part in the project. ☐

I don't want to take part in the project ☐

Name & signature ……………………………… Date:……………………

Appendix 4

Ethics Application - Mr Mohamed Sidoumou: Ethics committee decision

Ethics committee decision

Action required

No action required

Decision

Approved

Notes

The Chair noted that the researcher had taken the Committee's advice and had met Dr Jowett to discuss the Committee's requirements. The Chair considered and approved the amended Participant Information Sheet and Consent Form.