Department of Computing

Simulation of Emotional Behaviours for Virtual Agents with Personalities

Yi Zhang

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This thesis contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

Yi Zhang

Date

Abstract

The last decade has witnessed an explosion of research interest on human emotion modelling for generating intelligent virtual agents. A number of computational emotion models are proposed. Among them, the OCC model is popularly accepted by affective computing researchers for its strong ability in emotion appraisal. Inspired by the OCC model, some other emotion models are also proposed including EM model and FLAME model. However, these models generally do not take personality into consideration. There exist a few emotion models that include consideration for personality, such as ALMA model, WASABI model etc. However, almost all of them use highly stylized stereotypes of personality types, which make emotional responses pale and unrealistic, far from the real world. Additionally, in most of the existing emotion models, virtual agents have very little sense of self-protection. They just passively accept all sorts of stimuli, even when the stimuli are harmful, with no ability nor intention to resist or dodge a harmful event so to protect themselves. Another problem for many existing emotion models is that they only produce a final emotional type without providing any detailed distinctions on Emotion Intensity (EI). For instance, smile, laugh and laugh-out-loud are usually treated equally, all regarded as *happiness*. Finally, almost all the existed emotion models do not have the ability to present the emotional changes as a dynamic process. The change of emotion should be a progression process, not a final result. Unfortunately this is missing in most of the existing models.

This thesis is aiming on establishing an emotion model with consideration on certain personalities. This model should also include a self-protection principle to increase its autonomy and help virtual agent against bad stimuli. Emotions are represented with various intensity levels in this model. In addition, the emotional changes subjected to external stimuli are modelled as a dynamic process that can be clearly represented and monitored through the changing values of PAD (Pleasure, Arousal and Dominance).

This thesis implements a basic emotion model including considerations of emotion, mood, instantaneous stimulus, duration stimulus and emotion decay. The well-known PAD (Pleasure, Arousal, and Dominance) model is embedded into the proposed model. All five basic emotional types *fear, anger, happiness, disgust* and *sadness* are well supported in the proposed model. This thesis assumes that changes of emotion from a stable status are caused by external stimuli. Once the applied stimulus is removed, emotion starts to decay and tends to go back to its neutral status. Two types of stimuli are considered in this work:

instantaneous stimuli which are removed immediately after they are applied; and the duration stimuli which are applied for a period of time. A stimulus is normally defined by a few key parameters such as *intensity, effect, desire* and *likelihood*, which are used to work out the valent caused by the stimulus. Moreover, *desire* can also be included to control the valent distribution during the time the stimulus is applied. Two personality models are introduced into the proposed emotion model, namely, Big Five Personality and NEO PI-R. Their effect on emotional changes are studied and evaluated. By comparing these two, it is found out that NEO PI-R provides a better measurement of different personality traits. Eleven facets out of the thirty facets in NEO PI-R are implemented in this emotion model, since the others have no direct affects to emotional changes.

A novel parameter, Emotion intensity (EI), is introduced to represent different strengths of the five basic emotional types. It is a very important scale to describe how strongly an agent feels that emotion. During virtual simulations, EIs of agents can be easily observed through agents' facial expressions and actions. In our experiments, facial expressions are used to represent the changes of EIs.

In addition, a Resistant value is introduced into our emotion model to enable virtual agents better autonomy when facing continuous negative stimuli. The Resistant value could be regarded as a kind of dislike feeling of the virtual agent. The dislike feeling gets accumulated when negative stimulus continues. It could start to decay when the harmful stimulus stops and returns to the neutral state. Two thresholds, named $Resistant_A$ and $Resistant_B$ are set to alter the values in the PAD model. This design is empirical based on observations described as follows. A virtual agent feels the emotion *sadness* when he initially gets hurt. Continuous application of the negative stimuli brings overwhelming feeling of being hurt (Resistant value over $Resistant_A$) which makes the agent feel totally helpless, emotion *fear* starts to appear. When the negative stimuli still continue (Resistant value over $Resistant_B$), the virtual agent starts to be desperate, emotion *anger* appears. He no longer fears, but could decide to fight back. With the introduction of the Resistant value, a mechanism is introduced for virtual agents to exercise self-defence and protection.

A 2D script driven RPG game is implemented in this research to evaluate the proposed emotion model with personality and the Resistant value. A number of experiments are conducted to the test emotional reactions of virtual agents with different personalities. Simple stimulus, hybrid stimuli, and multiple stimuli applied concurrently or continuously are used to evaluate the emotional changes of NPCs with different personalities in the RPG game. Highly satisfactory results have been achieved which demonstrate the ability of the proposed emotion model in simulating complex emotion.

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Publications

This thesis is based upon several works that have been published over the course of the author's Master Degree, listed as follows in chronological order:

- Yi Zhang, Ling Li (2013). A New Model with NEO PI-R for Emotion Stimulations. *Proceedings of the 2013 International Conference on Cyberworlds.*
- Yi Zhang, Ling Li (2014). A Personality Model Based on NEO PI-R for Emotion Simulation. *Journal of the IEICE TRANSACTIONS on Information and Systems.*

Chapter 1

Introduction

1.1 Background

The concept of affective computing is proposed by Professor Picard in 1997 at MIT Media Lab. She noted that affective computing is associated with the emotions and anything else which can exert influence on emotions. This technology is nascent, but has great potential in the field of computational intelligence (Picard, 2000).

The usage of affective computing technology is various, which includes but not limited to emotional speech, facial affect detection, body gesture, physiological monitoring and visual aesthetics. It could shed light on Internet-based therapy by creating new techniques to assess frustration, stress, and mood indirectly, through natural interaction and conversation. Building virtual intelligent agents with emotional computations can bring artificial intelligence technology into the next level. Such virtual intelligent agents not only can express their emotions, but are also able to understand the meaning of a certain amount of emotions, especially responding to human emotions. For instance, in e-learning situations, virtual intelligent agents can detect from available cues from various sensors and cameras when learners are having difficulties and automatically provide expanded explanations or decrease the difficulty level. Such virtual agents can either show up on the screen or be projected by holograph, vividly standing right in front of the learners, so they will not become frustrated easily or lose interest. In contrary, the difficulty level can be raised when a learner is interested and focused, providing them with better sense of satisfaction. Virtual intelligent agents can also be used to look after elderly or cognitively impaired people (Yaghoubzadeh *et al.*, 2013). Physiological monitoring, which is used to detect peoples' emotional state by monitoring and analyzing their physiological behaviours, sometimes through wearable devices with various sensors, enables people to have the ability to communicate affective-cognitive states with computer and multimodal channels of information can be analyzed (Picard, 2003). Such applications can dramatically increase the understanding of how affection influences peoples' health both physically and mentally, enabling users with more self-awareness of their affective states and guiding them to communicate with computers or with each other more effectively (Picard, 2000).

Affective computing could provide benefits in many areas, almost without limit.

There have been some arguments on how emotions and moods tend to contaminate purely logical computers, causing more problems, instead of helping to solve problems. Such arguments have been solidly refuted by a massive amount of work over the last two decades. For instance, the research work of Slovic (Slovic, 2000) , Gibson (Gibson, 2013), Hoffmann *et al.* (Hoffmann and Russ, 2012), Stolorow (Stolorow, 2014) , Pettigrew and Andrew *et al.* (Pettigrew, 2014) covered perception, decision-making, empathic understanding, creativity and memory, each of which plays a vital role for affecting people's emotions in many underlying processes. These findings suggest that emotion greatly contributes to the intelligent functioning of computer systems and plays a crucial role in regulate and bias computational processes.

That being said, submarines do not swing their tails and airplanes do not flap their wings. Many living intelligent creatures having emotions does not mean that intelligence requires emotion. There always are some alternative choices. Propellers may not look like tails or wings, but still provide the same or even more locomotion power. Since humanity rises, people never stop learning things from nature. As the most intelligent creature on earth, why can not human beings learn things from themselves? Many people are fond of Spock, the half-Vulan, half-human character in Star Trek (Asherman, 1986). He is highly intelligent, highly rational and highly unemotional (Picard, 2003). There might be some species existing in the Universe who are more intelligent than human beings. But for now, we do not know where they are. Improving Artificial Intelligence technology by researching ourselves is a very good start.

The research of affective computing combines engineering and computer science with psychology, neuroscience, psychophysiology, sociology, education, cognitive science and more (Picard *et al.*, 2004). The improvement of human affective experience with technology requires a lot of efforts. The goal of affective computing is to make machines work more effectively, not just making them more emotional. Affective computing focuses on the balance between express/forbear emotions, sense what others are feeling and ignoring. It is about how to use emotions in intelligent interactions and decision makings (Picard, 2003). Computational models need to be proposed to fulfil this seemly impossible task.

In the latest two decades, more and more researchers work on computational models of human emotional process, trying to disclose this secret and making machine or virtual agents (or non player characters) start to feel. Based on the different research theories, many computational models are proposed, such as OCC, EM, FLAME and PAD etc. Detailed discussions on them will be provided in Chapter 2.

1.2 Motivation and Objective

There are a number of disadvantages in the existing computational emotion models.

- Many emotion models do not take personality into consideration, although some do combine with personality. Up to date, almost all the existing emotion models with personality considerations use highly stylized stereotypes of personality types and emotional responses, in turn make emotional response pale and unrealistic, hardly able to correspond to real behaviours of real people (Picard, 2003).
- The virtual intelligent agents in most of the emotion models have very limited sense of self-protection. They just passively accept various stimuli, even when the stimuli are harmful. Agents are often not designed to know how to protect themselves, or rise against negative or harmful stimuli (Picard, 2003).
- Many emotion models just produce a final emotional state and fail to monitor the emotional changes during the whole process.
- Many emotion models can only provide emotional status the agent ends up with. It does not provide any information on how strongly the agent feels that emotion. Emotions such as smile, laugh and laugh-out-loud are usually treated equally and regarded as *happiness*.

This research aims to improve the computational emotion models. The desired improved emotion model should have the following features:

- The improved emotion model should come with a set of personalities. Based on which facets of personalities they belong to, the virtual agents will have different and rational emotion responses and behaviours.
- The improved emotion model should have the ability to show different strengths of emotional status.
- The emotional change should have a clear development process. The process should be represented by the emotional value changes demonstrated clearly against a time-line.
- Virtual agents should possess a self-protection mechanism. When dangerous or bad things occur, the agents should have the ability to protect themselves. For instance, a boy was bullied very hard. He might become suicidal, to protect himself from

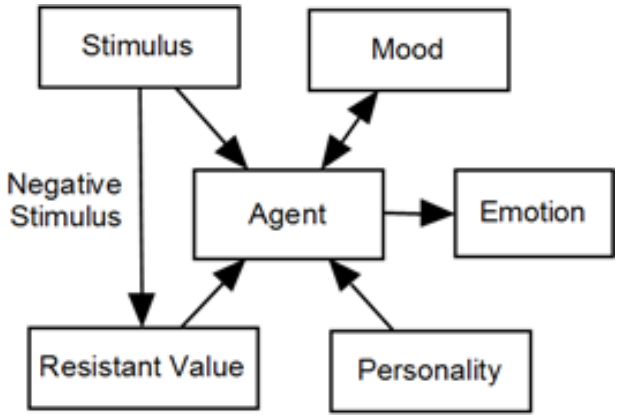


Figure 1.1: The overview of the proposed emotion response model

getting hurt again and again. Or he might become angry and decide to fight against the bully, which might stop the continuous bully on him.

1.3 System Framework

Emotions are proven to play a crucial role in human intelligence. Many emotion models have been proposed for intelligent virtual agents (Salmeron, 2012). This research aims to propose an improved emotion model expected to simulate personalized emotion response more realistically. In the proposed emotion simulation system, the well-known PAD emotion model is used to represent basic emotions, which includes *anger, disgust, fear, happiness* and *sadness*. The personality model NEO PI-R is incorporated into the PAD model to simulate emotional responses of people with different personalities. Their Resistance value to certain negative stimuli will also play an important role in their reactions.

Figure 1.1 demonstrates the workflow of the proposed emotion response model. Emotion is the only output for an agent. It is an affective state of consciousness. A stimulus is an object or event that is apprehended by the senses. It is one of the fundamental factors causing emotional change. In this research, many different kind of stimuli are considered. The simplest single stimuli, such as positive/negative/instant/gradual stimulus, are included. Multiple stimuli, hybrid stimuli and continue stimuli are also considered to test their different effects in the improved model.

Mood is a state of quality of feeling at a particular time, another key aspect in this model. It is also an emotional state, just a bit more stable than an instantaneous emotion reaction and lasting relatively longer than emotion, Mood can be in effect for hours, days or even

longer (Hudlicka, 2008). When people are in their good mood, small bad things will not kill their happiness. In contrary, small good things are hard to cheer up people in bad mood.

Emotion changes all the time and generally emotional changes do not last long. They could last only in milliseconds or seconds. In this research, we assume emotional changes are only caused by stimulus/stimuli and every emotion decays within its own decay phase.

Emotion Intensities (EIs) along with emotional types are used to describe emotional changes of virtual intelligent agents in this project. It changes dynamically through the whole process. During experiments, EIs of agents can be easily observed and monitored through their facial expressions.

Personality is the soul of people, which is relatively stable for a particular person. Many aspects affect people's personality, such as life experiences, upbringings, educations, etc. Personality plays a significant and powerful role in emotion reactions. It often affects emotion responses greatly.

The Resistant value is a novel parameter proposed in this research, specifically for negative stimulus. In a way, it can be regarded as a "Hate" valence inbuilt in the agent. It is effective when simulating some critical situations. For example, a bullied kid could fight back, and a wounded animal could hurt their hunter when they have no way to run. This is a very basic rule for creatures to survive in the nature, and the proposed Resistant value attempts to simulate such a rule, although in a simplistic way.

1.4 Significance and Contributions

A novel computational emotion model has been proposed with personality model based on NEO PI-R incorporated, which makes the simulation of intelligent emotions much more realistic and believable. This model is based on the PAD emotion scale to demonstrate the emotional changes. By focusing on the internal difference of virtual intelligent agents, their personalities and resistance to negative external events are simulated in much greater details. Emotion Intensities (EIs) are used to produce various facial expressions of agents. It provides an easy way to observe agent's emotional changes. A number of experiments are conducted, which proves that the proposed emotion model can simulate rational emotional changes which demonstrate more personality effects. With the improved model, much more human-like agents can be produced and simulated.

1.5 Structure of the Thesis

In this thesis, a novel model based on NEO PI-R is proposed to simulate different personalities for intelligent agents. Further, a Resistant formulation is proposed for the simulation of the complicated and often confusing negative emotional types *anger, sadness, fear* and *disgust*. The personality model and the Resistant formulation are incorporated with the PAD emotion model to simulate unique emotional responses of intelligent agents to certain stimulus/stimuli based on their own personalities and Resistant values. A RPG game is created to demonstrate the performance of the improved models. Experiments show that the proposed personality model is able to provide better descriptions on different personalities compared to existing models and subsequently produce more reasonable and believable emotional responses. The rest of the thesis is organized as follows:

Chapter 2 provides the literature review in the related research fields. It discusses many different emotion models including OCC, EM, FLAME, Ekman, and PAD. Research attempts to simulate personality in affective computing, especially two personality models Big5 and NEO PI-R, are also discussed.

Chapter 3 describes our methodologies in modelling emotions. In this chapter, a basic emotion model is formed which include considerations on emotion, mood, stimulus and emotional decay.

Chapter 4 discusses the improved emotion model, focused on personalities being considered during affective computing. Personality models Big5 and NEO PI-R are discussed and compared. The proposed personality model based on NEO PI-R model and how it can be incorporated into the PAD emotion model are discussed in details. The formulations of the Emotional Intensity and Resistant value are also discussed here.

Chapter 5 describes the experiments conducted to demonstrate the different emotional responses from different personality settings that our model is able to produce under various types of external stimuli.

Chapter 6 concludes the thesis and suggests some future research directions.

Chapter 2

Related Work

Significant progress has been made in computer science and its applications. However, it is still impossible for a computer to fully simulate human emotions. Emotion is an essential part of human intelligence. It is very difficult to analytically describe our emotion. In fact, researchers on emotions do not always agree with each other on the definitions of emotion, mood and motivation (Kopp and Wachsmuth, 2004). While it is possible for a robot to have artificial facial expressions as convincing as natural human faces (Moridis and Economides, 2009), the underlying factors driving the change of the expressions remain largely a challenge.

In 1988, the OCC model has established itself as the standard emotion model. Since then, more and more researchers extended the work, either refined the model itself or embedded it into their research (Ortony and Clore, 1988).

In 1995, Rosalind W. Picard is credited with starting the branch of computer science known as Affective Computing (Picard, 1995). Many researchers from different fields, such as computer science, human psychology, cognitive science and robot industries, try to find a way to measure emotions and emotional evolution. Many emotion models have been developed.

2.1 Emotional Models

2.1.1 OCC Model

The OCC (Ortony, Clore, & Collins) model (Becker, 2001; Ortony, 1990) is a classic model for emotions. Figure 2.1 below provides an overview on emotion processes in OCC model. Many research works on emotion begin from the OCC model (Moridis and Economides, 2009; Kanda *et al.*, 2008; Smith and Kirby, 2001). In this model, the cause of emotion is divided into three branches: consequences of events, actions of agents, and aspects of

objects, which include almost all the stimuli from the nature. With a series of responses to the above branches, agents can generate 22 emotional types, such as *joy, distress, hope*, and *fear* etc. Table 2.1 presents the detailed specifications of all emotional types mentioned above. It is a complex model that can be easily mapped into the real world.

2.1.1.1 Consequences of Events

The first branch of Figure 2.1 is the valanced reactions to the consequences of events. Agents express pleasure or displeasure with events and their consequences go through the whole branch. However, a difference is made between focusing on consequences of events for others and focusing on consequences of events for an agent itself. Assuming the agent is more concerned about the consequences for others, its final emotional type goes to *FORTUNES-OF-OTHERS*, which including *happy-for, resentment, gloating* and *pity*. If the agent is more focused on the consequences for itself, its emotional type will be further divided into *PROSPECT-BASED* and *WELL-BEING*, depending on whether the consequences are prospected by the agent or not. If the event is prospects relevant, the agent's emotional type ends up with *joy* for pleasant event, or *distress* for unpleasant event, otherwise its emotional type goes to *hope* for pleasant event, or *fear* for unpleasant event. Assuming the prospects relevant consequences get confirmed, the agent's final emotional type ends up with *satisfaction/fears-confirmed*, otherwise it ends up with *relief/disappointment*, for pleasant/unpleasant event respectively.

Considering the following examples, a virtual agent, Alice, heard that another agent, Jack, is running a very successful business. If Alice is a good friend of Jack, she will probably feel *happy-for* him. She is pleased about this event which is presumed to be desirable for Jack. This *happy-for* feeling perfectly matches its definition in Table 2.1. However if Jack is an enemy of Alice, this consequences of the event might be unpleasant to Alice. Her emotional type probably would end up with *resentment*, since she does not want Jack to have a successful business. In another example, Alice heard that she is going to be retrenched. This could lead to very serious consequences for herself. She prays (prospects relevant) with *fear* that it is just a rumor and nothing would happen to her. At the end of the day, she is notified that she is indeed retrenched and have to leave her job soon, *fears-confirmed*. Or she is told that the redundancy procedure has been cancelled for a certain reason. She probably would feel *relief*.

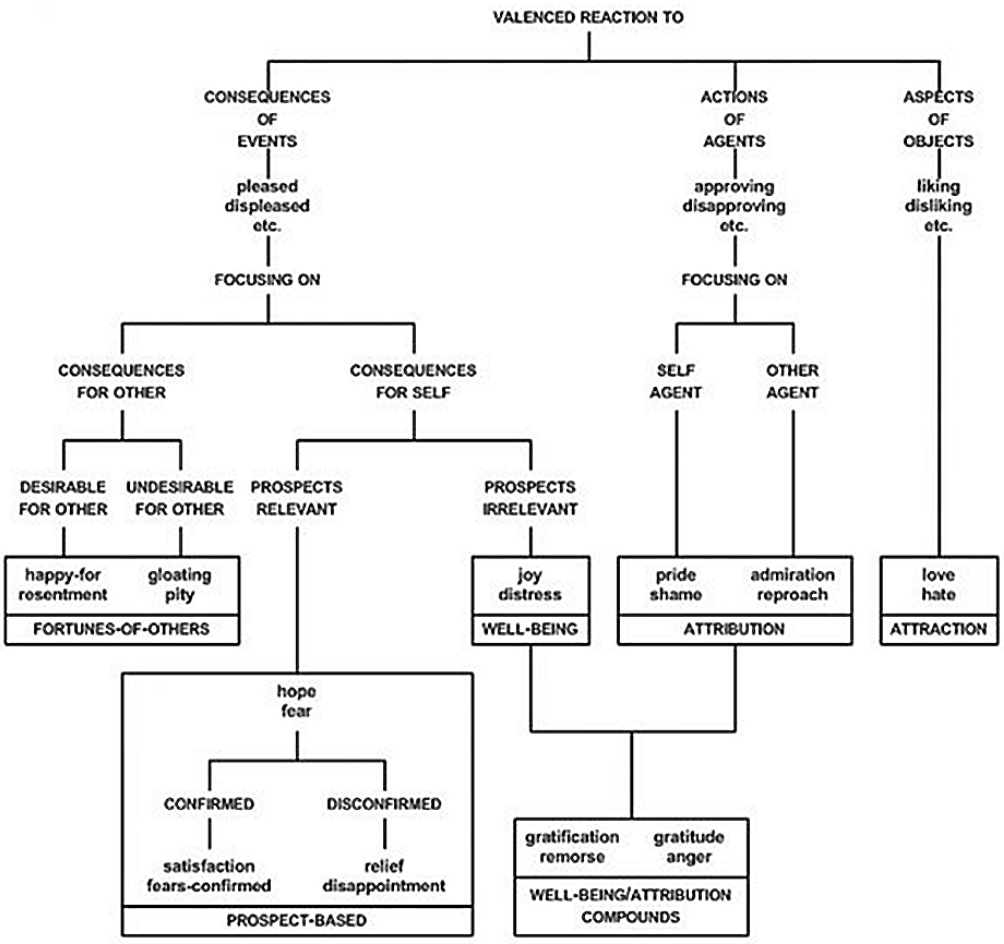


Figure 2.1: OCC emotional model (Ortony, 1990)

Emotional Type	**Definition**
Joy	(pleased about) a desirable event
Distress	(displeased about) an undesirable event
Happy-for	(pleased about) an event presumed to be desirable for someone else
Pity	(displeased about) an event presumed to be undesirable for someone else
Gloating	(pleased about) an event presumed to be undesirable for someone else
Resentment	(displeased about) an event presumed to be desirable for someone else
Hope	(pleased about) the prospect of a desirable event
Fear	(displeased about) the prospect of an undesirable event
Satisfaction	(pleased about) the confirmation of the prospect of a desirable event
Fears-confirmed	(displeased about) the confirmation of the prospect of an undesirable event
Relief	(pleased about) the disconfirmation of the prospect of an undesirable event
Disappointment	(displeased about) the disconfirmation of the prospect of a desirable event
Pride	(approving of) one's own praiseworthy action
Shame	(disapproving of) one's own blameworthy action
Admiration	(approving of) someone else's praiseworthy action
Reproach	(disapproving of) someone else's blameworthy action
Gratification	(approving of) one's own praiseworthy action and (being pleased about) the related desirable event
Remorse	(disapproving of) one's own blameworthy action and (being displeased about) the related undesirable event
Gratitude	(approving of) someone else's praiseworthy action and (being pleased about) the related desirable event
Anger	(disapproving of) someone else's blameworthy action and (being displeased about) the related undesirable event
Love	(liking) an appealing object
Hate	(disliking) an unappealing object

Table 2.1: The emotional type specifications of the OCC model (Steunebrink *et al.*, 2009)

2.1.1.2 Actions of Agents

The second branch of Figure 2.1 is the valanced reactions to the actions of agents. Emotional types in this branch are more related to approve/disapprove actions of agents. Again a difference is made between focusing on the agent itself and focusing on others. If the agent focuses on itself, it feels *pride* if his actions get approved, and feels *shame* if his actions get disapproved. If the focus is on other agent's action, its emotional type turns to *admiration* for approved actions, and *reproach* for disapproved actions. These four emotional types are included in a subset, namely *ATTRIBUTION*. Combining with the *WELL-BEING* from the first branch, a new subset *WELL-BEING/ATTRIBUTION COMPOUNDS* can be generated. There are four emotional types in this subset, such as *gratification, remorse, gratitude* and *anger*. The following rules show how they are generated.

Gratification equals to *joy* + *pride*

Remorse equals to *distress* + *shame*

Gratitude equals to *joy* + *admiration*

Anger equals to *distress* + *reproach*

Considering the first example in Section 2.1.1.1, Jack is running a very successful business. His success is approved by the public. He feels the *pride* when he looks at himself (focusing on self), while his good friend Alice feels *admiration* (focusing on other agent). Combining with emotions from the first branch, eventually, the emotional type for Jack ends up as *gratification*, since his success is approved by others, and he is pleased by this desirable event. Alice's emotional type ends up as *gratitude*, because she approves Jack's success and is pleased by that event as well. Similarly, *distress* and *shame* often leads to *remorse*, while *distress* and *reproach* more likely will turn to *anger*. Table 2.1 shows all definitions.

2.1.1.3 Aspects of Objects

The last branch in Figure 2.1 is the valanced reactions to the aspects of objects. The emotional types within this branch are very simple. If the agent likes something or someone, his emotional type becomes *love*. On the contrary, if the agent dislikes something or someone, his emotional type turns to *hate*. Assuming Alice likes Jack, she probably show love to him. The examples above are only intending to demonstrate the effects of different

branches of emotional causes. They are not presented for the purpose of analysing what emotions will occur in what mixtures or sequences (Ortony, 1990).

2.1.1.4 Classification

Classification is a stage where the agent performs scaled reactions to consequences of events, actions of agents, or aspects of objects, leading to information on what emotional categories are affected. Which one the agent chooses to respond upon depends on some knowledge, such as its Goals, Standards and Attitudes (Bartneck, 2002). It seems that the three branches described above include everything. However, it is actually not the case. Consider the following example. Mike wins a game, but he is injured during the game. It is hard to work out whether he is pleased or not. This is a very common situation for half goal accomplished. According to the second branch, it is hard to determine whether Mike's action gets approved or disapproved too. His actions might get approved by his parents, hence he might be proud for the victory. At the same time, his actions could be disapproved by his parents for the serious injury; He might feel *distress* as a consequence. Finally, in the last branch, there is no evidence showing what emotional type Mike will have. He may feel *love* for the success, or *hate* for the injury. This example is trying to demonstrate that people are not always dealing with a complete success/fail. Sometimes there are situations in the middle. Obviously, OCC model is not designed to handle them.

Additionally, a history model is missing from the OCC model. Agent should have certain memory. For example, Alice gets bitten by a dog when she is walking on a street. She feels *distress* for it is an unpleasant and undesirable event. She probably would feel *fear* or *distress* again if she walks on that street or encounters a similar dog again. This is an internal stimulus that could be represented in a history model, which is quite useful but not included in the OCC model.

Moreover, the whole model focuses on appraisal among the three branches and ignores the individual differences. In reality, different people going through the same event could experience dramatically different consequences. It is because of their different personalities, which is missing from the OCC model. Here is another example. Many people watch the same movie. Some people may smile for a happy ending, while others may cry because they are deeply touched by the story, but some others may be disappointed since the clich ending does not meet their expectations. Here the same external stimulus causes different emotional responses. Many factors contribute to such differences, but personalities play one of the most important parts among them. Personality sometimes acts as a magnifier, amplifying certain aspects of the environment while ignoring others when people respond

to the environment.

2.1.1.5 Quantification

In the quantification stage, the agent calculates the intensities of the affected emotion response resulting from the above three branches of causes. The intensities of the emotional categories resulting from events, actions and objects are defined as the desirability, praiseworthiness and appealing-ness respectively. More desirability, more praiseworthiness and more appealing-ness get more intensity valence, which sounds pretty fair. But such a strategy is not always right. Considering the example in Section 2.1.1.4, Mike wins the game, but he is injured. It is hard to work out the desirability. Victory is a desirable event, but getting injured is not. According to the second branch, it is hard to determine if this action is praiseworthiness too. In most cases, people feel like they lose something when they get some other things. Finally, in the last branch, there is no evidence showing whether this event is appealing or not, because the winner gets injured.

Emotions are so complex. Each emotion has its own intensity level. Some of them can be detected from facial expression, such as smile. People smile when they are greeting each other. People smile when their hard work gets rewarded. Obviously, the two smiles above are different on intensity. For instance, normally people will not laugh-out-loud for a simple greeting, which could scare off others. Thus, proper quantification is critical. Ranking all the intensity of events, actions of agents, and aspects of objects is an impossible mission, but we can start from normal daily life events, such as greetings, shaking hands, invitations etc. More can be achieved with the development of machine learning and artificial intelligence.

2.1.1.6 Interactions Between Emotions

The interaction between the different emotional types is another important aspect that is missing from the OCC model. Although the first branch and the second branch have some cross-over, emotions in the subset *WELL-BEING* such as *joy/distress* interact with emotions in the subset *ATTRIBUTION* such as *pride/shame/admiration/reproach* which subsequently generate four different emotional types, namely, *gratification, remorse, gratitude* and *anger*. In fact, the four generated emotional types are just the upgraded version of emotions in the subset *ATTRIBUTION*.

Interactions between emotions happen all the time. Consequences of events, actions of agents, and aspects of objects cross each other. Two examples are described in Section 2.1.1.1, Alice heard that her best friend Jack is running a very successful business; and she is retrenched from her current job. If the two events happen one after another, the current form of the OCC model will simply give *fears-confirmed* as the final emotional type. In reality, good news always brings extra bonuses to positive emotions which could greatly alleviate the effects caused by negative emotions, sometimes overwhelming it. For example, Jack offers her a new job which makes her very happy.

2.1.1.7 Mapping to Facial Expression

Emotions are often mapped into different facial expressions to communicate the emotions the character feels to the outside world. The Ekman emotion model (Ekman, 1992) is very popularly used, which supports six basic facial expressions of *happiness, sadness, anger, disgust, fear* and *surprise*. Interestingly, among the 22 emotional types, half of them are mapped into *happiness*, such as *happy-for, gloating, joy, pride, admiration, love, satisfaction, relief, gratification,* and *gratitude*. The rest are mapped into *sadness, anger, disgust, fear* and *surprise* respectively. With the help of context information, people might be able to distinguish what the real emotion is, even with the same expression. The examples in Section 2.1.1.1, Section 2.1.1.2 and Section 2.1.1.3 made this very clear by walking through the whole emotion appraisal tree, with different focusing targets.

2.1.1.8 Changing Facial Expressions

The duration of an expression might be very short, just a couple of seconds or even milliseconds. However, it still runs its course from the beginning to the end. Meanwhile, all emotions should have their duration phase and decay phase. Normally people will not smile half an hour for a simple greeting. Considering the following example, Alice gets retrenched, but she gets a better job from her best friend Jack, who is running a successful business. Her emotion could flow from *displeased, fear, fears-confirmed*, ending up with *joy* for getting a better job. Generally, the transition from one facial expression to another should be smooth, since human cognition procedure and facial muscle movement require certain duration.

2.1.1.9 Summary

The OCC model is a very interesting emotion model. It provides a very clear and convincing structure of the stimulus conditions of emotions and the variables which affect their intensities. This classic psychological emotion model is very popular among affective computing researchers who reason about emotions and trying to embed them into artificial intelligent machines (Steunebrink *et al.*, 2009).

As discussed above, the OCC model is not one with no fault. A history model and different emotion interactions are missing from it. The whole model focuses on appraisal among the three branches and ignores the individual difference. A proper personality descriptor is needed to refine this model (Bartneck, 2001). Another major problem of the OCC model is that it cannot deal with partial goal success/fail. Although the 22 emotional types successfully mapped to facial expressions, the OCC model did not clearly explain the emotional intensity, emotion duration, and emotion decay, which are very important on building intelligent agents.

2.1.2 EM Model

In 1992, an emotional agent TOK is created by Reilly and Bates for their OZ project (Loyall and Reilly, 1992). The aim of the project is to provide users with the experience of living in a vivid micro-world.

As demonstrated in Figure 2.2, TOK is placed in a simulated physical world and a loop of sense-think-act is running throughout the whole simulation. Based on the given cycle, TOK receives sensor data first, which is recorded by the Sensory Routines, passed through the Integrated Sense Model, and integrated into a partial internal world model. The agent TOK is divided into three parts: Sensory Routines, HAP (action) and EM (emotion) (Loyall and Reilly, 1992). The Sensory Routines are responsible to sense the physical world and get original inputs. The HAP keeps a goal tree of the current active goal and works like a planner. The EM is in charge of the emotional process. HAP gets emotions and attitudes etc. from EM as inputs. It then works out a specific goal from its current goal tree, and carries it out. It also returns to the EM model a set of information to process, which includes the goal success/failure, attitudes, standards and events, etc. Occasionally, emotions in EM dominate goals in HAP, and vice versa. In essence, emotions are the key preconditions of the goals and behaviours.

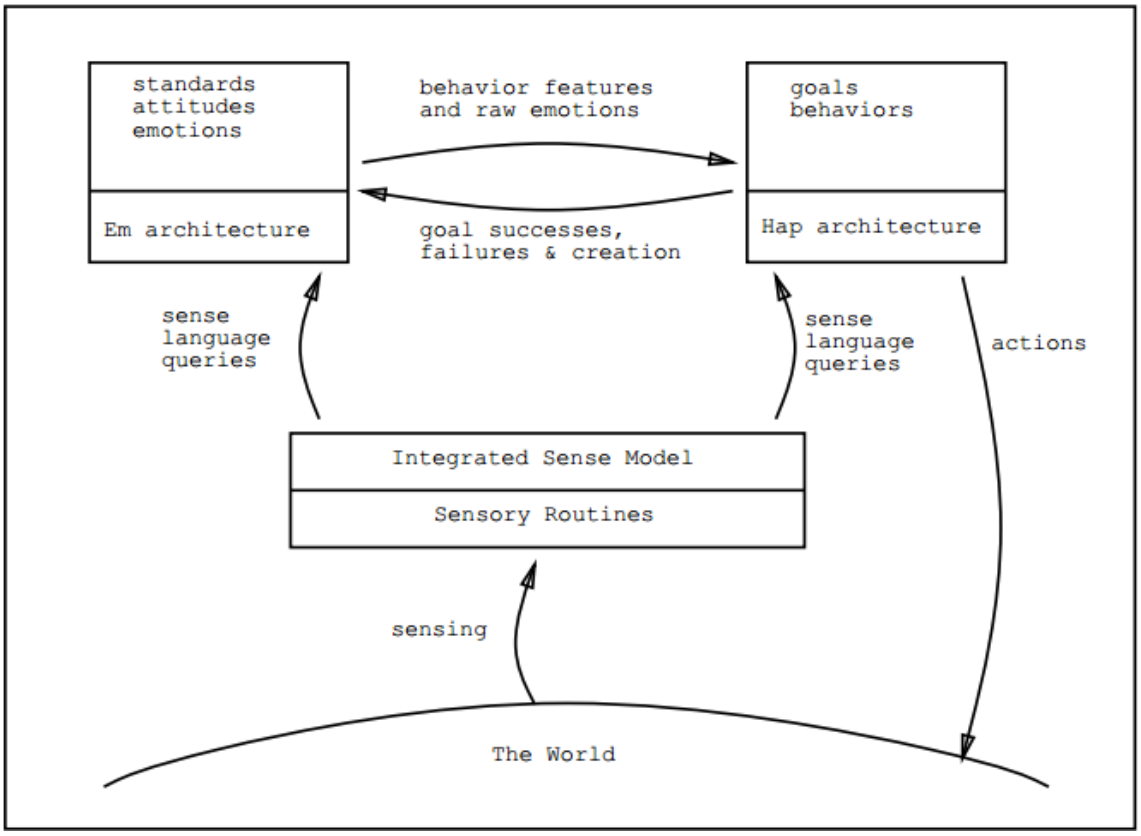


Figure 2.2: TOK Architecture (Bates *et al.*, 1994)

EMOTION	CAUSE
Joy	Goal success (*)
Distress	Goal failure (*)
Hope	Prospect of goal success (*)
Fear	Prospect of goal failure (*)
Pride	Action of self approved according to standards
Shame	Action of self disapproved according to standards
Admiration	Action of other approved according to standards
Reproach	Action of other disapproved according to standards
Love	Attention to liked object
Hate	Attention to disliked object
Gratification	Action of self causes joy and pride
Gratitude	Action of other causes joy and admiration
Remorse	Action of self causes distress and shame
Anger	Action of other causes distress and reproach

(*) Denotes difference from OCC model

Figure 2.3: Emotions in EM and their causes (Reilly and Bates, 1992)

Figure 2.3 shows emotions in EM and their causes. It can be seen that EM and OCC have much in common. Actually, EM is a scaled down version of OCC. It reduces emotional responses down to 14 types, and changes the cause of *Joy/Distress/Hope/Fear* from the consequence of events to the result of goals (El-Nasr *et al.*, 2000). These are the major differences between them.

2.1.2.1 Summary

Since EM is a subversion of OCC, it inherits all the pros and cons from OCC. The EM system provides the power to model fairly deep phenomena, such as personal and cultural standards, attitudes, interpersonal relationships, emotions. Moreover, it has been integrated into an action architecture that affects and gets affected by the workings of EM. Many interesting aspects of emotions are involved. However the EM model also has its drawbacks. OCC emphasizes the importance of expectations. As its follower, EM does not support dynamic expectations, but generates static expectations according to the predefine rules (Ortony, 1990). In reality, people's expectations change over time, which causes people's behaviour change (El-Nasr *et al.*, 2000). For instance, a thirsty man wants water.

During the water drinking duration, his desire on water is decreasing, until he is full and cannot drink anymore. The desire on water turns to zero then.

2.1.3 FLAME

In 1998, another computational emotional model, named FLAME (Fuzzy Logic Adaptive Model of Emotions) is created by El-Nasr and her colleagues. It is based on various previous models, mainly the OCC model (Ortony, 1990) and Roseman *et al.*'s emotion-eliciting events appraisals model (Roseman *et al.*, 1990). FLAME uses fuzzy logic to represent emotions, events and emotional observations. In addition, this model can manage conflicts in mixtures of emotions (El-Nasr *et al.*, 2000; Elliott, 1992), although some other approaches, such as functional or interval-based mappings, can also address this problem. FLAME uses fuzzy logic mainly because of the simplicity and clear linguistic rules.

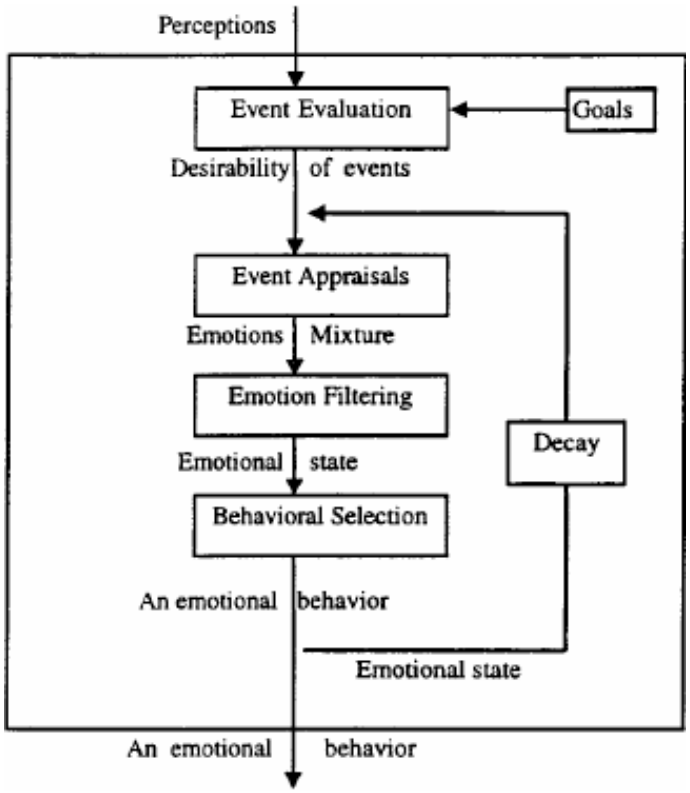


Figure 2.4: FLAME emotional progress component (El-Nasr *et al.*, 2000)

Figure 2.4 shows the details of the FLAME emotional progress component. Information is passed from one process to the other. Each box denotes one process, and when connected with arrows a work flow is formed in the model. The processes start with the environmental perceptions as input into *Event Evaluation* and get evaluated. Two major criteria

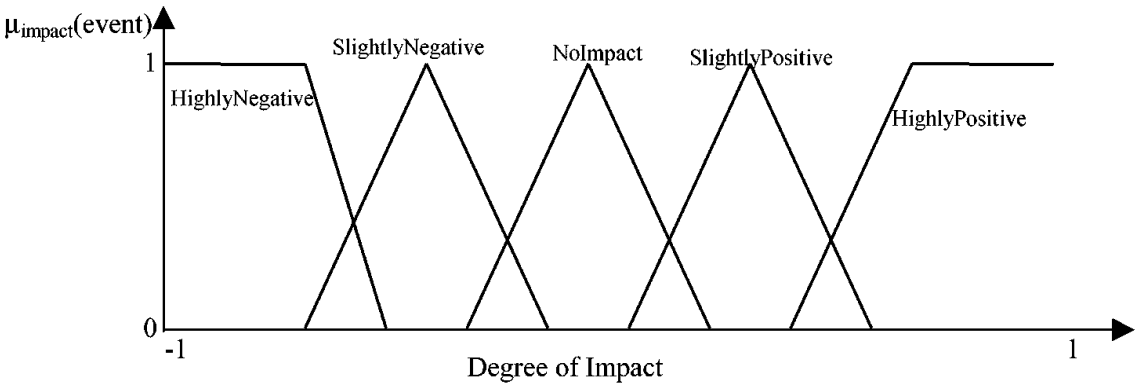
determine the event evaluation process: the importance of the goals affected by the event, and the degree by which the event affects these goals. According to these two criteria, fuzzy rules are applied to determine the desirability of an event.

2.1.3.1 Event Evaluation

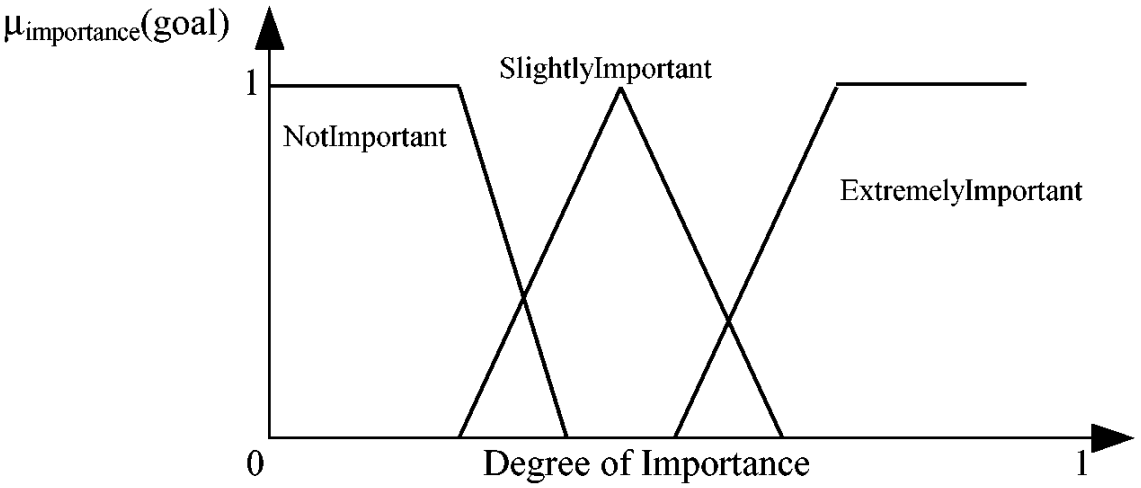
Firstly, which goals are affected by the event and the degree of impact that the event holds on these goals get determined by the experience model. A desirability value is applied to each event perceived by the agent. It denotes the aspiration of a certain event the agent wants. Next, the question comes to whether it has positive or negative impact to the agent's goal and what its impact level is. Five fuzzy sets with triangular membership functions are used to describe the impact of a certain goal. The fuzzy sets are termed: *HighPositiveImpact, LowPositiveImpact, NoImpact, LowNegativeImpact* and *HighNegativeImpact* (see Figure 2.5a).

Secondly, according to the impact calculated by the first step and the importance of the goals, mapping rules work out a desirability level of the event. The priority of each goal is represented using three fuzzy sets of triangular membership functions, which are *NoImportance, SomeImportance* and *ExtremeImportance* (see Figure 2.5b). Finally, the desirability of event with triangular membership functions is termed as *HighlyUndesired, SlightlyUndesired, Neutral, SlightlyDesired* and *HighlyDesired* (see Figure 2.5c).

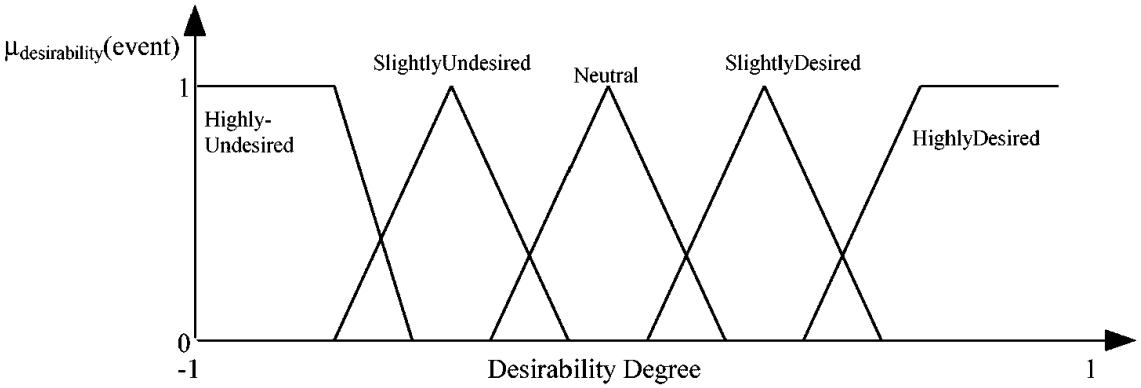
The event evaluation is described by the following rules:



a) Membership functions for event impact



b) Membership functions for goal importance



c) Membership functions for event desirability

Figure 2.5: FLAME membership functions

If

$$\begin{aligned} &\textit{Affect}(G_1, E) \textit{ is } A_1 \\ \textit{AND } &\textit{Affect}(G_2, E) \textit{ is } A_2 \\ &\cdots \\ \textit{AND } &\textit{Affect}(G_k, E) \textit{ is } A_k \\ \textit{AND } &\textit{Importance}(G_1, E) \textit{ is } B_1 \\ \textit{AND } &\textit{Importance}(G_2, E) \textit{ is } B_2 \\ &\cdots \\ \textit{AND } &\textit{Importance}(G_k, E) \textit{ is } B_k \end{aligned} \tag{2.1}$$

then

$$\textit{Desirability}(E) \textit{ is } C$$

Where, k denotes the number of goals simulated in the system; G denotes the goals affected in the simulation; E denotes a certain event; A denotes the event impact fuzzy sets; B denotes the goal importance fuzzy sets; C denotes the event desirability fuzzy sets;

The rules read as follows: if goal G_1 is affected by event E to a degree A_1 and goal G_2 is affected by event E to a degree A_2, etc., and the importance of G_1 is degree B_1 and the importance of G_2 is degree B_2, etc., the desirability of event E will be degree C. Mamdani's model (Yen and Langari, 1998) is used to derive a desirability degree, which will be passed to the next process. Sup-Min is used by Mamdani's model to work out the matching degrees. Consider the following rules:

$$\begin{aligned} &\text{if } x \textit{ is } A_i \text{ Then } y \textit{ is } C_i \\ &\cdots \\ &\text{if } x \textit{ is } A_n \text{ Then } y \textit{ is } C_n \end{aligned} \tag{2.2}$$

Where, x denotes an input variable; y denotes an output variable; A_i and C_i denote fuzzy sets; i denotes the ith rule;

Assuming the value of x is a fuzzy set A', the degree of impact is a membership function $\mu_{A'}(x)$. The matching degree ω_i between the input $\mu_{A'}(x)$ and the rule antecedent $\mu_{A_i}(x)$

is described as the following equation:

$$\omega_i = \underset{X}{sup}(\mu_{A_i}(x) \wedge \mu_{A'}(x)) \tag{2.3}$$

Where, Operator $\wedge$ takes the minimum of the membership functions; Operator $under set X sup$ takes the maximum over all x; The matching degree affects the inference is calculated using the equation below:

$$\mu_{C'_i}(y) = \omega_i \vee \mu_{C_i}(y) \tag{2.4}$$

Where, C' denotes the value of variable y inferred by the ith fuzzy rule; The Mamdani model uses the max operator ω to combine the inference results of all fuzzy rules, as shown in the following equation:

$$\mu_{comb}(y) = \mu_{C'_1}(y) \vee \mu_{C'_1}(y) \vee \cdots \mu_{C'_k}(y) \tag{2.5}$$

Based on the centre of area (COA) defuzzification (Patel and Mohan, 2002), this combined fuzzy conclusion is defuzzified in the following equation:

$$y_{final} = \frac{\int \mu_{comb}(y) y \, dy}{\int \mu_{comb}(y) \, dy} \tag{2.6}$$

where a number y_{final} is evaluated based on the above equation. It will be used as a measure of the input event's desirability.

2.1.3.2 Event Appraisals

Once the desirability value is calculated, it will be input into an appraisal process to find out the emotional state changes of the agent. According to the situation and the event, a set of emotions will be generated using the OCC model (Ortony, 1990). Fourteen emotions are well supported in this model (see Table 2.2). For instance, *joy* could be described as the occurrence of a desirable event. It is a direct function of the level of desirability, generated by the event evaluation step. Other emotions such as *love* or *hate* towards other agents are appraised based on the actions of the others and how they help the agent to achieve its goals. To properly monitor other agents' behaviours and responses with rational behaviour, a complicated social model is required. For the emotions listed on the table, we need three elements to get them implemented.

- The desirability of the event as a result of the event evaluation process;
- Standards and event judgement resulting from the agents' learning process or experience;

Emotion	**Rule**
Joy	Occurrence of a desirable event
Sad	Occurrence of an undesirable event
Disappointment	Occurrence of a unconfirmed desirable event
Relief	Occurrence of a unconfirmed undesirable event
Hope	Occurrence of an unconfirmed desirable event
Fear	Occurrence of an unconfirmed undesirable event
Pride	Action done by the agent and is approved by standards
Shame	Action done by the agent and is disapproved by standards
Reproach	Action is done by the other and is not approved by the agents' standards
Admiration	Action done by the other and is approved by the agents' standards
Anger	Complex emotion; sad + reproach
Gratitude	Complex emotion; joy + admiration
Gratification	Complex emotion; joy + pride
Remorse	Complex emotion; sad + shame

Table 2.2: Result for generation of emotions

- Expectations of events to occur as a result of the agents' learning process or experience.

In short, desirability is used to work out the impact level of a certain event. Standard and event judgement are common senses, confining agents on what they should do, and what they should not do. Expectations of events are used to describe what an agent wants. Emotions such as *hope, sad, fear,* etc., require more than desirability. Other measures such as expectations and standards are quite important in emotion stimulation. For example, *hope* is caused by the occurrence of an unconfirmed desirable event. Considering a student with the expectation that he has 80% chance to get an grade of "A" in the exam. The intensity of *hope* is not a direct function of expectation. Rather, the harder he studies, the higher the certainty he has, the less the *hope* (El-Nasr *et al.*, 2000) because he is more certain that he would get an A, not just merely "hoping" for it. The intensity of *hope* can be described as follows:

$$Hope = (1.7 \times expectation^{0.5}) + (-0.7 \times desirability) \tag{2.7}$$

The Table 2.3 illustrates how the intensity of various emotions, such as *joy, sadness, disappointment, relief, hope* and *fear* are calculated by given an expectation value and a desirability value.

Emotion	**Intensity**
Joy	$Joy = (1.7 \times expectation^{0.5}) + (-0.7 \times desirability)$
Sadness	$Sadness = (2 \times expectation^{2}) - desirability$
Disappointment	$Disappointment = Hope \times desirability$
Relief	$Relief = Fear \times desirability$
Hope	$Hope = (1.7 \times expectation^{0.5}) + (-0.7 \times desirability)$
Fear	$Fear = (2 \times expectation^{2}) - desirability$

Table 2.3: Calculating intensities of emotions

Emotions such as *pride, shame, reproach* and *admiration* are more likely to rely on the agent's standards. They do not directly depend on expectations and desirability. Standards are the primary variable to calculate the above Emotion Intensities. For example, an agent takes something from a store and forgets to pay for it. His behaviour is disapproved by the standard of the "Exchange of Equal" rule which makes him feel *shame* about it. There is no direct dependency on expectation or desirability. The intensity of this event could be regards as the intensity of *shame*. Of course, here it is assumed that the agent is a good person who observes the common social standard. Otherwise it could be a totally different case.

2.1.3.3 Emotion Filtering

After the processed in Section 2.1.3.1 and Section 2.1.3.2, a mixture of emotions is collected and ready to get filtered into a coherent emotional state. In this stage, some inhibition factors are used to filter the mixture, based on Bolles and Fanselow's (Bolles and Fanselow, 1980) approaches. They believe that emotions could be inhibited or enhanced by other states, such as motivational states. EL-Nasr *et al.*, (El-Nasr *et al.*, 2000) agree that emotional filtering could be domain-dependent and influenced by personality or other complicated factors. They also believe that mood aids in emotion filtering. In their method emotion filtering mainly depends on motivational states, which is likely to interrupt the cognitive process to achieve a higher goal. A virtual intelligent pet-like agent PETEEI (El-Nasr and Yen, 1998) is implemented by EI-Nasr *et al.* to perform a series of simulations. Table 2.4 shows the intensity of motivational states calculation.

Motivational state	**Intensity is related to**
Pain	Number of Hits by user, the intensity of the hits
Tired	Amount of movement, time last slept
Thirst	Frequency of movement, intensity of movement (running is higher than walking. etc.), time last drank, quantity that was drunk
Hunger	Intensity of movement, frequency of movement, time last ate, the quantity of food eaten

Table 2.4: Calculating the intensity of motivational states in PETEEI

2.1.3.4 Behaviour Selection

Fuzzy implication rules are used again to determine a rational behaviour given a mixture of emotions. The behaviour relies on the agent's emotion and the situation or the occurred event. For example, the behaviour "Bark-at-user" is described as follows:

If

$$\begin{aligned} & \textit{Anger is High} \\ \textit{AND} \quad & \textit{dish-was-taken-away} \end{aligned} \tag{2.8}$$

then

$$\textit{BEHAVIOUR} \quad \textit{is} \quad \textit{Bark-at-user}$$

The barking behaviour relies on the emotional intensity of the agent and the current event happening to it. Assuming PETEEI is angry for some other reason, if the user does not take the dish away, it would not necessarily bark at the user, because the user might not be the main cause of its anger. Therefore, it is very important to evaluate both the cause of the event and the emotion. To generalize the rules shown above, the fuzzy rules are as follows:

If

$$\begin{aligned} & \textit{emotion}_1 \textit{ is } A_1 \\ & \textit{AND emotion}_2 \textit{ is } A_2 \\ & \ldots \\ & \textit{AND emotion}_K \textit{ is } A_K \\ & \textit{AND Event is } E \\ & \textit{AND Cause } (E, B) \end{aligned} \tag{2.9}$$

then

$$\textit{BEHAVIOUR is } F$$

where, k denotes the number of emotions in the system; $\textit{emotion}_1$, $\textit{emotion}_2$ and $\textit{emotion}_k$

denote a mixture of emotions; A_1, A_2 and A_k denote the emotional intensity: *LowIntensity, MediumIntensity* or *HighIntensity*; E denotes a certain event; B denotes the cause of the event E; F denotes certain behaviour;

Behaviours such as "bark-at-user", "play-with-ball" etc. are represented as singletons with discrete states. Similarly, events such as "dish-was-taken-away", "ball-was-taken-away", etc. are simulated as singletons as well. Events such as "dish-was-taken-away", "ball-was-taken-away" etc. are non-environmental events. They are all caused by the user.

2.1.3.5 Decay

Finally, the emotional state starts to decay and is fed back to the model for the next processing loop. This progress is very important for a realistic emotional model. Generally, emotions do not disappear immediately once their causes are gone. Instead they go into a decay phase, and eventually change back to the neutral state (Velásquez, 1997). FLAME uses two constants as decay rate to describe the positive emotion decay and negative emotion decay respectively. $\phi < \delta$ means the positive emotions decay faster than the negative emotions decay. Trial and error is used to find the best settings for the above parameters. The following equation is validated by testing the different decay strategies using an agent-based simulation.

$$\begin{cases} I_{e_i}(t+1) = \phi \times I_{e_i}(t) & : 0.1 < \phi < 0.3 \\ I_{e_i}(t+1) = \delta \times I_{e_i}(t) & : 0.4 < \delta < 0.5 \end{cases} \tag{2.10}$$

where ϕ denotes positive emotion decay rate; δ denotes negative emotion decay rate; I_{e_i} denotes the state of emotion ; t denotes a certain time;

2.1.3.6 Summary

FLAME successfully used fuzzy rules to explore the capability of fuzzy logic in modelling the emotional process. Before FLAME is proposed, most of the emotional intelligent agents were modelled as having emotions as a black-and-white matter (El-Nasr and Yen, 1998), which is obviously incorrect. In reality, an event is always associated with many different goals. To obtain a rational emotion, all these goals need to be properly appraised. However, personality model is still missing from FLAME, which is a very important part.

Personalities sometimes can enhance/weaken the effect of a certain stimulus. Additionally, emotion is not a static state, but a dynamic process. Emotional changes over time are required. FLAME does not support this feature either.

2.1.4 Ekman Model

Paul Ekman is a pioneer in the study of emotions and facial expressions. When he was 14, his mother got severe mental illness and it had tragic consequences. So he decided to devote his life to help people like his mother and became a psychotherapist. In 2001, he collaborated with John Cleese for the BBC documentary series *The Human Face* (ekm, 2015). In 2009, his work is widely referenced in the TV series *Lie to Me*. He gained a reputation as "the best human lie detector in the world" (ekm, 2009).

Ekman started developing techniques for measuring nonverbal communication in 1950s. He published his first nonverbal communication paper in 1957, which describing how difficult it is to find ways to empirically measure nonverbal behaviour (Ekman, 1957). Charles Darwin (DARWlN, 1872) claimed that emotions were biologically determined and universal to human culture in 1872. However, the mainstream belief in 1950s was that facial expressions and their means were determined through learning processes. Anthropologists like Margaret Mead (Mead, 1963) strongly believed that facial expressions and the emotions they represent were determined by people's culture background. In other words, people learned the ability of making/reading facial expressions from their societies. In 1968, Ekman set out to test this theory. He travelled to the secluded Fore tribe in Papua New Guinea to study the facial expressions of people there. Interestingly he found out that the tribal folks could correctly identify emotion in facial expressions by looking at photos of people from other cultures, although the tribe had never been exposed to any outside cultures. This study made Ekman believed that facial expressions were cross-cultural (Ekman, 1989). He focused on developing techniques for measuring nonverbal communication. He found out that human beings are capable of making over 10000 facial expressions, among which only 3000 are relevant to emotion (Watson and Tellegen, 1985). He added that facial muscular movements that created facial expressions could be reliably identified through empirical research. Later on, his research proved that there was a universal set of certain facial expressions existed in the whole world. He published this list of universal facial expressions in 1972, which comprised six basic emotions. The definitions and related muscular movements of the six basic emotions are listed in Table 2.5.

Emotion	Picture	Definition	Facial Muscular Movements
Anger		Antagonism toward a person or object often experienced after you feel you've been wronged or offended	Lowering eyebrows, tightening and narrowing lips, glaring eyes, tightening lower eyelids; less commonly, thrusting jaw forward
Happiness		Pleasant feeling of contentment and well-being	Smiling - pulling up corners of mouth, contracting large orbital muscles around eyes
Surprise		Feeling of upset or surprise at an unexpected occurrence	Raising eyebrows high (which may cause wrinkles across forehead), opening eyes wide, dropping jaw so mouth is agape
Disgust		Intense displeasure or condemnation caused by something offensive or repulsive	Narrowing eyebrows, curling upper lip, wrinkling nose
Sadness		Feeling of unhappiness or sorrow	Drooping eyelids, lowering corners of mouth, pouting lips, downcast eyes
Fear		Feeling of apprehension caused by perception of danger, threat or infliction of pain	Raising eyebrows and/or drawing eyebrows together, tensing lower eyelids, stretching lips horizontally, opening mouth slightly

Table 2.5: Six basic emotions (ekm, 2014)

2.1.4.1 Other Universal Emotions

Later on, Ekman's theory evolved. He rejected his previous belief that a pleasant-unpleasant scale was sufficient to capture the differences among emotions. In the 1990s, Ekman proposed an expanded version of basic emotions, including 7 positive emotions and 4 negative emotions (Ekman, 1999). The newly included emotions are:

Positive emotions:

Amusement, Relief, Sensory pleasure, Pride in achievement, Excitement, Satisfaction, and Contentment;

Many evidences indicate that positive status such as these could reflect qualitatively different emotions. For instance, Shiota *et al.* disclosed the different groups of facial action units for portrayals of awe, amusement, and pride (Shiota *et al.*, 2004). Sauter and Scott found out that people express achievement, amusement, contentment, sensual pleasure, and relief by using different vocal patterns (Sauter and Scott, 2007). However, whether these patterns are culturally universal remains questionable (Sauter *et al.*, 2010).

Negative emotions:

Contempt, Embarrassment, Guilt, and Shame;

Keltner and Buswell conduct experiment to determine whether embarrassment, guilt and shame are distinct in facial expression. In the experiment, 14 different facial expressions are presented to the observers, including embarrassment, shame, and candidates of guilt (sympathy, self-contempt, and pain). Result shows that observers can accurately identify the expressions of embarrassment and shame, but fail to label any expression as guilt (Keltner, 1996). Tangney and Miller indicate that embarrassment is a relatively distant neighbour of shame and guilt, and the differences among the three could be clarified simply by intensity of affect or by degree of moral transgression (Tangney *et al.*, 1996).

2.1.5 PAD Model

Many affective computing researchers believe emotion and other affective phenomena should be organized into a continuous two or three dimensional space with a certain set of scales (Russell, 2003; Mehrabian and Russell, 1974; Barrett, 2006; Watson and

Tellegen, 1985), such as positive-negative valence, activity or arousal, and dominance or potency (Dormann, 2006; Tsai *et al.*, 2008). More than a century ago, in 1896, Wundt (Wundt, 1896) proposed three bipolar dimensions of pleasant-unpleasant, excited-quite, and tense-relaxed to describe the great variance in emotions. In 1980, Russell (Russell, 1980) proposed a circumflex model of affection, which has two orthogonal axes; pleasantness (horizontal) and activation (vertical), to explain emotional behaviour. Snider and Osgood (Snider and Osgood, 1969) focused on semantic differential, a type of rating scale designed to measure opinions, attitudes and values. They found three recurring attitudes: Evaluation, Activity, and Potency (EAP), which people use to evaluate words and phrases. However, the semantic differential factors of EAP differ significantly from force-fitted factorial approaches to personality. The EAP factors do not include any kind of studies of personality or any personality-oriented theory or bias. Instead, they are getting identified constantly in highly varied areas of psychological study. Hence, it is difficult to regard EAP factors as being the outcome of a particular investigator's theoretical or experimental bias. Instead, Mehrabian (Mehrabian, 1996b) proposed the three dimensional PAD (pleasure, arousal, dominance) emotional state model to describe and measure individual differences in temperament. He proposed formulas that use PAD values to compute and predict a wide range of personality scores, such as Anxiety, Depression, Panic, Empathy, Affiliation, Achievement, Extroversion, Neuroticism, Emotional stability and so on. His semantic differential studies and researches have indicated that human judgments on different stimuli can be represented in terms of these three dimensions (Mehrabian and Russell, 1974). The three dimensions of the PAD model are briefly described as follows.

Pleasure

The dimension of pleasure ranges from unpleasant to pleasant (Clore, 1994). Many researchers on human psychology have revealed that induced pleasure inspires individuals greatly to explore the story behind the stimuli. For instance, Isen has reported that people in positive emotions are more capable of processing complicated information and they are more optimistic in regard to facing new challenges (Isen *et al.*, 1987). She adds that positive emotions enhance people's sensibility to stimuli in an environment.

Arousal

Arousal is a state of heightened physiological activity. The dimension of arousal measures the intensity of the emotions which ranges from calm to excited (Clore, 1994). It is considered one of two attractive dimensions to evaluate the aesthetics of human factors and design (Liu, 2003). Berlyne has proposed his motivation theory in 1971 (Berlyne, 1971). He believes that arousal represents motivational conditions produced by external stimuli

as a result of learning. He also claims that arousal emotion is relevant to the uncertainty, novelty, expectation, and complexity of the stimuli (Berlyne, 1974). Additionally, according to the information rate-arousal theory (Mehrabian and Russell, 1974), it is directly related to the amount of information in an environment.

Dominance

Dominance signifies the controlling and dominant nature of the emotions. An individual's feeling of dominance in an environment is based on the extent to which one feels unrestricted or free to act in various ways (Mehrabian, 1996b). In 1970, Proshansky *et al.* proposed "freedom of choice and behaviour" as a dimension of emotion to describe one's dominant feeling in an environment (Proshansky *et al.*, 1970). For example, privacy and territoriality provide greater freedom of choice while formal social situations tend to have more rules to constrain one's behaviour (Mehrabian, 1970). Physical stimuli come with more intensity, more ordered, and more power often lead to one's submissive feelings, because they show more restriction than other stimuli (Mehrabian and Russell, 1974).

Emotions Mapping to PAD Space

Specific terms describing emotions can be visualized as points and mapping into a three-dimensional PAD emotion space. Alternatively, when the PAD scale scores are standardized, each emotion term can be described briefly in terms of its values on the pleasure-displeasure, arousal-nonarousal, and dominance-submissiveness axes. The following sample ratings illustrate definitions of various emotions (Cao *et al.*, 2008; Jiang and Qin, 2014; Shi *et al.*, 2012; Li *et al.*, 2005) when scores on each PAD scale range from -1 to +1:

Emotion	**Pleasure**	**Arousal**	**Dominance**	**PAD Subspace**
Fear	-0.64	0.60	-0.43	-P+A-D
Anger	-0.51	0.59	0.25	-P+A+D
Happiness	0.40	0.20	0.15	+P+A+D
Bored	-0.65	-0.62	0.33	-P-A+D
Curious	0.22	0.62	-0.01	+P+A-D
Disgust	-0.40	0.20	0.10	-P+A+D
Sleepy	0.20	-0.70	-0.44	+P+A-D
Dignified	0.55	0.22	0.61	+P+A+D
Sadness	-0.40	-0.20	-0.50	-P-A-D
Elated	0.50	0.42	0.23	+P+A+D

Table 2.6: Emotion Space Mapping to PAD Space

Table 2.6 shows the mapping between Emotion Space and PAD Space. According to the value given to *angry*, it is a highly unpleasant, highly aroused, and moderately dominant emotional state. Comparing to *fear*, it has almost the same scale values of Pleasure and Arousal as *angry*, but has much stronger submissiveness value. Although they are both negative emotions, people with *angry* emotion tend to have more control over the others, while people with *fear* emotion have a tendency of being controlled.

2.2 Personality Model

Personality is used to describe individual's coherency and consistency of affects, cognitions, desires and behaviours over time and space (Revelle and Scherer, 2009). What an individual feels, believes, wants and does changes from time to time, situation to situation. Personality reveals a patterning over time and across situations, which could be used to recognize, describe and even to understand an individual (Revelle, 2007). Personality reflects individual differences over time and space in feeling, action, appraisal and desires. Emotion does the same things at a particular time and location. The relationship between these two could be considered as climate to weather (Revelle and Scherer, 2009).

In this thesis, two most popular personality models Big Five (Lei and Yu-Geng, 2004) and NEO PI-R (Costa and MacCrae, 1992; Costa and McCrae, 1985; Briggs, 1989) are studied to demonstrate how personality affects emotional changes.

2.2.1 BIG Five Model

The Big Five (McCrae and John, 1992) personality model include five broad domains, which are *Openness, Conscientiousness, Extraversion, Agreeableness*, and *Neuroticism* respectively. They are also known as OCEAN for their acronyms. The Big Five personality traits have been widely used in interview, self-descriptions, and observations. It is proposed to understand various behaviours and the relationship between personalities (Komarraju *et al.*, 2011).

Openness to Experience

Openness is a measurement of inventive/curious and consistent/cautious, which reflects the degree of intellectual curiosity and a fondness for novelty and diversity. People with this trait tend to appreciate arts, adventures, unusual ideas, and various experiences.

They tend to be more aware of their feelings, compared to other people. They usually think and act in imaginative and independent ways. Intellectuals generally score high on *Openness to Experience*. Hence, Intellect becomes one of the best aspects of the *Openness to Experience* trait. Some researchers actually interpret the *Openness* factor as *intellect*, rather than *Openness to Experience* (Komarraju *et al.*, 2011).

Another aspect of *Openness to Experience* is cognition and thinking in symbols and abstractions far removed from concrete experience. The symbolic cognition includes many forms, such as mathematical, logical or geometric thinking, artistic or metaphorical words, music/movie/art composition or performances. People who score low on *Openness to Experience* tend to have narrow common interests. Their preferences are plain, straightforward, and ambiguous. They prefer conservative to reform, familiar to change, and simple over complex. Psychologists agree that people score high on *Openness to Experience* often appears to be healthier and more mature. Nonetheless, both open and closed styles of thinking are useful in the reality. The open style of thinking might serve a professor well, but research has shown that closed-style thinking is related to better job performance in law keeper, sales, and many other service occupations.

Conscientiousness

Conscientiousness is exemplified by being disciplined, organized, achievement-oriented, and prefer planned rather than spontaneous behaviour (Costa and McCrae, 1992). It concerns the way in which people control, regulate, and direct their impulses. Impulses are not fundamentally bad. Sometimes, people do need a snap decision due to time constraints, and acting on first impulse can be a very effective response. Impulsive individuals act spontaneously and impulsively, which could be seen by others as fun, colourful and zany.

However, acting on impulse can lead to trouble in many ways. Some impulses are antisocial. Uncontrolled impulsive acts not only harm the victims and their families, but also leave the retribution to the perpetrator. Moreover, impulsive acts often result in immediate rewards but undesirable long-term consequences. For instance, hurling an insult may break up an important relationship; Using drugs will eventually cause addiction and greatly damage one's health.

Besides, Impulsive acts could diminish a person's effectiveness in significant ways. Impulsive acts disallow people from having an alternative choice. Most of time people could make a better decision if they can slow down and think the matter over. The ability to think about future consequences before acting on an impulse potentially separates humanity from earlier life forms. It is one of the hallmarks of intelligence, involves impulse

management. Consequently, prudence is an alternative label for *Conscientiousness* domain, which perceived by others as intelligent. The benefits for high *Conscientiousness* are obvious. People scoring high on this domain have better ability to avoid trouble and achieve high levels of success by purposeful planning and persistence.

Extraversion

Extraversion is about outgoing versus solitary, energetic versus reserved. It is displayed through pronounced engagement with the external world. Extraverts have a higher degree of sociability, assertiveness, and talkativeness. They love being with others, and are often recognized as being full of energy and owning positive emotions. They tend to be enthusiastic and action-oriented and are likely to say "Yes!", "OK" or "Let's go" while facing new opportunities. In groups they probably talk more than average, enjoy asserting themselves, and draw attentions.

Introverts are short of energy, exuberance, and activity levels. They tend to be quiet, keeping a low profile, deliberate, and disengaged from the social world. Their lack of social involvement should not be considered as equal to shyness or depression. Introverts simply prefer to be alone, and enjoy their own world. The independence and reserve of the introvert are sometimes misguided as unfriendliness or arrogance. In reality, an introvert is less likely to seek others out and invite them into his/her world, but could still be quite happy to share his/her thoughts when others approach.

Agreeableness

Agreeableness refers to being helpful, cooperative, and sympathetic towards others. Agreeable individuals prefer to get along with others. They have a positive view of human nature. They believe people are mostly honest, moral and trustworthy. Consequently, they are considerate, friendly, helpful, and willing to compromise with others in order to build a better relationship.

Disagreeable people place their interests above having a good relationship with others. Mostly, they are unconcerned about others' wellbeing. Consequently, it is unlikely for them to extend themselves for others. Sometimes they doubt or question others' motivation because disagreeable individuals tend to be suspicious, unfriendly, and uncooperative.

Hence, *Agreeableness* has a great superiority on attaining and maintaining popularity. Agreeable individuals are generally better loved than disagreeable individuals. Conversely, *Agreeableness* might not fit for a role that requires making tough decisions. Disagreeable

individuals can be outstanding scientists, critics, or soldiers.

Neuroticism

Neuroticism measures the tendency to experience negative feelings, which includes anxiety, anger, or depression. It is also known as *Emotional Stability*. People score high on *Neuroticism* may experience primarily one specific negative feeling mentioned above, but are likely to suffer a few of them at the same time. *Neuroticism* individuals are emotionally reactive. Their reactions tend to be more intense than average. These responses are not likely to affect most other people. *Neuroticism* individuals are more likely to amplify negative effects, such as interpreting ordinary situations as threatening, and minor frustrations as hopelessly difficult. Their negative emotional reactions tend to last much longer than normal. In other words, they are often in a bad mood. These problems in emotional regulation can greatly decrease a neurotic's ability to think clearly, make decisions, and cope effectively with stress.

At the other end of the scale, people who score low in *Neuroticism* are less easily to get upset. They tend to be calm, emotionally stable, less emotionally reactive and free from sustained negative feelings. Freedom from negative feelings does not mean that low scorers experience a lot of positive feelings, but they have better abilities on emotional regulation, and resist negative emotions.

2.2.2 NEO PI–R

Another personality model is the Revised NEO Personality Inventory (NEO PI-R) model (Costa and MacCrae, 1992; Costa and McCrae, 1985; Briggs, 1989). Its original version only contained three factors: Neuroticism, Extraversion, and Openness, which was published in 1978 as the NEO Inventory (NEO-I) (Shock *et al.*, 1984). In 1985, Paul Costa and Robert McCrae added two more facets: Agreeableness and Conscientiousness (Costa and McCrae, 1985). Consequently, they published the first manual for the NEO that include all five domains in the "Big Five" personality traits. Later, it was renamed as the NEO Personality Inventory (NEO PI). In this version, assessment included six facets for the three original factors only (Costa and McCrae, 1985). Four years late, a manual supplement was issued (Briggs, 1989). In 1992, a major revision introducing facet scales for Agreeableness and Conscientiousness was published (Costa and MacCrae, 1992). In 2005, McCrae *et al.* changed certain items to enhance internal consistency and readability, which brought the version to NEO-PI-3. NEO PI-R incorporates the latest advances both in personality structure and assessment (Boyle *et al.*, 2008).

Domains	**Facets**	
Neuroticism	Anxiety	Self-conscientiousness
	Angry Hostility	Impulsiveness
	Depression	Vulnerability
Extraversion	Warmth	Activity
	Gregariousness	Excitement-seeking
	Assertiveness	Positive emotions
Openness to Experience	Fantasy	Action
	Aesthetics	Ideas
	Feelings	Values
Agreeableness	Trust	Compliance
	Straightforwardness	Modesty
	Altruism	Tender-mindedness
Conscientiousness	Competence	Achievement striving
	Order	Self-discipline
	Dutifulness	Deliberation

Table 2.7: Domains and facets measured by NEO PI–R

2.2.2.1 NEO PI–R Domains and Facets

The NEO PI-R is used to provide a comprehensive description of personality traits. In other words, it is a description about people's characteristic and enduring emotional, interpersonal, experiential, attitudinal, and motivational styles. It is potentially useful every time individual differences in personality are related. Many researchers have used it as a powerful tool for research (Furnham and Crump, 2014; Hjemdal *et al.*, 2012; Holden and Marjanovic, 2012), analysing structure and stability of personality and its impact on life course. NEO PI-R measures the most important 30 facets within 5 major domains of personality. Questions such as the origins of personality, its psychophysiological basis and expression, its action-reaction to the cognitive process, and its influence both on mental and physical health can also be addressed. Table 2.7 provides domains and facets which measured by NEO PI-R. Detailed discussions of the NEO PI-R facets are presented in Chapter 4.

As Table 2.7 demonstrates, the five major domains of personality in the NEO PI-R model include *Neuroticism, Extraversion, Openness to Experience, Agreeableness* and *Conscientiousness*. 11 facets out of 30 are currently included in our proposed personality model. They are considered more significant than the others in affecting emotional responses. The

remaining 19 facets are more related to behavioural responses. They are not covered by this project. Below the facets of six domains are described in details.

Neuroticism is related to negative emotions. People with high value in this domain are more prone to psychological distress. The first 5 of the 6 facets in this domain described below are included in our model:

- *Anxiety*: One of the unpleasant state, people with this facet are easy to get anxious, distress or uneasiness by fear of danger or misfortune.
- *Angry Hostility (AH)*: People with this trait tend to become unfriendly or angry easily.
- *Depression*: People with this trait usually feel sadness, despondency and loneliness. It is a condition of general emotional withdraw and dejection.
- *Self-consciousness (SC)*: Another unpleasant feeling, also known as self-awareness, people with this trait tend to excessively aware of being observed by others.
- *Vulnerability*: People with this facet are usually having less ability to handle a hostile environment. They are easily get wounded or hurt.
- *Impulsiveness*: People with this trait are more likely to act on impulse rather than careful thought, being actuated by emotional or involuntary impulses.

Extraversion measures people's willingness to be more active. People who are in high extraversion tend to find out social stimulation to engage with others. We implemented the first two facets in this domain:

- *Warmth*: People with this trait are friendly, enthusiastic and kind, interesting in others.
- *Positive Emotion (PE)*: People with this trait often look at the bright side, tendency to experience happiness, joy and gratitude.
- *Gregariousness*: People with this trait prefer to seek and enjoy the company of others.
- *Assertiveness*: One of the communication skills, a kind of behaviour characterized by a confident declaration. People with this trait are more likely to make bold assertions.

- *Activity*: People with this facet are usually more likely to take actions or carry out their plan, instead of having deep thoughts only.
- *Excitement Seeking*: People with this facet are longing for environmental stimulation. Extreme sport players generally score high in this facet.

Agreeableness is the domain that is more related to being kind, sympathetic and considerate, indicating individual differences in cooperation and social harmony. The first 3 of the facets are included in our model:

- *Altruism*: People with this trait are more likely to be unselfish and devote themselves into the welfare of others.
- *Compliance*: It is more related to interpersonal conflict. People with low compliance trend to be aggressive, quarrelsome and vindictive.
- *Tender Mindedness (TM)*: People with this trait usually have more sympathy or compassionate for the others.
- *Trust*: People with this trait believe in the good intentions of others.
- *Straightforwardness*: People with this trait are honest and frank in expression, free from crookedness or deceit.
- *Modesty*: People with this trait are free from vanity and boastfulness, preferring not to draw attention to their achievements and be humble.

Conscientiousness describes the degree of thoroughness, carefulness or vigilance. People with this trait are very motivated to complete a task well. Only the first facet is included in our model:

- *Dutifulness*: People with this trait are always filled with a sense of obligation.
- *Competence*: People with this trait have strong belief in their have the ability to do something successfully with their own ability, knowledge and skill.
- *Order*: People with this trait tend to personal organization and sequencing.
- *Achievement Striving*: People with this trait have the inner motivation for personal achievement and sense of direction.

- *Self-Discipline*: It is also known as self-control. People with this trait have the ability to get tasks done despite any distractions
- *Deliberation*: People with this trait are more likely to have long and careful consideration, movement or thought.

The domain *Openness to Experience* is not included in our personality model. All of its six facets (*Fantasy, Aesthetics, Feelings, Actions, Ideas*, and *Values*) are more related to seeking and appreciating experiences. People who score high in openness tend to have more liberal views. People who are low in openness tend to be more conservative. Hence, they are difficult to be incorporated into any emotional models in affective computing, hence are currently not included in this project.

2.2.3 Recent Development in Emotion Modelling

In 2010, Marsella and his team summarized 23 popular emotion models and introduced many theories used by those emotion models (Marsella *et al.*, 2010), such as the appraisal theory which emphasizes the importance between emotion and cognition, OCC model, FlAME, and EMA (Marsella and Gratch, 2009) etc. are built with this theory; dimensional theory which argues that emotion should be conceptualized as points in a two dimensional or three dimensional space, e.g. the PAD model, not as discrete entities. Many emotion models were built with appraisal theory, since the importance of cognition to emotional changes. While dimensional theory provides an easy way to demonstrate emotions. Nowadays, more and more emotion models are built in both theories. ALMA (Gebhard, 2005) model and WASABI model (Becker-Asano, 2008; Becker-Asano and Wachsmuth, 2010) are implemented with dimensional theory with some features from OCC model. Personality is also included in these two models. However, their experiments do not show how personalities influence virtual agents' emotional changes. The PCMD model (Zhang *et al.*, 2015) is derived from ALMA, which enables virtual agent Sophie to show personalized behaviours in the emotional interactions with users. Only two personalities are used in the PCMD model, optimistic and pessimistic. In their results Sophie's behaviour patterns are mainly driven by her mood, not her personality. Xiao *et al.*'s emotion model (Xiao *et al.*, 2014) supports three personality traits: Psychoticism, extraversion, and neuroticism. A game is simulated in which a knight attacks agents with the above three personalities. However, only emotion *happy* and *fear* are observed in their work. We believe that proper study of personality is essential for emotion modelling due to the understandably important influence of personality towards emotional responses. Psychological personality models such as Big-5 personality model or NEO PI-R should be utilized since they are well-accepted

personality models. Their effects on emotion modelling deserve to be properly studied and evaluated. Personality, mood, and stimulus should be the key aspects causing emotional changes. Although the OCC model is very old, its appraisal progresses are still quite useful and relevant today on modelling stimuli and agent's desirability.

2.3 Summary

This chapter has presented related works for this thesis. Section 2.1 covers five emotional models implemented in different ways. OCC model, EM model and FLAME model use appraisal method to evaluate their emotional states respectively. The appraisal method is the most fruitful source for researchers to explain the relationship between emotion and cognition. It is also known as the predominant force among psychological perspectives on emotion (Marsella *et al.*, 2010). Many other emotion models are created in this method, such as EMILE model (Gratch, 2000), EMA model (Marsella and Gratch, 2009), ParleE model (Bui, 2004), PEACTIDM model (Marinier *et al.*, 2009) etc. Among them, OCC model is the classic one and the most popular one, while the EM Model and FLAME model are derived from the OCC model. However their limitations are also obvious. The biggest problem among these models is that they treat all agents the same with no individuality. The other two emotion models discussed are Ekman model and PAD model. The former claims six basic emotional types known as *anger, happiness, surprise, disgust, sadness* and *fear*, while The later is built in a 3-dimensional space whose three axes represent the PAD (Pleasure, Arousal, and Dominance) values for various emotional types. Section 2.2 reviews two personality models: Big Five and NEO PI-R. Recent work shows more and more emotion models begin to support personalities, the relevant experiment results are not such persuasive.

In this thesis, our proposed emotion model is mainly based on PAD model, since PAD model provides a better way to describe and calculate emotion values. Unlike the OCC model, all stimuli are defined in three elements *intensity, effect* and *likelihood*. Agent's *Desire* is also included to illustrate Emotion Intensity (EI) changes during the stimulus/stimuli phase. Out of the two personality models above, we have chosen the NEO PI-R personality as the basis of our proposed model, since it provide a more detailed description and measurement of personality, comparing to the crude Big Five personality model.

Chapter 3

Basic Emotion Modelling

This chapter describes the basic emotion model used in this thesis, which is based on the PAD model. It includes emotion, mood, stimulus and emotion decay.

3.1 Emotion

Emotion is a complex psycho-physiological experience of an individual's state of mind as interacting with biochemical (internal) and environmental (external) influences. For humans, emotion fundamentally involves physiological arousal, expressive behaviours, and conscious experience (Ekman, 1992). Emotion is associated with mood, temperament, personality and disposition, and motivation. Darwin believes that the expression of emotion exists widely both in man and animals (Darwin, 2002). Emotional changes are caused by stimuli, which are anything that could potentially affect the subject of interest, such as facial expression, gestures, voice etc. Emotions reflect short-term effect. Changes of emotions will usually decay and disappear completely after a certain period of time. As discussed in Section 2.1, many emotion models exist in the field of affective computing. Among them, PAD model has good definitions of emotional types. In this thesis the PAD model will be employed as the base emotion model.

$$E = \begin{bmatrix} P \\ A \\ D \end{bmatrix}, -1 \leq P, A, D \leq 1, \tag{3.1}$$

$$\text{We assume } E = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} \text{ as the neutral emotion state.}$$

Meanwhile, Ekman model is also used in our emotion model. *Anger, happiness, disgust, sadness and fear* are well supported in our emotion model, except *surprise*. *Surprise* is very different from the other emotional types. When people experience an unexpected

occurrence, their eyebrows are highly raised, eyes are widely open and their jaws are dropped. However, *surprise* is a neutral emotional status, which could be resulted from a good thing, such as a surprise birthday party, bumping into an old friend that has been lost contact for many years; or could be from something bad, such as an unexpectedly bad news. *Surprise* does not happen all the time. It has to been triggered by a certain unexpected occurrence. To properly modelling it, we have to figure out what is expected to occur and what is not. This is not straight forward, even with a Memory model with proper decay functions to store and update agent's knowledge. A further discussion has been provided in Section 6.2.1. Table 3.1 demonstrates the emotional types that are considered in our model.

Emotion	**Pleasure**	**Arousal**	**Dominance**	**PAD Subspace**
Fear	-0.64	0.60	-0.43	-P+A-D
Anger	-0.51	0.59	0.25	-P+A+D
Happiness	0.40	0.20	0.15	+P+A+D
Disgust	-0.40	0.20	0.10	-P+A+D
Sadness	-0.40	-0.20	-0.50	-P-A-D

Table 3.1: Emotional types used in our model

3.2 Mood

Moods reflect a relatively long-term effect (hours to months), which generally are not directly related to a stimulus (Hudlicka, 2008). It has the feature of diffusivity. In other words, it is not a specific experience about a specific stimulus, but a relatively stable emotional state. For instance, an employee is in a positive mood when promoted for good performance. This experience will infect all his activities with happy mood in a relatively long term. Currently, mood is simply modelled as three basic states: Positive, Negative and Neutral. There is still no uniform definition in the psychology field on how to measure mood. In this project, we consider mood as a simple weighted extension of emotion as shown in the equation below:

$$M_t = K \times P_{t-1} \tag{3.2}$$

where M_t is the Mood value of an agent at time t; K is the weighting coefficient, $0 < K < 1$; and P_{t-1} is the Pleasure value of an agent at time $t-1$, assuming $P_{t-1} = 0$ when $t = 0$; Arousal and Dominance have no direct contributions to mood, however, a well proportional relation exists between Pleasure and mood. Equation 3.2 explains the above relationship properly.

3.3 Stimulus

As mentioned before, anything that could affect the emotional state of an agent is considered a stimulus. Stimuli can be divided into two types: Internal stimuli, such as homeostatic imbalances, blood pressure etc.; and External stimuli which includes vision, touch, smell, taste, sound etc. (Allen and Schwartz, 1940). In this project, stimuli are specifically defined as external stimuli and are greatly simplified. The OCC model divides External stimuli into three types: consequences of events, actions of agents, and aspects of objects. It concentrates on if an agent gets pleased/displeased by the consequences of certain events; if an agent's action gets approved by standards; and if an agent likes/dislikes certain objects. The OCC model is rather complicated, that is why no equation is provided by them. Rather, the OCC model is trying to provide descriptions on who gets benefit from certain stimuli; if these stimuli are desirable ones; and if these stimuli are going to happen. More details have been provided in Section 2.1.1.

3.3.1 Instantaneous Stimulus

An instantaneous stimulus refers to a certain stimulus that starts and finishes instantly. Its stimulating duration can be ignored. For example, getting punched in the face; getting hit hardly by a ball; losing a wallet. Something happening and finishing instantaneously could still lead to very serious consequence. The equation of instant stimulus is given as follows:

$$S_{Instant} = \mu \times S_{Intensity} \times S_{Effect} \times S_{Likelihood} \times e^{\gamma \times ABS(A_{Desire})} \tag{3.3}$$

where $S_{Instant}$ denotes a certain instant stimulus; μ denotes the weighting coefficient of $S_{Instant}$, representing how much $S_{Instant}$ affects the agent ranged from 0 to 1; $S_{Intensity}$ denotes the stimulus strength valued from 0 to 1; S_{Effect} denotes whether the stimulus is considered positive or negative to the agent, ranged from -1 to 1; $S_{Likelihood}$ denotes the likelihood of the stimulus happening to the agent, valued from 0 to 1; and A_{Desire} denotes how strong an agent wants a certain stimulus, valued from -1 to 1; This formulation of a stimulus is very simple and clear. $S_{Instant}$, S_{Effect}, $S_{Likelihood}$ share same contributions to the $S_{Instant}$. Any of them goes to 0 will result in $S_{Instant} = 0$. $e^{\gamma \times ABS(A_{Desire})}$ makes A_{Desire} more important than the other three. As the saying goes, one man's trash is another man's treasure. Something is regarded as "trash" because it is no longer needed. If it is needed by someone, the "trash" becomes "treasure". Emotional change is very subjective. It mostly depends on an agent's desire. Equation 3.3 does not include any time variables.

3.3.2 Duration Stimulus

In reality, most of stimuli last for a certain period of time, such as playing game with friends, eating delicious food, or getting bullied at school. These stimuli contain lots of actions or so called sub stimuli. It is an impossible mission to map all of them to emotional changes. A combined stimulus with duration is thus simply treated as a whole object that lasts for a period of time, hereafter called "duration stimulus". Equation 3.3 still makes sense here. However, here the emotional change happens right after the duration stimulus starts. The equation of duration stimulus has to reflect the stimulus efforts on emotional changes from one moment to the next.

$$S_{Duration} = \begin{cases} \mu \times S_{Intensity} \times S_{Effect} \times S_{Likelihood} \times e^{\gamma \times ABS(A_{Desire})} \frac{t}{T_{Duration}}, \\ 0 < ABS(A_{Desire}) < 0.5, 1 \leqslant t \leqslant T_{Duration} \\ \mu \times S_{Intensity} \times S_{Effect} \times S_{Likelihood} \times e^{\gamma \times ABS(A_{Desire})} \frac{T_{Duration}-t}{T_{Duration}}, \\ 0.5 \leqslant ABS(A_{Desire}) < 1, 1 \leqslant t \leqslant T_{Duration} \end{cases} \tag{3.4}$$

where $S_{Duration}$ denotes a certain duration stimulus; $T_{Duration}$ denotes the stimulus lasting time; t denotes the current time, $1 \leqslant t \leqslant T_{Duration}$; and A_{Desire} denotes how much an agent wants to have a certain stimulus, in other words, the desire towards it. The range for A_{Desire} is from -1 to 1. A negative stimulus usually comes with a negative A_{Desire} value. A certain stimulus is not strongly desired by an agent when $0 < ABS(A_{Desire}) < 0.5$. In this case, the initial influence caused by this stimulus is not very strong, but it will get stronger and stronger during the stimulus. On the other hand, a certain stimulus can cause very strong influence to the agent at the beginning, followed by increase-rate drops. Equation 3.4 includes two general duration stimuli. Both of the stimuli have exactly the same total amount of $S_{Duration}$. The only difference between two is the order of the $S_{Duration}$ values.

Intensity

Intensity measures the strength of a stimulus. *Intensity* as 0 means that the stimulus is so trivial it can be ignored, while *Intensity* as 1 represents a very strong stimulus. For example, a person hit by a pillow feels less pain than hit by a brick. Generally, a stronger stimulus comes with stronger effect. A person hit by a brick might end up with serious bleeding, which causes a much stronger physical and emotional effect.

Effect

$Effect$ is resulted from a certain stimulus. It is one of the most important elements. -1

means that the stimulus has an extremely negative effect on the agent, while 1 means the stimulus has an extremely positive effect on the agent. Generally, people measure the effect of a stimulus by reviewing the results they cause. Mostly, positive stimulus leads to positive effects for the agent, while negative stimulus brings negative effects to the agent. For instance, people feel sad when they get hurt, feel happy when they get rewarded. However, sometimes, a positive stimulus carries certain negative effects, while a negative stimulus can lead to some positive effects. Consider the following example. Mike wanted to help his mother wash dishes. Unfortunately, he smashed them all by accident. During the cleaning of the mess, Mother found her long-lost wedding ring. Helping mother is a praise-worthy behaviour, but smashing dishes is a bad result. However it is also the reason that Mother found her ring. Mostly, people care effects/results more than stimuli/progresses, which makes *Effect* a key element in our model.

Likelihood

Likelihood is another key element. 0 denotes that the stimulus is not going to happen, while 1 denotes that the stimulus will definitely happen. Stimulus can affect agents, even when it has not happened yet. For example, Mike is hiking in the woods when he received the weather forecast that there are 90-percent chances of raining soon. There is a very big chance of him to be caught in the rain. Mike might have to stop hiking immediately and feel quite disappointed. However, if the rate of raining is only 10 percent, Mike might continue his hiking and is not bothered too much by the event. Here the stimulus "raining" has not happened yet, but its likelihood of happening does affect Mike's action and emotion.

Desire

Desire is another very important element in our model. It is not a property of the stimulus itself, but a property of an agent towards a stimulus. *Desire* is an intensity level which describes how strong an agent wants a certain stimulus, -1 means that the agent totally does not want this stimulus, While 1 means that the agent's desire for this stimulus reaches the maximum. Generally, people long for a certain stimulus because the result/effect of that stimulus makes them happy, rich, healthy or experience extraordinary. *Desire* can dramatically affect emotional changes. For example, both Alice and Kate are big fan of dolls and both want a particular blue doll. For Kate, that blue doll is the last piece to complete her collection of a certain precious set, which makes her desperate to have it. Consequently, Kate would feel more happiness than Alice when she gets the blue doll.

3.3.3 Emotional Intensity and Change Process

Emotional changes, including emotional type changes and Emotion Intensity (EI) changes, should have a clear development process. Most of the existing emotion models for intelligent virtual agents pay little attention to such a process. Most of them derive an agent's emotional type according to a certain stimulus, but ignore the Emotion Intensity (EI) and the change process. In this thesis, we aim to show agent's facial animation changes along with emotion value changes against a timeline.

Assume the effect on emotional change by a stimulus is a fixed amount, *Desire* would not change the total amount of the effect, but it could change its distribution throughout the whole stimulus phase. For example, Mike is new to the school and he is bullied at his first school day. A_{Desire} is assigned as -0.4 since it is a very bad experience and no one wants to be bullied. Sadness emotion shows up in his face. During the bully, his feeling is getting worse and worse. In this case, it fits to the first equation in Equation 3.4. Influence caused by stimulus increases during the stimulus. Another example, Mike is bullied many times during the first semester. A_{Desire} is assigned as -0.9 since Mike extremely hates being bullied. When the bully happens again, he feels Sadness/Fear. The influence caused by the stimulus could suddenly reaches its peak, which makes Mike desperately scream. In this situation, the second equation in Equation 3.4 fits to this scenario.

The stronger the stimulus influence is, the faster the PAD values increase. Higher PAD absolute values mean higher EI. Detailed discussion is provided in Section 4.2.4.

3.4 Emotional Decay

Decay of emotion measures how fast the strength of a certain emotion decreases. It starts when a certain stimulus stops applying. From observations of the real emotional changes it is assumed that such decays happen exponentially, i.e., the emotional strength drops slowly in the beginning but the rate of decrement increases exponentially with time. It is assumed that decays always happen to all emotions caused by stimuli and over a given duration all agents will eventually go back to some values between the peak PAD values and the neutral. In this thesis, we simply regard it as

$$\frac{E_{Peak} \times ABS(E_{Peak})}{2}$$

High PAD values decay to half of their peak values, while low PAD values decay to more than half of their peak values. Since a very good news keeps people happy relatively long,

even after the emotional decay. While a trivial good news would not keep people happy that long. It is closer to neutral when emotional decay is over. Eventually, this decayed PAD values, especially the Pleasure value is used to calculate mood status. The emotional decay is formulated simply as follows:

$$E_{Decay} = (\Delta E_{PAD})/2^{(T_{Duration}+T_{Decay}-t)} \tag{3.5}$$

$$\Delta E_{PAD} = E_{Peak} - \frac{E_{Peak} \times ABS(E_{Peak})}{2}$$

,

$$T_{Duration} < t \leq (T_{Duration} + T_{Decay})$$

where N_{Decay} denotes the number of decay order; T_{Decay} denotes the decay duration; $T_{Duration}$ denotes duration of the stimulus; $T_{Decay} + T_{Duration}$ defines the complete period for an emotion caused by a certain stimulus and then decayed towards the neutral; t denotes the current time; E_{Decay} denotes the PAD decay values; E_{Peak} denotes the PAD peak values; ΔE_{PAD} denotes the PAD values changes caused by the stimulus; As discussed, when a stimulus is finished, decay starts.

3.5 Summary

In this chapter, the basic components of our emotion model are discussed, including emotion, mood and stimulus. In this proposed model, emotion is represented as PAD values at any time, while mood is more related to Pleasure value. Mood reflects a relatively long-term effect and is simply classified as good, neutral and bad mood. Stimulus is categorized into instantaneous stimulus and duration stimulus. Basic elements of stimulus such as *Intensity, Effect, Likelihood* and *Desire* are introduced. Since emotional change is a very subjective matter, *Desire* plays one of the most important roles here. In this thesis, both the instantaneous and the duration stimuli are considered, as shown in the many experiments described in Chapter 5. More experiments are conducted for duration stimuli since they are generally more complicated than instantaneous stimuli.

Chapter 4

Advanced Emotion Model

An advanced emotion model is proposed in this thesis which is built based on the basic model described in Chapter 3 but includes many extensions, namely, personality feature which is implemented with NEO PI-R personality model; self-protection mechanism which is built with Resistant value; and Emotional Intensity which is not actually implemented for the proposed emotion model, but it is used to represent agent facial expression changes alone with its PAD values change.

4.1 Personality Model

Personality refers to individual differences among people in cognition, behaviour patterns and emotion (Michel *et al.*, 2004). In other words, it reflects individual differences in mental characteristics. Big-5 personality and NEO PI-R personality are the two most popular personality models.

4.1.1 Big-5 Personality Model

In the well-known Big-5 personality model, personality is classified into five domains, namely, the Big Five Factors, which include *Openness to Experience, Conscientiousness, Extroversion, Agreeableness*, and *Neuroticism*. These personality factors are usually stable over time and about half of the variance is found to be attributable to a person's genetics instead of one's environment effects (Lucas and Baird, 2004; Briley and Tucker-Drob, 2014). On the other hand, environmental influences have significant impacts on building one's personality traits (Briley and Tucker-Drob, 2014; Jeronimus *et al.*, 2014). In reality, people with different genes interacting with each other in such a complicated social and natural environment, which makes their behaviours and emotional statuses even harder to be predicted. Mehrabian proposes a mapping between the Big-5 personality and PAD emotion model (Mehrabian, 1996a), as shown in Equation 4.1, Equation 4.2, and Equation

4.3.

$$\begin{aligned} Pleasure &= 0.21 \times Extraversion + 0.59 \times Agreeableness \\ &+ 0.19 \times EmotionStable \end{aligned} \tag{4.1}$$

$$\begin{aligned} Arousal &= 0.15 \times Openness + 0.30 \times Agreeableness \\ &- 0.57 \times EmotionStable \end{aligned} \tag{4.2}$$

$$\begin{aligned} Dominance &= 0.25 \times Openness + 0.17 \times Conscientiousness \\ &+ 0.60 \times Extraversion - 0.32 \times Agreeableness \end{aligned} \tag{4.3}$$

The Big-5 personality trend on PAD space could be described as follows:

$$PAD_{Trend} = K \times Personality \tag{4.4}$$

where *personality* denotes the Big-5 personality; $K = \begin{bmatrix} 0 & 0 & 0.21 & 0.59 & 0.19 \\ 0.15 & 0 & 0 & 0.30 & -0.57 \\ 0.25 & 0.17 & 0.60 & -0.32 & 0 \end{bmatrix}$ denotes the Big-5 personality transfer matrix.

Assuming an agent has 50% of *Openness to Experience*, 40% of *Conscientiousness*, 80% of *Extraversion*, 70% of *Agreeableness*, and 50% of *Emotion Stable*, its personality matrix is

$Personality = \begin{bmatrix} 0.5 \\ 0.4 \\ 0.8 \\ 0.7 \\ 0.5 \end{bmatrix}$, according to Equation 4.4, we can easily evaluate $PAD_{Trend} = \begin{bmatrix} 0.676 \\ -0.189 \\ 0.449 \end{bmatrix}$

However, this mapping on *Neuroticism* is a bit blurry. Personality trait *Neuroticism* is sometimes also called *Emotional Stable*, which are the opposite end of *Neuroticism*. A high score in *Emotionally Stable* means a low score in *Neuroticism*, and vice versa. Equation 4.1 and Equation 4.2 only covers cases with high scores of *Emotionally Stable*, ignoring cases of low scores in this trait. When people score low in *Emotionally Stable*, they

tend to experience negative emotions such as anxiety, anger, or depression, as discussed in Section 2.2.1. In the PAD model, *Anxiety*(-P-A-D) is associated with strong negative Pleasure, moderate negative Arousal, and strong negative Dominance; *Anger*(-P+A+D) is associated with strong negative Pleasure, strong positive Arousal, and moderate positive Dominance; and *Depression*(-P-A-D) is associated with strong negative Pleasure, low negative Arousal, and strong negative Dominance. Such differences are not represented in Equation 4.1, Equation 4.2 or Equation 4.3. Generally speaking, Big-5 personality model is not detailed enough. A better and more detailed measurement of personality is desirable for better modelling of emotions.

4.1.2 NEO PI–R personality Model

The NEO PI-R personality model has five major domains, each of them having six facets. Section 2.2.2.1 provides detailed explanation for each NEO PI-R personality facet. Altogether thirty facets as shown in Table 2.7. The NEO PI-R is recognized as a good standard for adult personality testing over the world. Reputable personality researchers use it to assess people's suitability on specific occupations. Individuals use it for self-assessment to learn who they really are. It is a common practice for human resource personnel to find people with the most suitable personality for certain positions during recruitment.

The details of the NEO PI-R personality model are given in Section 2.2.2. Since many personality facets of NEO PI-R model are not directly linked to emotional change, we have carefully chosen 11 facets from NEO PI-R to be incorporated into our emotion model, namely, *Anxiety, Angry Hostility, Depression, Self-consciousness, Vulnerability, Warmth, Positive Emotion, Altruism, Compliance, Tender Mindedness* and *Dutifulness*, which are more related to emotional changes. All these 11 facets are assigned a value from 0 to 1 respectively. For example, if the value for *Angry Hostility* is less than 0.5, the agent is assumed to be less likely to get angry. Among the 11 personality traits, *Anxiety, Depression*, *Self-consciousness* are more related to the emotion *sadness*; *Angry Hostility* and low *Compliance* are more related to *anger*; *Vulnerability* is more connected with *fear*; and *Positive Emotion* shows one's ability to look on the bright side and be *happier*. The following equations describe how these personality facets are connected to the respective Emotional Trends (ET), which represent the tendency for an agent to feel the respective

emotions:

$$ET_{Fear} = (Vulnerability - 0.5) \times ABS(Vulnerability - 0.5) \tag{4.5}$$

$$ET_{Happiness} = (PE - 0.5) \times ABS(PE - 0.5) \tag{4.6}$$

$$\begin{aligned} ET_{Sadness} = {} & \alpha\,(Anxiety - 0.5) \times ABS\,(Anxiety - 0.5) \\ & + \beta\,(Depression - 0.5) \times ABS\,(Depression - 0.5) \\ & + \gamma(SC - 0.5) \times ABS(SC - 0.5) \end{aligned} \tag{4.7}$$

$$\begin{aligned} ET_{Anger} = {} & (AH - 0.5) \times ABS\,(AH - 0.5) \\ & - \delta\,(Compliance - 0.5) \times ABS(Compliance - 0.5) \end{aligned} \tag{4.8}$$

where α, β, and γ denote the weighting coefficients of *Anxiety, Depression, Self-Consciousness* and *Compliance* respectively. They all range from 0 to 1.

The other four facets, *Altruism, Tender Mindedness, Warmth* and *Dutifulness*, basically describe whether a person likes to interact with others and the manners he interacts with them. According to the NEO PI-R manual (Costa and McCrae, 1992), *Altruism, Tender mindedness* and *Warmth* contribute less on emotional changes directly. However they are important when determining whether a person is likely to get involved in certain situations when he is not directly affected. For example, an agent, Mike, saw that another agent Jack (a stranger to Mike) tripped and fell. It is usually hard to determine whether and how this incident would affect Mike's emotion. Mike's personality, especially on the traits of *Altruism, Tender mindedness* and *Warmth*, becomes important here to determine whether he would decide to get involved in this event or stimulus. The following equation describes the probability of an agent responding to a certain stimulus:

$$\begin{aligned} Response_{Trend} = {} & \epsilon\,(TM - 0.5) \times ABS\,(TM - 0.5) \\ & + \varepsilon\,(Altruism - 0.5) \times ABS\,(Altruism - 0.5) \\ & + \theta\,(Warmth - 0.5) \times ABS\,(Warmth - 0.5) \\ & + \sigma(Dutifulness - 0.5) \times ABS(Dutifulness - 0.5) \end{aligned} \tag{4.9}$$

Where ϵ, ε, θ, and σ denote the weighting coefficient of *Altruism, Tender Mindedness, Warmth* and *Dutifulness*. If $Response_{Trend} < 0$, the agent will ignore the stimulus happened to other agents. If $Response_{Trend} \geq 0$ agent will respond to the stimulus. Here $Response_{Trend}$ can be regarded as a basic ability on perception or belief.

The 11 personality traits are hence incorporated into the emotional model to calculate the emotional trends of an agent in *fear, happiness, sadness, anger, disgust*, and his/her probability of responding to certain events happening to other agents. Personality and emotions are very complex. A person could have many different sides of personality and at any time he could experience many different, sometimes conflicting, emotions. We consider an agent's emotions and behaviours are often only affected by a few dominant trends. In this research, only the first two dominant emotional trends are chosen at any instant.

4.2 Emotion Modelling Based on NEO PI–R

4.2.1 PAD Trend Based on NEO PI–R Facets

According to the popularly used Ekman's model (Cohen and Massaro, 1993), there are six basic classes of emotions: *anger, disgust, fear, happiness, sadness* and *surprise* (Shi *et al.*, 2012). In the proposed emotion model, we have implemented *anger, disgust, fear, happiness* and *sadness*. *Surprise* is not supported since it requires a memory module and complicated decision-making procedures based on memory. Detailed discussion on *surprise* is provided in Section 3.1 and Section 6.2. The PAD values corresponding to *anger, disgust, fear, happiness* and *sadness* are shown in Table 3.1.

Combining with the emotional trends derived above, the PAD trends of an agent, which describes the most possible PAD values an agent tends to reach based on his/her personality traits can be obtained as follows:

$$PAD_{Trend} = ET_1 \times PAD_1 + ET_2 \times PAD_2 \tag{4.10}$$

where ET_1 is the 1st most dominate emotion trend; ET_2 is the 2nd most dominate emotion trend; PAD_1 and PAD_2 denotes the standard PAD values in Table 3.1 corresponding to ET_1 and ET_2;

4.2.2 Mapping NEO PI–R Facets to the PAD Space

In the proposed model, the emotional trend calculated based on the personality traits are constantly mapped into the PAD model to dynamically simulate the emotional change of an agent. Equation 4.11 and Equation 4.12 describe how the PAD values are dynamically

updated at every time step.

$$E_t = E_{t-1} + M_t + (PAD_{Trend} + \rho) \times S_{Duration} - T_M \tag{4.11}$$

$$0 < t \leq T_{Duration}$$

$$E_t = E_{t-1} + M_t - \text{PAD}_{Decay} \tag{4.12}$$

$$T_{Duration} < t \leq T_{Duration} + T_{Decay}$$

where E_t denotes the PAD value at time t; E_{t-1} denotes the PAD value at time t-1; M_t denotes the agent's mood at time t; and T_M is the threshold to restrict PAD values within [-1,1].

As formulated in Equation 4.11, the emotion of an agent, as represented by the PAD values, is dependent on the external stimulus, current mood, desire and the personality of the agent. Equation 4.12 shows that the PAD values slowly decay to neutral after the external stimulus stops.

4.2.3 Mapping PAD Space to Emotion Space

After the PAD values are updated at every time step, they are substituted into Equation 4.13 to measure the distances between the current PAD values and the defined PAD values given in Table 4.1.

Emotion	**Pleasure**	**Arousal**	**Dominance**	**PAD Subspace**
Fear	-0.64	0.60	-0.43	-P+A-D
Anger	-0.51	0.59	0.25	-P+A+D
Happiness	0.40	0.20	0.15	+P+A+D
Disgust	-0.40	0.20	0.10	-P+A+D
Sadness	-0.40	-0.20	-0.50	-P-A-D

Table 4.1: Emotional types used in our model

The defined emotional status given in Table 4.1 with the closest distance with the current PAD values is regarded as the current emotional status.

$$d_i = [(E_t - Emotion_i)^T (E_t - Emotion_i)]^{\frac{1}{2}} \quad , i = 1, 2, 3, 4, 5 \tag{4.13}$$

where $Emotion_i$ denotes the PAD values in Table 3.1; and d_i denotes the distance between E_t and the defined emotions.

4.2.4 Emotion Intensity

Equation 4.13 provides a way to determine the final emotional status at time t. Most of the existing emotion model would stop here and take this as the final output. However, such methods only determine what emotional status the agent ends up with. It does not provide any information on how strongly the agent feels that emotion. We therefore proposed another parameter, *Emotion Intensity (EI)* to represent the intensity of the agent on the obtained emotional status. Such a parameter also provides a useful means to describe the dynamic process of emotional change, as shown in the example later in the section. Furthermore, it is an important scale when facial expressions are used to describe the emotion of an agent. For example, happiness could link to smile and laugh. Happiness with low intensity often makes someone smile, while happiness with high intensity is more likely to make someone laugh. A good measurement of Emotion Intensity (EI) is essential in creating an emotion model with proper facial expressions.

The EI is simply formulated in our model as follows:

$$EI = ABS(\alpha \times P) + ABS(\beta \times A) + ABS(\gamma \times D) \tag{4.14}$$

where α, β and γ are weight coefficients for the PAD values in each emotional type. These coefficients are different for each emotional type, but they have to satisfy $\alpha + \beta + \gamma = 12$, $\alpha \geq 0$, $\beta \geq 0$, and $\gamma \geq 0$. Because we only implement 12 facial expressions for *anger, disgust, fear, happiness* and *sadness* respectively. The higher the range of EI, the better the facial expression animation quality is. Table 4.2 shows the α, β and γ we used. Again, these values are generated by empiricism. It can be other values, as long as they can highlight the traits of these emotions.

According to Table 3.1, the trait of *anger* comes with strong negative Pleasure and strong positive Arousal, which makes α and β the dominant coefficients in this case. Meanwhile, Pleasure is a leading value in *happiness*, α should be the primary coefficient here. No

	α	β	γ
Anger	5.5	6.5	0
Disgust	8	4	0
Fear	5	4	3
Happiness	10	1	1
Sadness	5	1	6

Table 4.2: Emotional intensity weight coefficients we used

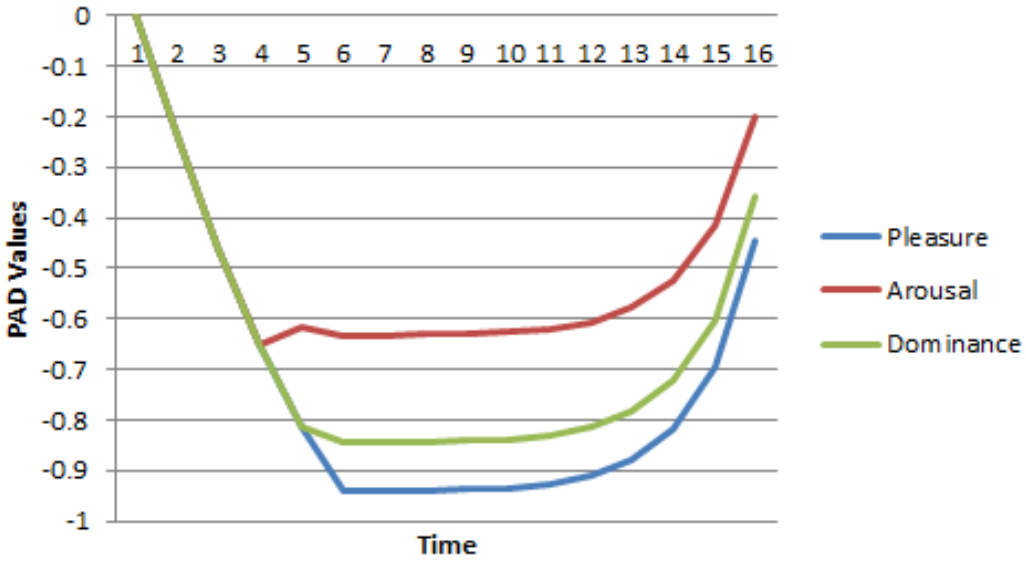


Figure 4.1: Carlos's PAD values when he is bullied

matter how the PAD values change, the value of EI will be confined between 1 and 12, which describes the agent's intensity scale in the obtained emotional status.

An example on EI is given as follows. Figure 5.3 shows that Carlos is bullied at school. Assume $S_{Intensity} = 0.9$, $S_{Effect} = -0.9$, $S_{Likelihood} = 1$, $T_{Duration} = 5$, $T_{Decay} = 10$, $A_{Desire} = -0.8$ and Carlos's personality is neutral. Figure 4.1 illustrates Carlos's PAD values changes during the bully and after the bully stops. It can be clearly seen that Carlos immediately feels sad when the bully continues. After the bully stops, his feeling of sadness levels and gradually decays. Table 4.3 shows Carlos's emotional status and the related EI on a timeline.

Time	1	2	3	4-9	10-12	13	14	15
Emotion	Sadness	Sadness	Sadness	Sadness	Sadness	Sadness	Sadness	Sadness
Emotional Intensity	3	6	10	9	8	7	6	3

Table 4.3: Carlos's emotion intensity

In Figure 4.1, Carlos's PAD values drop very quickly during $T_{Duration}$ due to the bully, then slowly decay to a certain level when bully is finished. Something interesting can be observed at Times 4 and 5 when the Arousal value starts to increase. Table 4.3 also shows a slightly sadness intensity drop during the same time phase, although the bully continues until Time 5. This is the effect of another novel parameter we proposed: the *Resistant* parameter. Carlos started to feel the urge to fight back when the bully became unbearable. Section 4.2.5 provides a detailed discussion on the *Resistant* parameter.

4.2.5 Resistant

The PAD (Pleasure, Arousal and Dominance) values are not always simply increased with positive stimulus or decreased with negative stimulus. Such phenomenon is especially obviously with negative emotions, due to the sometimes very subtle distinctions between *sad, fear, disgust* and *anger*. For example, when something negative happens, people will first become sad. If the bad stimulus continues, people's Arousal value might increase. If the stimulus still persists, people may feel the urge to fight against the bad stimulus. The Dominance value starts to increase, people become angry. We propose a novel method to simulate the changes between negative emotions.

A Resistant value R_t is proposed to represent the real time stress index of an agent. $Resistant_A$ and $Resistant_B$ are the two thresholds for changing the PAD trends. Table 4.4 demonstrates the PAD signs based on R_t value, $0 < Resistant_A < Resistant_B < 1$. In short, an agent reaches a point where the negative stimulus becomes difficult to bear when R_t reaches $Resistant_A$. When R_t reaches $Resistant_B$, the agent's Dominance value will increase as well. He/she starts to get disgusted or angry, feeling the desire to fight against the stimulus.

$$R_t = R_{t-1} + \frac{ABS(\Delta P) + ABS(\Delta A) + ABS(\Delta D)}{3} \qquad (4.15)$$
$$S_{Effect} \times S_{Likelihood} < 0$$

where R_t denotes the Resistant value at time t; ΔP, ΔA and ΔD denote the difference of PAD value from time $t-1$ to time t.

The Resistant values and the two thresholds will be used to change the sign of the PAD trends as shown in Table 4.4.

PAD Trend	Conditions
-P-A-D	$0 < R_t \leq Resistant_A$
-P+A-D	$Resistant_A < R_t \leq Resistant_B$
-P+A+D	$Resistant_B < R_t$

Table 4.4: PAD signs based on resistant value

4.3 Summary

In this chapter, NEO PI-R personality model and two novel parameters, Emotional Intensity (EI) and Resistant, are introduced into the proposed model. Section 4.1 provides a detailed discussion on Big-5 personality model and NEO PI-R personality model. By comparing these two, we find out that NEO PI-R personality model is better for the subtlety of measurement in each personality facet. Since not all of the NEO PI-R personality facets are emotion related, only 11 facets, namely *Anxiety, Angry Hostility, Depression, Self-consciousness, Vulnerability, Warmth, Positive Emotion, Altruism, Compliance, Tender Mindedness* and *Dutifulness*, are chosen and embedded into the proposed advanced emotion model. Section 4.2 describes emotion modelling based on NEO PI-R personality. Emotion, mood, stimulus and the above 11 NEO PI-R personality facets are connected together through the PAD model. Additionally, a novel parameter, Emotion Intensity (EI), is proposed to represent emotional status in different strengths, and another novel parameter Resistant is introduced to handle continuous negative stimuli. The advanced emotion model is able to handle all five basic emotions, *fear, happiness, sadness, anger* and *disgust* with different intensity. Being assigned to different personalities, agents can show various facial expressions with proper Emotion Intensity, even when they are subjected to the same stimulus. In some special occasion that requires agents' attention/help, this proposed advance model also enables agents to make their own decisions whether they want to involve this event/stimulus or not.

Chapter 5

Experimental Results and Analysis

5.1 Test System Overview

Conscript (Vella, 2008), an open source game engine, is used to develop a simple RPG as our test environment, as shown in Figure 5.1. The sole purpose of this RPG is to simulate the different emotional responses based on different personalities and different stimuli, hence the game interface is rather preliminary. The PAD values of agents in the game can be changed in real time when subjected to certain external stimulus/stimuli as shown in Figure 5.2. Some predefined stimuli include: An old man slides down on the road and asking for help; getting bullied at school; getting praised for good work; getting punched in the face; failed to pass an exam. The player can control a character in the game, and use her to chat with other agents, hereby represented by NPCs, to impose some predefined stimuli. Figure 5.1 shows the player-controlled character is chatting with NPC Owen. Alternatively, the player can use an application interface to impose a stimulus directly on any chosen NPC, as shown in Figure 5.3. The corresponding emotional changes of the NPC are shown by the changing PAD values represented by the actual values shown in Figure 5.2, and by the changing graphs and simple animations of facial expressions, as shown in Figure 5.4.

Script driven simulation offers a good way to manage agents and game scenarios. One script per agent plus additional script for the game scenario are utilized for the actions and interactions of agents, which allows creation of complicated simulations. All agents have their own characteristics, such as name, gender, initial PAD values, personality etc., as shown in Figure 5.5. They can move around freely in the simulation environment. At any time, the scripts can be interrupted by the external stimuli, controlled by the player. They resume their previous actions when the imposed external stimuli are finished.

Figure 5.1: Game Environment

5.1.1 Animation of Facial Expressions

In this thesis, the animations of facial expressions are required to represent the emotional changes of the agents vividly. A few tools have been explored.

Haptek is a SDK which enables users to create and control 3D avatars with facial expressions with script support (Liu *et al.*, 2011). As shown in Figure 5.6, emotions such as *anger, disgust, happiness, fear* and *sadness* have been implemented.

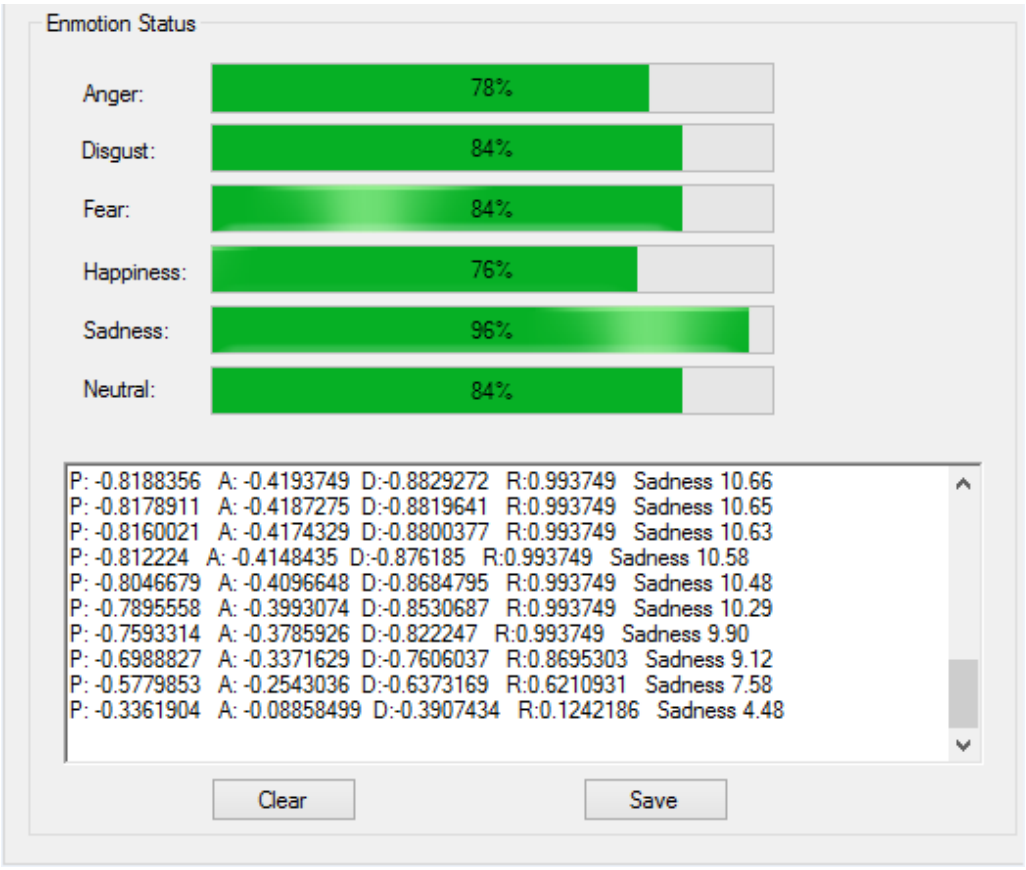


Figure 5.2: Real time PAD Values changes

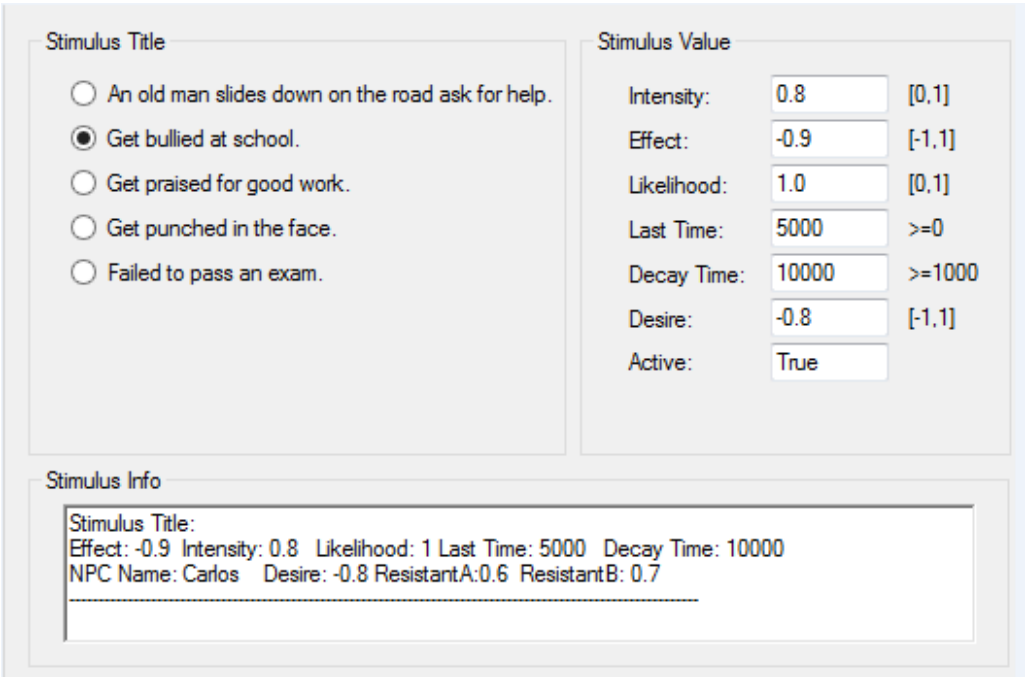


Figure 5.3: Predefined stimuli

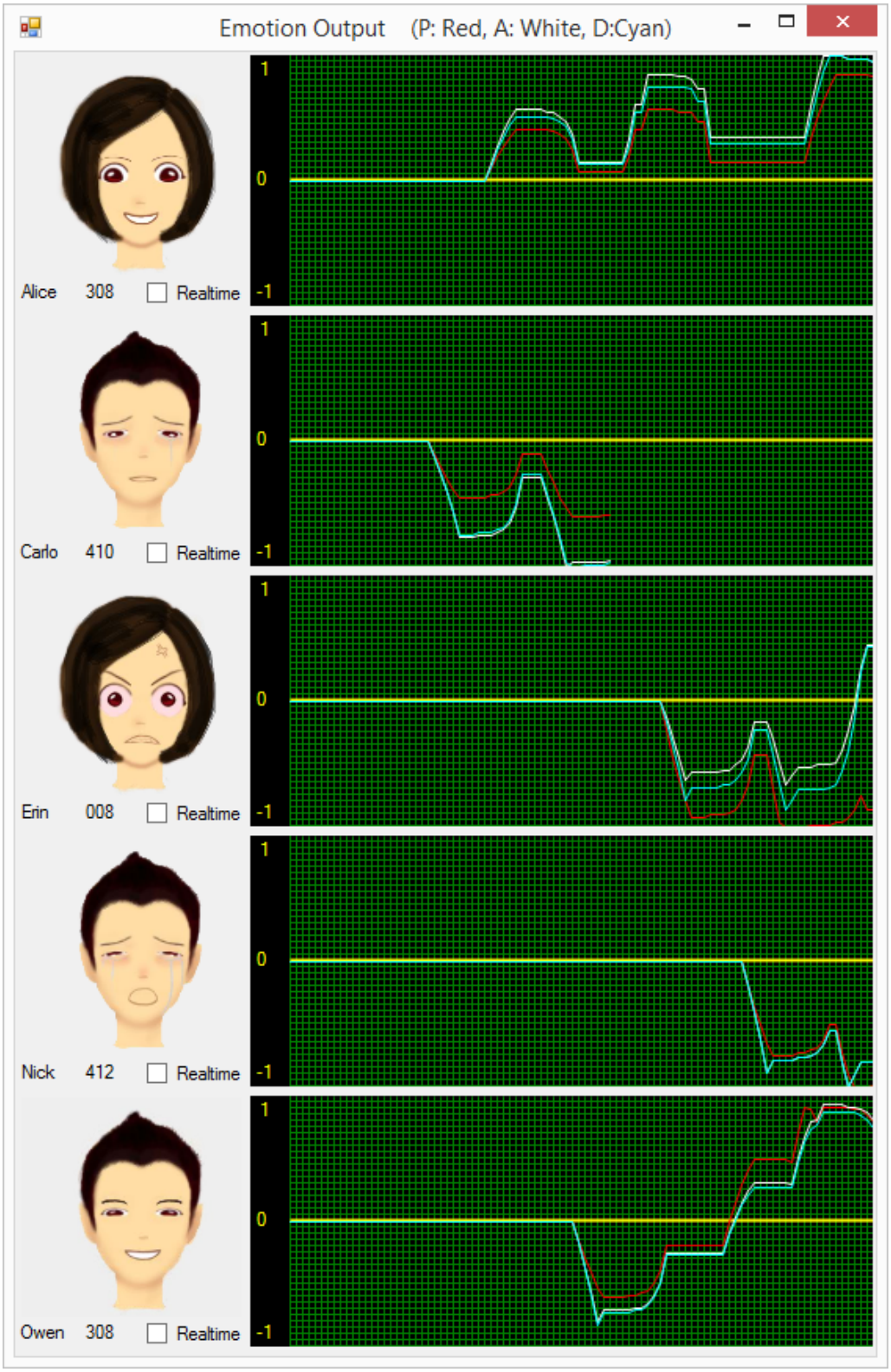


Figure 5.4: Emotional status shown in facial animation and graph

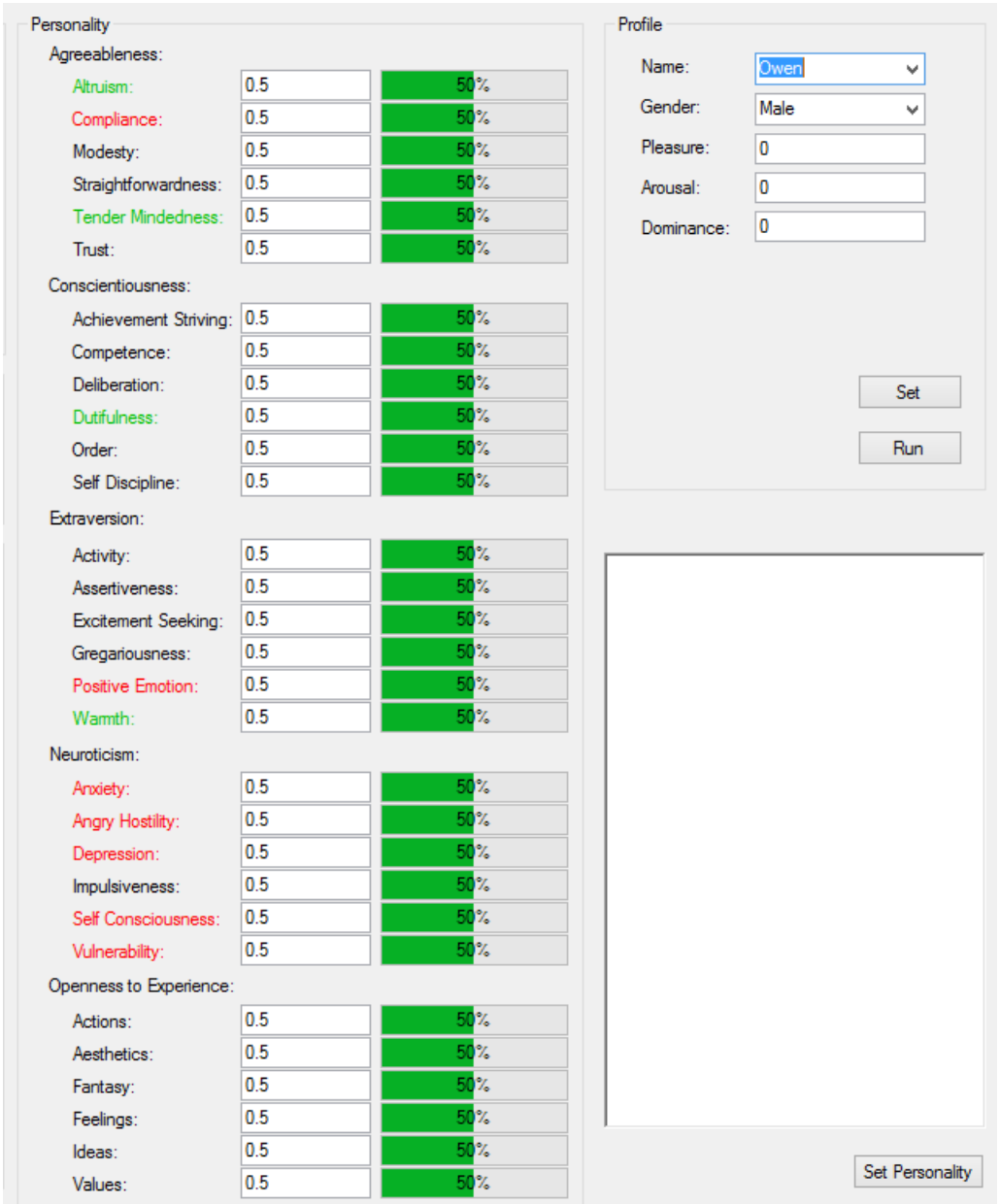
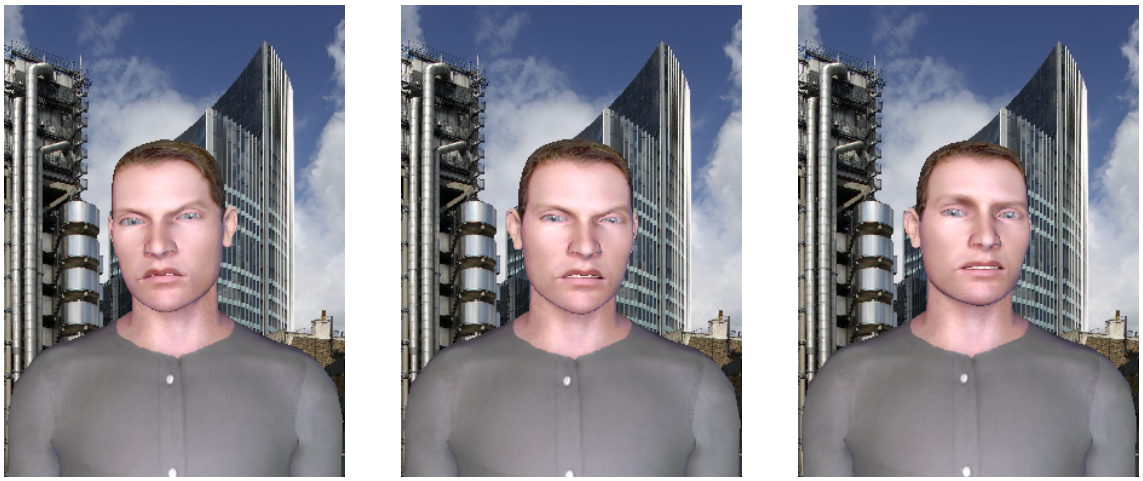
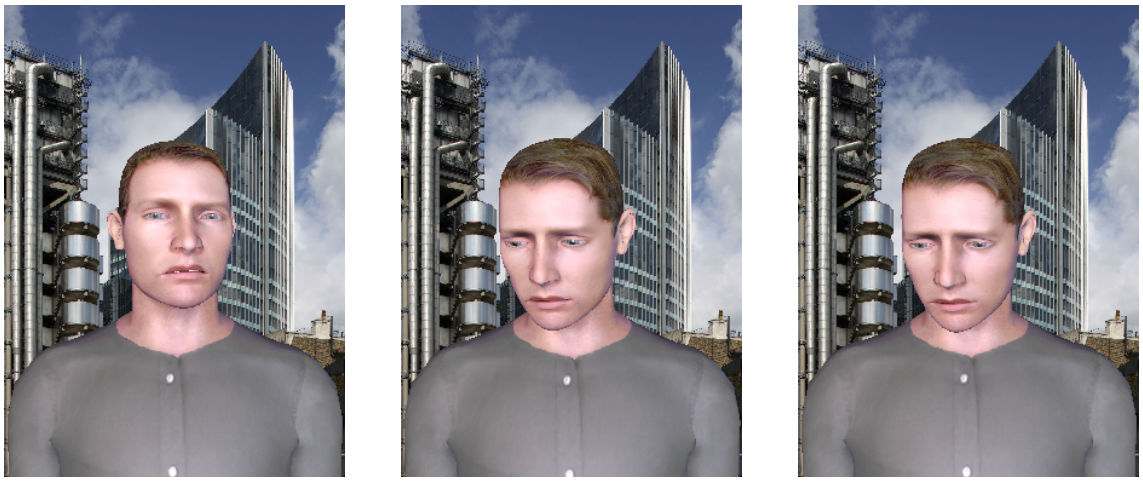


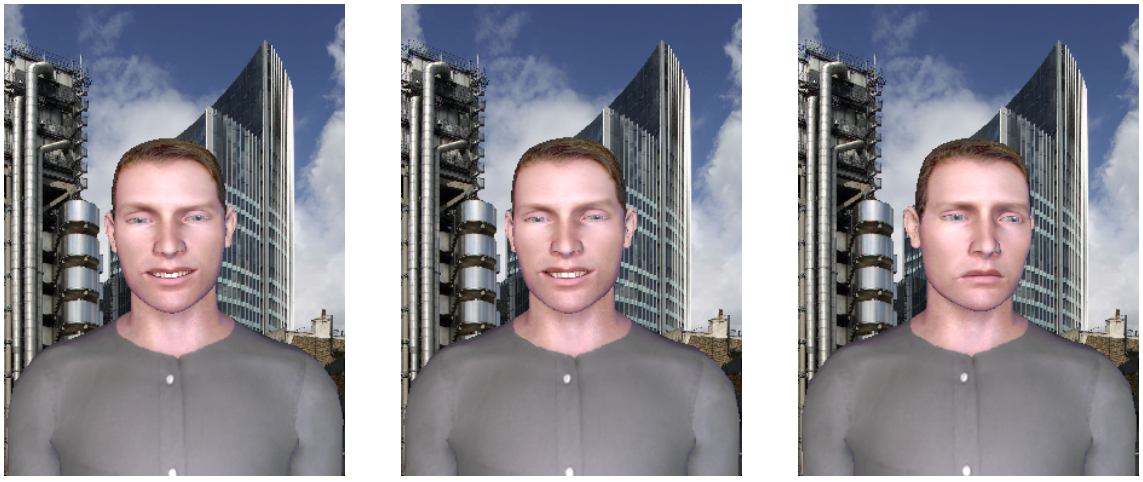
Figure 5.5: Game Profile



a) Anger1 b) Anger2 c) Disgust1



d) Disgust2 e) Fear1 f) Fear2

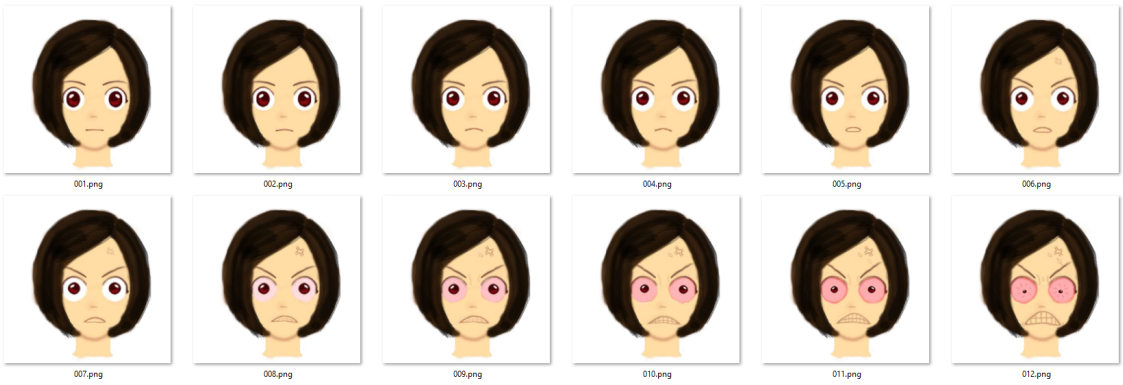


g) Happiness1 h) Happiness2 i) Sadness1

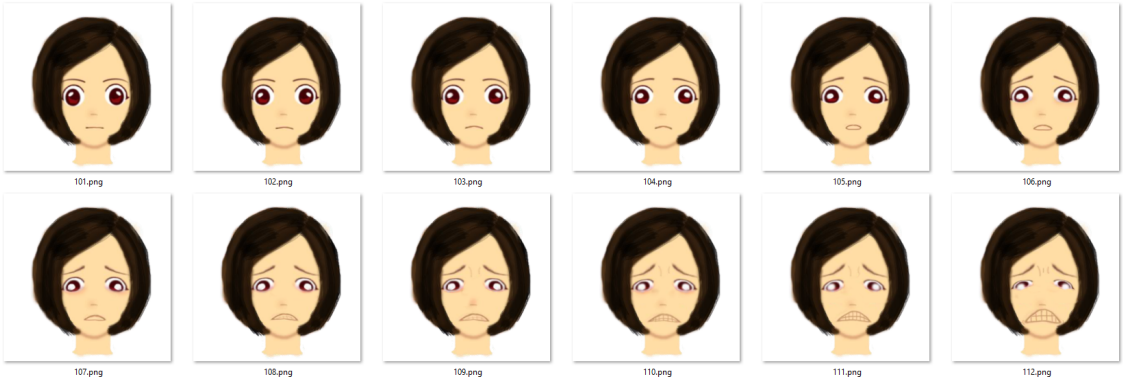
Figure 5.6: Haptek male facial expressions

Haptek provides certain emotion animation scripts, including emotional changes and head moves. They are well designed with reasonable realism. However, the scripts are predefined with fixed time. Additionally, facial changes made by Haptek are not real time, unable to match the real time change of PAD values in an emotion modelling system. 3D game engines Torgue (Maurina, 2006) and Unreal (Games, 2006) are also explored, but they have the same problem, i.e., animation is not real time. Although 3D facial expressions could provide better quality representation, they are more time-consuming and unable to reach real time when running on an ordinary desktop computer. Since the focus of this research is on the emotional change subjected to stimuli, we have decided to create a simple 2D facial expression animation system which is able to illustrate the emotional changes with different Emotion Intensities (EIs) in real time.

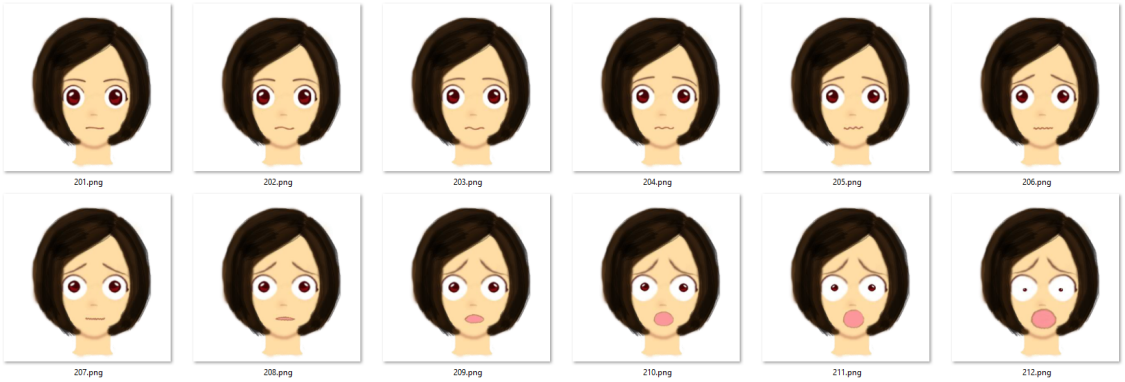
Figure 5.7 illustrates a girl's facial expressions with 12 different Emotion Intensities in *anger, disgust, fear, happiness* and *sadness.*



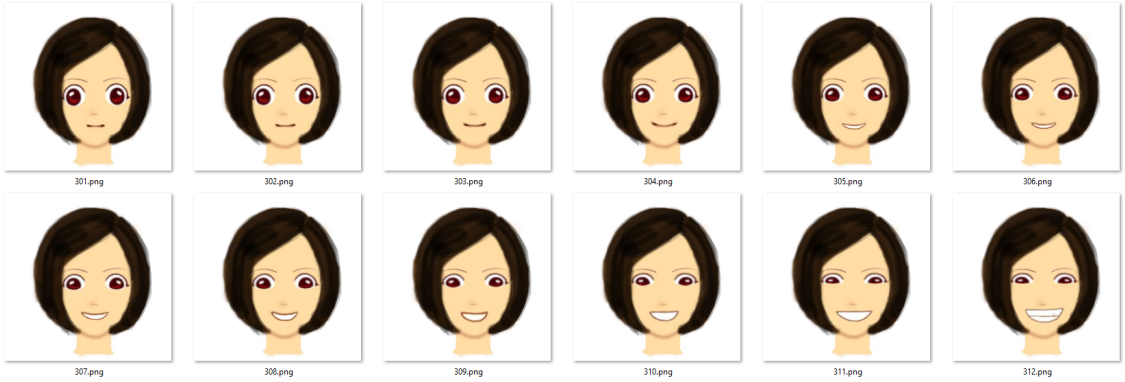
a) Anger



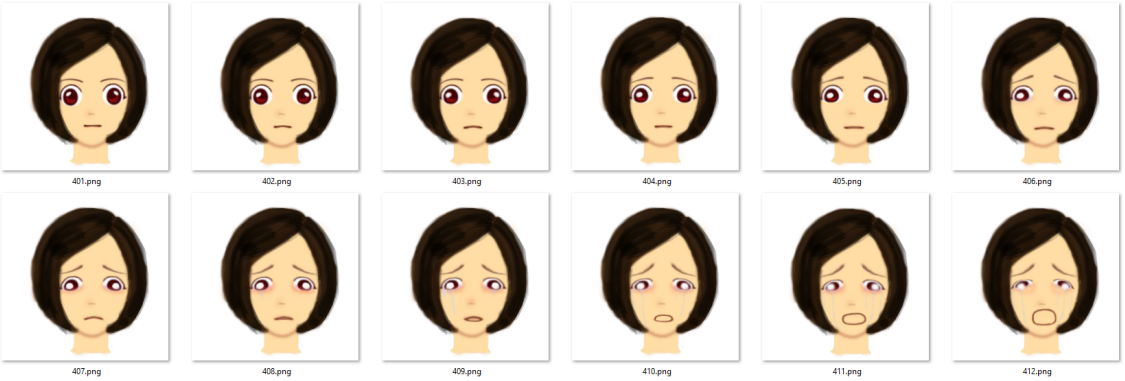
b) Disgust



c) Fear



d) Happiness



e) Sadness

Figure 5.7: Girl facial expressions

All the created facial images are loaded into our testing environment, a role playing game (RPG). When a possible emotional type is determined by Equation 4.13 and a proper Emotion Intensity (EI) is given by Equation 4.14, a corresponding facial expression will be chosen among them to show the emotion of the respective NPC. This process is very fast, able to match the emotional changes without any delay.

5.1.2 Testing Procedure

The testing procedure is mainly based on interactions between NPCs and the Player. Such interactions can be in the form of conversations, or the player could explicitly impose a complicated stimulus to a particular NPC. Figure 5.1 shows that NPC Owen is chatting with the player-controlled-character through the dialogue boxes. Figure 5.2 shows his emotional status in both bar chart and the PAD values. The PAD values as given as floating point numbers, enabling precise comparison. The emotional type with the highest value determines the current emotional status of the NPC Owen and together with the Emotion Intensity (EI) value, his current facial expression is subsequently determined. Figure 5.4 shows the PAD values of different NPCs in changing graphs and dynamic facial animations, which provides a clear trend of the PAD values and a visual representation of their emotional changes.

In the following sections, Eight (8) experiments with duration stimulus/stimuli conducted in the test environment will be described in detail. They are organized according to the types of stimulus/stimuli applied.

5.2 Simple Stimulus

Two experiments are conducted for simple stimulus. One is with a single positive stimulus, and the other is with a single negative stimulus. These two experiments are conducted to show how agents' emotional statuses are influenced by their different personality facets.

5.2.1 Experiment 1 – Single Positive Stimulus

In the first experiment, a positive stimulus is applied to the NPC Owen, who is praised by his boss. A few different personality traits are assigned to Owen and the corresponding emotional reactions are recorded. The Pleasure value is observed as the dominant emotion for Owen in this experiment since the stimulus is a simple positive one. This stimulus is implemented through a conversation which is shown in Table 5.1. Table 5.2 shows the dominant emotion and its peak Emotional Intensity (EI) throughout the whole duration as a result of the simple stimulus.

Figure 5.8 shows Owen's Pleasure value on positive stimulus during the whole period which includes both the stimulus duration time and decay time. His Arousal and Dominance values follow a similar trend to the Pleasure value. Different personality traits have been assigned to Owen. It can be seen from the graph that Owen can reach

Oven: Hey boss, I just finished all the work.
The player controlled character: Cool, good job mate. (Getting praised by boss is imposed.)
Oven: You are so kind. God bless you.

Table 5.1: Conversation for a single positive stimulus

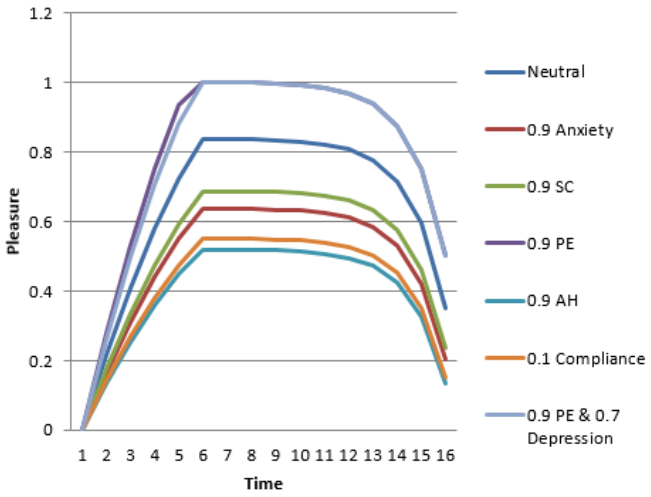


Figure 5.8: Pleasure value on single positive stimulus

	Neutral	0.9 Anxiety	0.9 SC	0.9 PE	0.9 AH	0.1 Compliance	0.9 PE & 0.7 Depression
Emotion	Happiness	Happiness	Happiness	Happiness	Happiness	Happiness	Happiness
EI	10	8	8	12	7	7	12

Table 5.2: Experiment 1 Results on various personalities

the emotional value of 1 for Pleasure in the shortest time if he is assigned a value 0.9 for Positive Emotion (PE). If he is assigned 0.9 for Positive Emotion (PE) but 0.7 for Depression, PE is the dominant personality which has great positive effort on Pleasure, Arousal, and Dominance, especially on Pleasure, while Depression strong negative effect on Pleasure, Arousal and Dominance. In this case, Owen still demonstrates very strong Emotion Intensity (EI), but is slower to reach the peak value of Pleasure. If 0.9 AH is assigned to Owen, he would not be able to reach very high level of Pleasure since his personality determines that he is prone to be angry which has very low Pleasure value.

Table 5.2 reflects the same results as above, but in different way. It shows the dominant emotion and its peak Emotional Intensity during the whole process. Owen would be the happiest when he is assigned as 0.9 PE, or 0.9 PE & 0.7 Depression. When he is assigned as 0.9 AH, or 0.1 Compliance, he has the lowest happiness intensity (7).

5.2.2 Experiment 2 – Single Negative Stimulus

In Experiment 2, a rather serious negative stimulus is applied: NPC Nick is bullied in school. Again, a few different personality traits are assigned to Nick. As a result, The Sad emotion is observed as the dominant emotion for Nick in this experiment. A conversation is also used to impose this negative stimulus, as shown as Table 5.3. The PAD Value are recorded and shown in Figure 5.9a, Figure 5.9b and Figure 5.9c respectively.

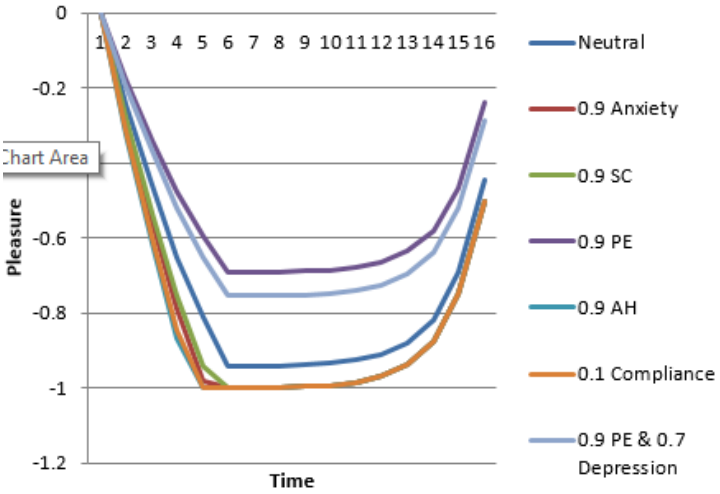
The player controlled character: Hey kiddo, give me $20 every week, I will protect you at school.
Nick: No.
The player controlled character: You need a lesson, then. (Getting bullied at school is imposed.)

Table 5.3: Conversation of a single negative stimulus

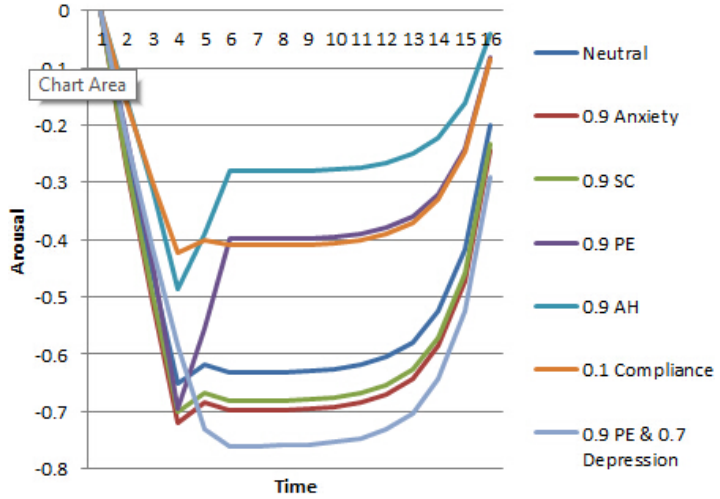
As shown in Figure 5.9a, if Nick is assigned a value 0.9 of Positive Emotion (PE) with no negative personality trait, he is able to always look at the bright side, which can somehow alleviate the hurt from bully. However the stimulus is too serious to be neutralized by personality. His pleasure value still dive to around -0.7 after being bullied. If he is assigned 0.9 of Angry Hostility (AH), he would reach the lowest value for Pleasure really quickly. People with this personality are easy to get angry, which is similar with being assigned 0.1 of Compliance. If Nick is assigned a mixed personality, -0.7 of Depression and 0.9 of Positive Emotion, he becomes sad slower but the Pleasure value is still higher than someone with a Neutral personality due to the high PE value.

Figure 5.9b demonstrates Nick's Arousal response. Being assigned 0.9 of Angry Hostility (AH) results in the highest Arousal. As discussed before, Anger emotion comes with a very high Arousal value. On the other end of the spectrum, 0.9 of Positive Emotion (PE) also results in a strong Arousal value, while 0.7 Depression brings an extremely low Arousal value. The lowest Arousal value is caused by this personality, which is in clear contrast with the one with only 0.9 PE. Normally, Anxiety makes people shy and do not know how to express themselves. When something bad happens, they tend to bear with it and allow negative emotions to build up consequently, rather than vent their feelings by getting angry, as shown by the low Arousal value.

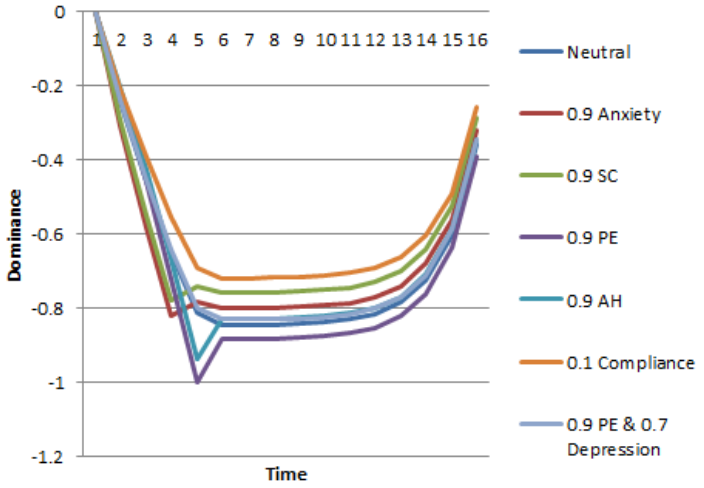
Figure 5.9c shows the changes of the Dominance value from this negative stimulus. 0.1 of Compliance is the personality trait resulting in the highest Dominance among the given personalities. Low compliance means the person is aggressive, quarrelsome and vindictive. Interestingly, both 0.9 PE and 0.9 AH show a drastic increase after reach



a) Pleasure value on single negative stimulus



b) Arousal value on single negative stimulus



c) Dominance value on single negative stimulus

Figure 5.9: PAD values on single negative stimulus

	Neutral	0.9 Anxiety	0.9 SC	0.9 PE	0.9 AH	0.1 Compliance	0.9 PE & 0.7 Depression
Emotion	Sadness	Sadness	Sadness	Sadness	Sadness	Sadness	Sadness
EI	10	11	11	10	12	12	11

Table 5.4: Experiment 2 Results on various personalities

their lowest value. That is when the stimulus duration is over, and the decay phase starts. Personality begins to have dominating effect on emotional changes. Although all personalities lead to the same emotion - Sadness - after the serious negative stimulus, their PAD curves are very different from each other and will have long term effect on the emotional changes and responses.

Table 5.4 illustrates the peak Sadness(-P-A-D) intensity in this experiment. When Nick is assigned as 0.9 AH or 0.1 Compliance, he has the highest Sadness intensity (12). As expected, personality of 0.9 PE results in the lowest sadness intensity, although the stimulus is too strong to be balanced out by the positive personality.

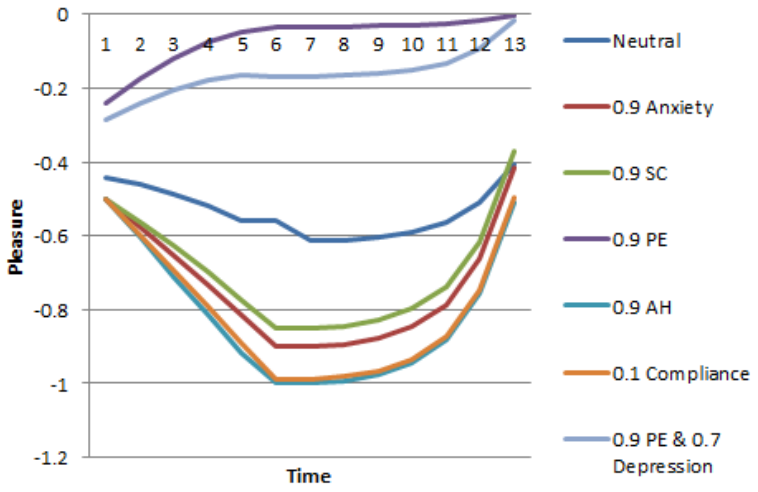
5.3 Relatively Complicated Stimulus

Six relatively complicated experiments are conducted here. Four of them involve positive stimulus comes after negative stimulus, positive stimulus and negative stimulus occur at the same time, and one extreme case negative stimulus happens again and again in a short time interval. The last case virtual agents have the ability to choose stimuli around them. The influence of personality and Resistant value are the key aspects in this section.

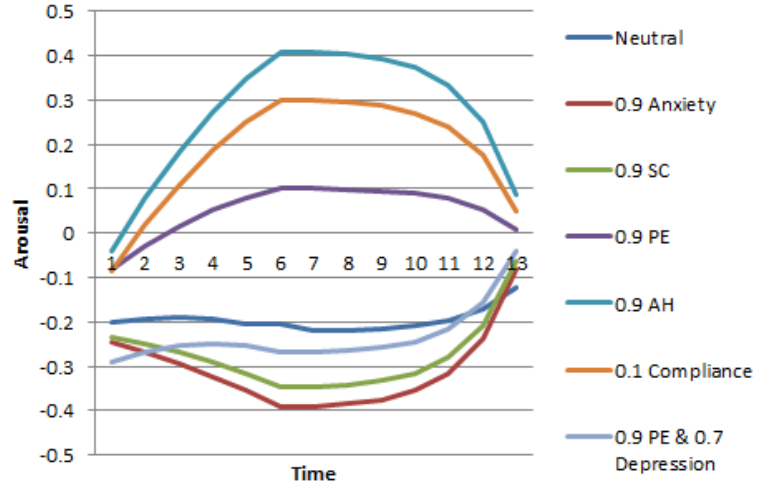
5.3.1 Experiment 3 – Subsequent Stimuli A

In this experiment, a trivial positive stimulus is applied after the event described in Section 5.2.2: NPC Nick gets a candy from a sympathetic onlooker after he is serious bullied. In this experiment, candy represents a light positive stimulus. As a result, emotions such as Sadness and Fear are still observed as the dominant emotion for Nick in this experiment. The PAD Value are recorded and shown in Figure 5.10a, Figure 5.10b and Figure 5.10c respectively. They started from the respective final values in Experiment 2.

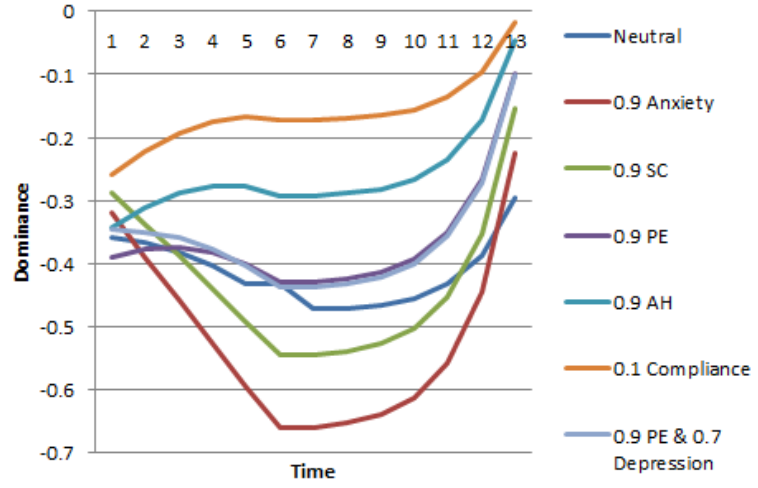
Comparing the final state of PAD values with those in Experiment 2, they are increased a little. As shown in Figure 5.10a, the Pleasure value increased a little. As expected, a light positive stimulus is not able to totally cheer Nick up. If Nick is assigned a value 0.9 of PE or a value 0.9 of PE with a value 0.7 Depression, his Pleasure value will rise up and slowly decay to neutral. The high value of Positive Emotion (PE) makes Nick more capable to appreciate the good side of the situation: A candy represents a good will of



a) Pleasure value on Subsequent stimuli A



b) Arousal value on Subsequent stimuli A



c) Dominance value on Subsequent stimuli A

Figure 5.10: PAD values on Subsequent stimuli A

	Neutral	0.9 Anxiety	0.9 SC	0.9 PE	0.9 AH	0.1 Compliance	0.9 PE & 0.7 Depression
Emotion	Sadness	Sadness	Sadness	Sadness	Fear	Fear	Sadness
EI	7	10	8	4	8	7	4

Table 5.5: Experiment 3 Results on various personalities

someone although it is not enough to comfort him totally. The other curves represent other personalities. They decreased at the beginning, and increased during the decay phase. The light positive stimulus contributes less PAD value rise when Nick's dominate personality is not PE. Nick is in a very bad mood for getting bullied. According to the Equation 4.11, while a particular mood is in dominant, a slight PAD value increase from the light positive stimulus will not stop the overall decreasing of the PAD values.

Figure 5.10b demonstrates Nick's Arousal response on a light positive stimulus. Being assigned 0.9 of Angry Hostility (AH) results in the highest Arousal. As discussed, Anger emotion comes with a very high Arousal value. On the other end of the spectrum, 0.9 of Anxiety resulted in extremely low Arousal value. The lowest Arousal value is caused by this personality, similar to the case in Experiment 2.

Figure 5.10c shows the change of the Dominance value from a light positive stimulus. Again 0.1 Compliance is the personality trait with the highest Dominance among the given personalities. The next one is 0.9 AH. Clearly both 0.1 Compliance and 0.9 AH show a rise of Dominance value during the trivial positive stimulus because either score low in Compliance or score high in AH brings quick Dominance increase. The other personalities result in decrement of Dominance due to very bad mood, just as Equation 4.11 shows. Again 0.9 Anxiety resulted in the lowest Dominance value due to the trait of Anxiety. Anxiety people are easy to get trapped by their bad mood and contribute negative value on dominance.

In Table 5.5, different emotions are observed. When Nick is assigned 0.9 for Anxiety, he has the highest Sadness(-P-A-D) intensity (10). Being assigned as 0.9 PE or 0.9 PE & 0.7 Depression, the Sadness intensity becomes 4, but the former has short duration. Moreover, Fear(-P+A-D) is observed when Nick is assigned as 0.9 AH or 0.1 Compliance, since these two facets have strong impact on Arousal. Negative Pleasure, positive Arousal and negative dominance are the major traits of emotion Fear.

5.3.2 Experiment 4 – Subsequent Stimuli B

In this experiment, a relatively strong positive stimulus is applied after the case in Experiment 2: NPC Nick stays home after he gets serious bullied. Father gets him a computer trying to cheer him up. As a result, The Happy emotion is observed for Nick

at the end of this experiment. The PAD Values are recorded and shown in Figure 5.11a, Figure 5.11b and Figure 5.11c respectively. Again they started from the final values in Experiment 2.

Figure 5.11a shows the Pleasure value on a strong positive stimulus. When Nick is assigned with 0.9 PE, 0.9 PE & 0.7 Depression or Neutral, his Pleasure value will eventually become positive. Among them, being assigned a value 0.9 of PE results in the highest Pleasure value. With the other personalities Nick is unable to turn around the negative Pleasure value. However, with a strong positive stimulus, the Pleasure values increased comparing with Experiment 3, although they are still negative.

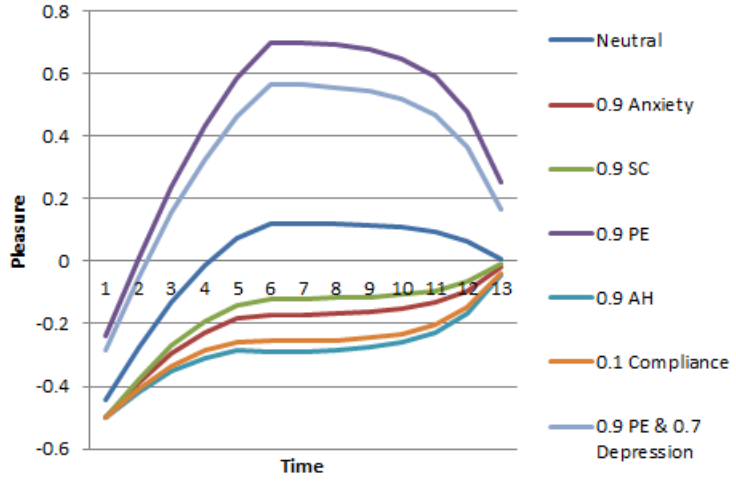
Figure 5.11b demonstrates the Arousal value on a strong positive stimulus. When Nick is assigned with 0.9 AH or 0.1 Compliance, his Arousal value reaches its peak very quickly. Being assigned a value 0.9 of PE has a very high Arousal value as well. The curves with other personalities have lower Arousal value comparing with the previous three personalities. If Nick is assigned with 0.9 of Anxiety, he gets lowest Arousal value result in a relatively negative mood similar to the case in Experiment 2.

Figure 5.11c demonstrates the Dominance value on a strong positive stimulus. When Nick is assigned with 0.9 AH or 0.1 Compliance, his Dominance value reaches its peak quickly as well. Being assigned a value 0.9 of Anxiety results in the lowest Dominance value again in this Experiment. People with this personality have less Dominance value to affect the surrounding and other people. More likely, they are easy to get affected hence the low Dominance value.

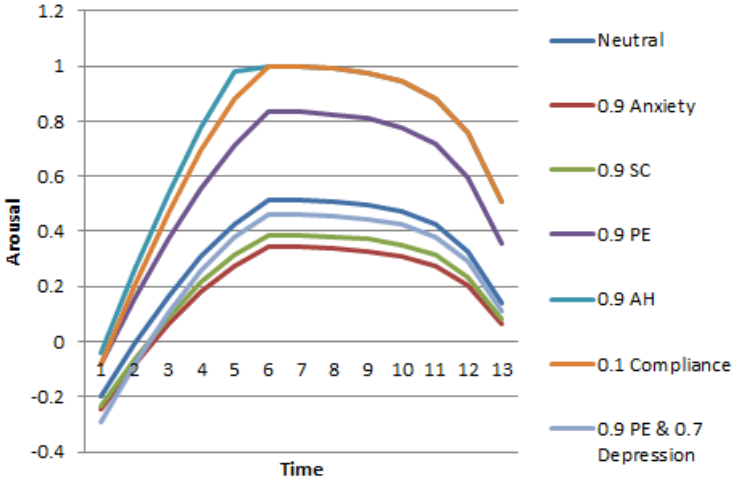
In Table 5.6, three emotions Happiness(+P+A+D), Disgust(-P+A+D) and Anger(-P+A+D) are observed. Among them, the biggest difference is the Pleasure value. Being assigned as 0.9 PE, 0.9 PE & 0.7 Depression or Neutral has a faster increase on Pleasure which makes Nick feel more Happiness. Other personalities are Neuroticism facets, which make Nick less likely to be cheered up since his Pleasure value is still negative. PAD values come with negative Pleasure, positive Arousal and positive Dominance are closer to Disgust(-P+A+D) and Anger(-P+A+D). Comparing to the third experiment, due to the strong positive stimulus, Pleasure, Arousal and Dominance have a quicker increase generally.

5.3.3 Experiment 5 – Multi-Stimuli A

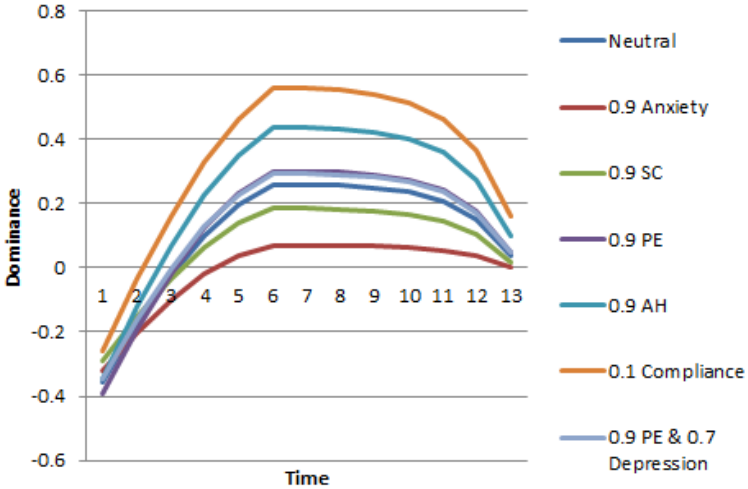
In this experiment, a light positive stimulus is applied together with a strong negative stimulus: NPC Nick is having a candy when he gets seriously bullied. The situation is referred to as Multi-Stimuli A. In this experiment, having a candy represents an



a) Pleasure value on Subsequent stimuli B



b) Arousal value on Subsequent stimuli B



c) Dominance value on Subsequent stimuli B

Figure 5.11: PAD values on hybrid Subsequent B

	Neutral	0.9 Anxiety	0.9 SC	0.9 PE	0.9 AH	0.1 Compliance	0.9 PE & 0.7 Depression
Emotion	Happiness	Disgust	Disgust	Happiness	Anger	Anger	Happiness
EI	2	3	3	8	8	8	6

Table 5.6: Experiment 4 Results on various personalities

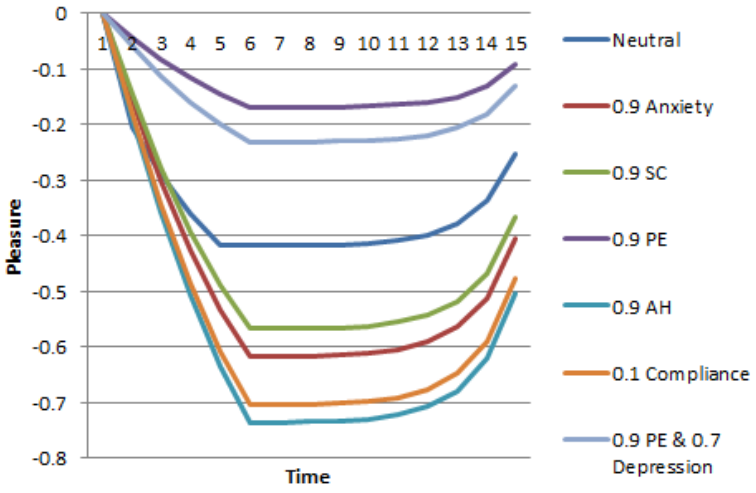
insignificant positive stimulus, which is far from sufficient in balancing the negative stimulus out. As a result, the Sad emotion is still observed while the personality is assigned as Neutral, 0.9 PE, or 0.9 PE & 0.7 Depression. The Disgust emotion is triggered for the other personalities. The PAD values are recorded and shown in Figure 5.12a, Figure 5.12b and Figure 5.12c respectively.

Comparing the peak of the PAD values in Section 5.3.3 with those for the single negative stimulus in Experiment 2, they are risen only a little. As anticipated, a light positive stimulus is not enough to neutralize the negative stimulus, i.e., to cheer Nick up. According to Figure 5.12a, if Nick is assigned a value of 0.9 PE, his Pleasure value will rise up and slowly decay to around -0.1. PE makes Nick to think more on the good side of the situation: The tasty candy; but the fact that he is bullied is still too frustrating for him to be happy. The other curves represent the changes of PAD based on other personality traits. The light positive stimulus causes even less PAD rise when Nick's dominant personality is not PE. According to Equation 4.11, when a negative mood is in dominance, a slight PAD value boost resulted from a light positive stimulus will not stop the PAD values from decreasing in general due to the strong negative stimulus.

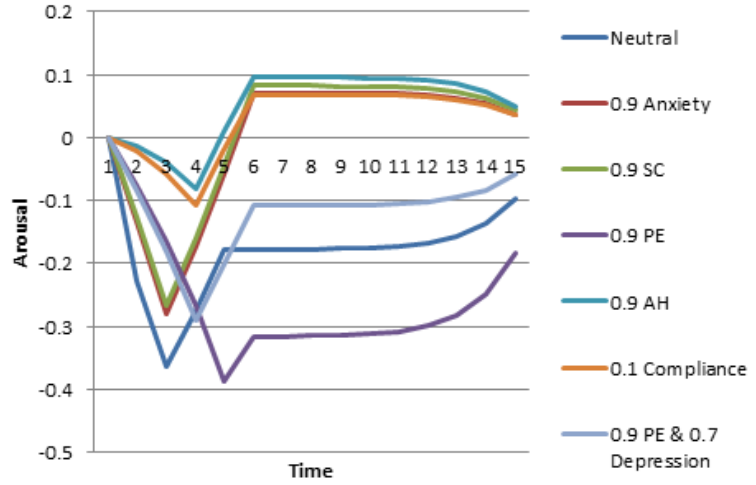
Figure 5.12b demonstrates Nick's Arousal response on Multi-stimuli A. 0.9 AH results in the highest Arousal value. As discussed before, the Anger emotion comes with a very high Arousal value. On the other end of the spectrum, 0.9 PE has extremely low Arousal value. The rise of Arousal value is caused by the Resistant value in this experiment. When Nick cannot stand the negative stimulus any more, his Arousal value begins to rise. However, his 0.9 PE personality and the light positive stimulus worked together to comfort him. Hence the lowest Arousal value is resulted from the 0.9 PE personality.

Figure 5.12c shows the change of Nick's Dominance value from Multi-stimuli A. Understandably, 0.1 Compliance results in the highest Dominance value among the given personalities, and the next highest is from the 0.9 Anxiety personality. As shown in the figure, all the personalities see a rise of Dominance value after a dramatic decrease. It is caused by the Resistant value as well. The Dominance value rises when the negative stimulus lasts beyond the Resistant thresholds.

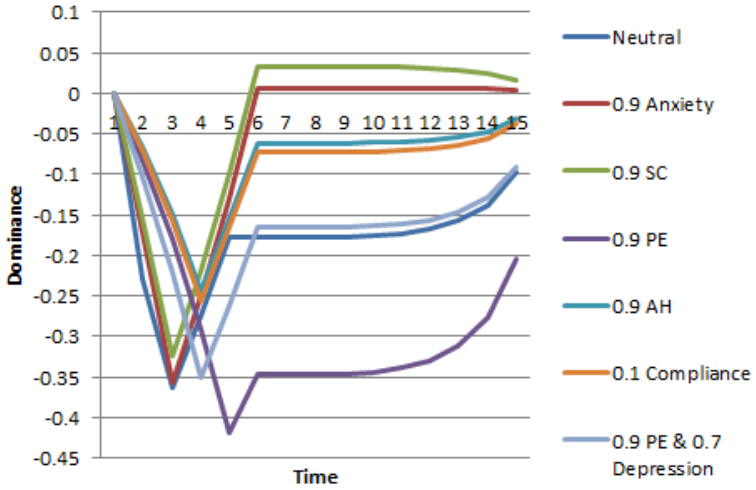
In Table 5.7, Nick feels Disgust(-P+A+D) when he is assigned as 0.9 anxiety, 0.9 SC, 0.9



a) Pleasure value on multi-stimulus A



b) Arousal value on multi-stimulus A



c) Dominance value on multi-stimulus A

Figure 5.12: PAD values on multi-stimulus A

	Neutral	0.9 Anxiety	0.9 SC	0.9 PE	0.9 AH	0.1 Compliance	0.9 PE & 0.7 Depression
Emotion	Sadness	Disgust	Disgust	Sadness	Disgust	Disgust	Sadness
EI	4	5	5	4	6	6	3

Table 5.7: Experiment 5 Results on various personalities

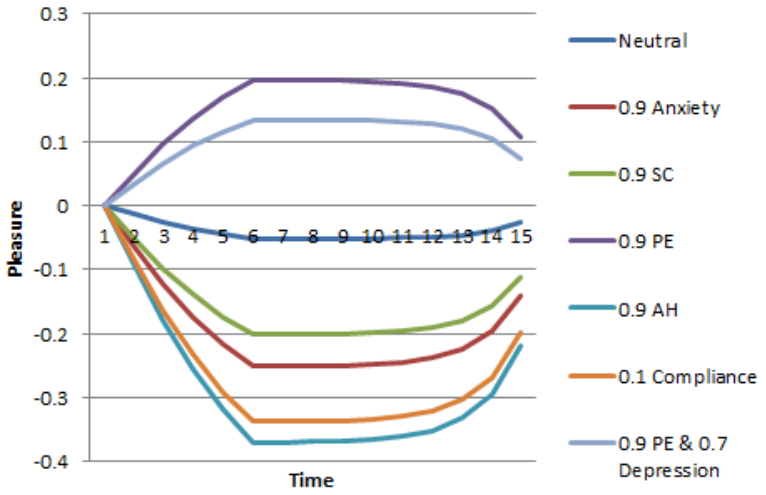
AH, or 0.1 Compliance. According to the Equation 4.11, a strong negative stimulus quick brings Nick to a very bad mood. Meanwhile a light positive stimulus could not balance the negative influence and result in negative PAD values either. High frequency of stimuli caused negative feeling (negative PAD values) enable Resistant value quickly rise. The increase of Resistant value makes Arousal and Dominance increase too. Hence, Nick's PAD values become -P+A+D. In this case, it is closer to Disgust(-P+A+D). When Nick is assigned to other personalities, he feels Sadness(-P-A-D). Comparing this experiment to the Experiment 3, Arousal and Dominance increase more quickly due to the Resistant value. The intensity of Sadness is decreased in other personalities because this experiment starts from $P = 0$, $A = 0$, and $D = 0$, which has less PAD values changes. Less PAD values changes lead to smaller Emotional Intensity (EI).

5.3.4 Experiment 6 – Multi-Stimuli B

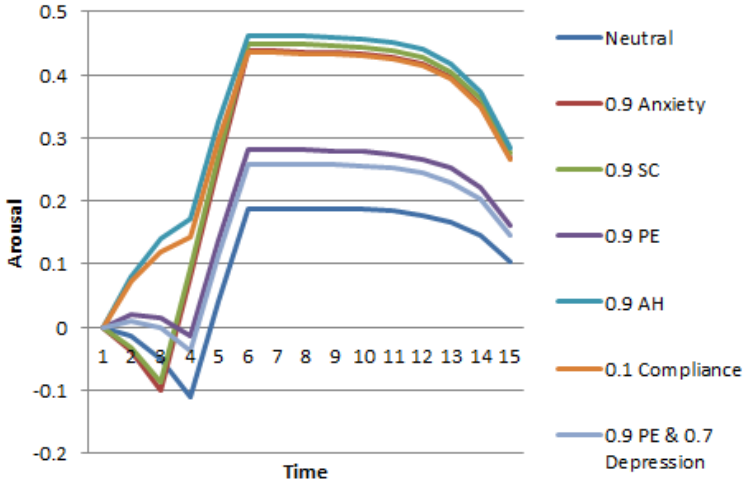
In this experiment, a strong negative stimulus (Being bullied at school) is applied to Nick at the same time as a strong positive stimulus occurs: His father is going to buy him a new computer. This situation is referred to as Multi-stimuli B. As a result, the Happy emotion is observed for Nick in this experiment for both 0.9 PE and 0.9 PE & 0.7 Depression personalities. The PAD values from different personalities are recorded and shown in Figure 5.13a, Figure 5.13b and Figure 5.13c respectively.

Figure 5.13a shows the Pleasure value on Multi-stimuli B. When Nick is assigned with personality traits of 0.9 PE, 0.9 PE & 0.7 Depression, his Pleasure value becomes positive after the stimuli since PE is his major personality trait. Among them, the personality of 0.9 PE results in the highest Pleasure value. The Pleasure value stays negative for other personality traits due to the existence of the strong negative stimulus. However, the Pleasure values are generally higher comparing to those in Experiment 2, towards the neutral value at the end of the duration.

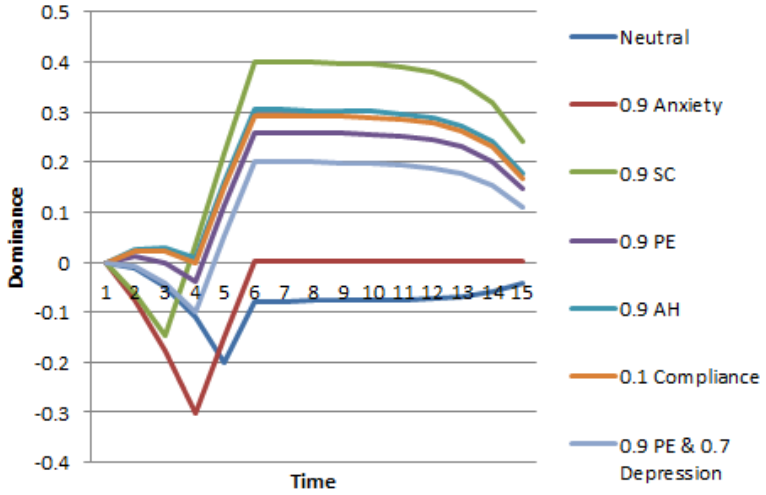
Figure 5.13b demonstrates the change of the Arousal value from Multi-stimuli B. When Nick is assigned with 0.9 AH or 0.1 Compliance, his Arousal value reaches its peak very quickly. The personality of 0.9 Self-conscious or 0.9 Anxiety results in a very high Arousal value as well. The dramatic increase starts when the Resistant value reaches $Resistant_A$ and $Resistant_B$. If Nick is assigned with the Neutral personality, the Arousal value becomes the lowest, resulting in less Arousal contribution.



a) Pleasure value on multi-stimulus B



b) Arousal value on multi-stimulus B



c) Dominance value on multi-stimulus B

Figure 5.13: PAD values on multi-stimulus B

	Neutral	0.9 Anxiety	0.9 SC	0.9 PE	0.9 AH	0.1 Compliance	0.9 PE & 0.7 Depression
Emotion	Neutral	Disgust	Anger	Happiness	Anger	Anger	Happiness
EI	0	4	4	3	5	5	2

Table 5.8: Experiment 6 Results on various personalities

Figure 5.13c demonstrates the change of the Dominance value from Multi-stimuli B. When Nick is assigned a personality of 0.9 SC, his Dominance value reaches its peak very quickly. Again the personality of 0.9 Anxiety results in the lowest Dominance value in this Experiment.

In Table 5.8, emotions such as Disgust(-P+A+D), Happiness(+P+A+D) and Anger(-P+A+D) are observed. Comparing to Experiment 4, the same results is achieved when Nick is assigned as 0.9 PE, 0.9 AH, 0.1 Compliance, or 0.9 PE & 0.7 Depression, but the Emotion Intensity (EI) is smaller in this experiment. Since this experiment starts from Neutral ($P = 0$, $A = 0$, and $D = 0$), the PAD values changes are smaller than those in Experiment 4. According to Equation 4.14, the less the PAD values, the smaller the Emotion Intensity (EI). When Nick is assigned other personalities, Experiment 6 has slightly higher Emotion Intensities than Experiment 4 in negative feelings for different emotional decay manners.

5.3.5 Experiment 7 – Continuous Negative Stimuli

In this experiment, the same negative stimulus is applied 4 times on Nick, i.e., he is bullied 4 times consecutively at school. The intention of this experiment is to evaluate the different emotional responses with reference to the proposed Resistant values as described in Section 4.2.5. The focus is on the changes of the Resistant value and its influence on the transition of negative emotions, hence Nick's personality is assigned as Neutral in this experiment.

	1st stimulus	2nd stimulus	3th stimulus	4th stimulus
Emotion	Sadness	Anger	Sadness	Anger
EI	11	11	12	12

Table 5.9: Experiment 7 Results

Figure 5.14 demonstrates the changes of the Pleasure, Arousal and Dominance values as well as the Resistant value. The first stimulus happened at time step 1: Nick gradually became Sad during the duration of the stimulus. The second stimulus happened at time step 11: Nick became Fear at the beginning, then turned to Anger during the duration. When he gradually calmed down, a bully happened again on him at time step 27; his emotion changed into Disgust, Sadness and Fear subsequently. When the fourth stimulus

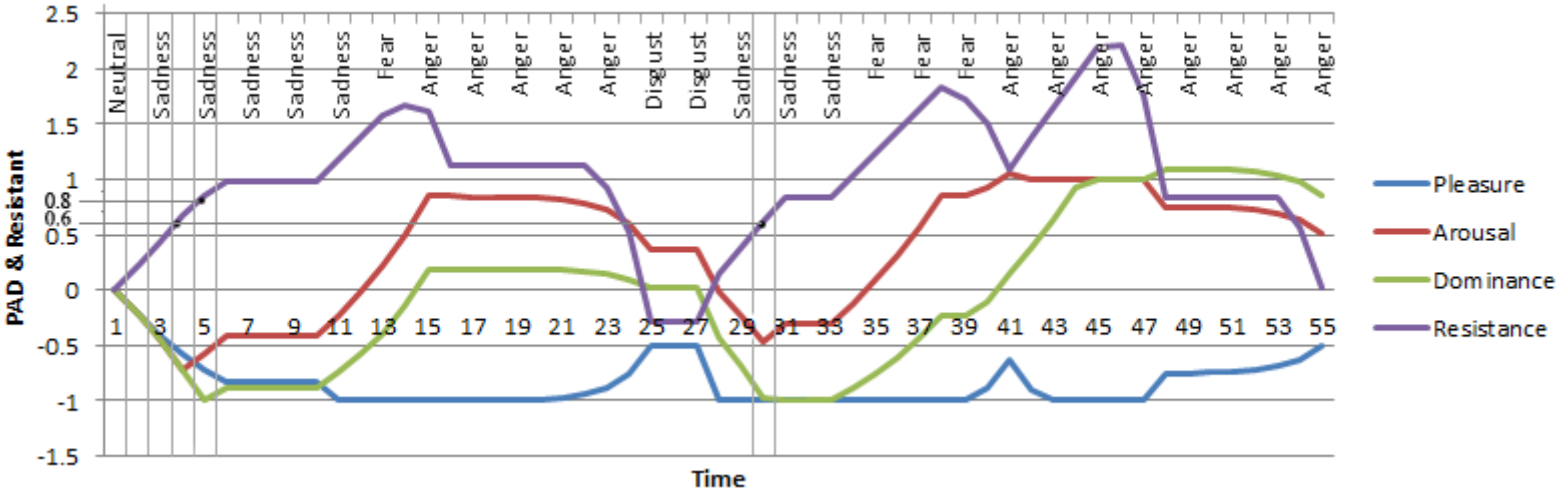


Figure 5.14: Emotional status on continuous negative stimuli

happened at time 41, the Dominance value reaches its peak and Arousal is very high too, while Pleasure is in negative. This is the emotion of great Anger. As shown in Figure 5.14, the Arousal (red curve) first starts to increase when the Resistant value (purple curve) is over 0.6 (at time step 4), and the Dominance (green curve) starts to increase after the Resistant value is over 0.8 (at time step 5). The next rises of the Arousal Dominance values are at time 30 and time 33 respectively, when the Resistant value is over 0.6 and 0.8 again respectively after the 3rd bully at time step 27. Similar to the PAD values, the Resistant value is also decayed after a stimulus stops applying. A new negative stimulus will interrupt the decay phase for the PAD and the Resistant values. Additionally, the Resistant value does not affect the PAD value during its decaying period. Emotional responses vary when the Resistant threshold and values changes.

Table 5.9 shows the dominant emotions with its highest intensity in the seventh experiment. Sadness and Anger are observed, Emotion Intensities for both of them are increasing during the experiment.

5.3.6 Experiment 8 – Stimulus Acceptance

In this experiment, an old man slides down on the road and asking for help. NPC Nick happens to pass by and sees the event. Nick is first assigned as 0.5 TM, 0.4 Altruism, 0.3 Warmth and 0.6 Dutifulness. Assume ϵ, ε, θ, and σ in Equation 4.9 have the same weight. $Response_{Trend} = -0.04$ is less than 0 and Nick is no responding to this event/stimulus. He just walks away and his emotional status has no changes. On the other hand, if Nick is assigned as 0.6 TM, 0.7 Altruism, 0.5 Warmth and 0.6 Dutifulness, $Response_{Trend} = 0.06$ is great than 0 and Nick is going to help the old man. The old man would appreciate Nick's help, which could be a new stimulus (Getting praised for helping others) for Nick. In a virtual world, virtual intelligent agents can sense a lot of event/stimulus, but they may or may not respond to all of them according to many conditions, such as their own personality.

5.4 Summary

In this chapter, eight experiments conducted in the research are described in detail and the results are analysed and discussed. It is shown by the experiments that personalities greatly affect agents' emotional changes, but they do not necessarily dictate such changes. Personality makes individuals different from one another, influencing one's cognition, behaviour and emotion. It works like a magnifier, amplifying certain aspects of the environment while ignoring others when people interact with the environment. The proposed Emotion Intensity (EI) parameter successfully provides a measurement for the dynamic changes of emotions, which is very effective to show the subtle differences of

people's emotions, even within the same emotional state. The seventh experiment tests the performance of the proposed Resistant parameter and verifies its effectiveness on representing negative emotional types such as *sadness, fear, anger* and *disgust* especially on the transitions among them. The last experiment demonstrates that personalities can also impact agents' choices when they have options. They can decide whether or not to accept certain stimuli.

Chapter 6

Conclusions

The last two decades have witnessed a rapid progress of affective computing technology. Emotion is no longer a surplus to a computer, but a somewhat essential in artificial intelligence systems. More and more computers start to have ability to "feel" human emotions, and trying to understand human mood. New emotion models are built by researchers to make computer even smart.

In this thesis we have proposed an improved emotion model based on the well-known PAD model in affective computing and the NEO PI-R personality model which is popular in the fields of social psychology, but yet to be widely implemented in the computer science fields. A novel parameter Emotion Intensity (EI) is proposed to represent different strength of *anger, disgust, fear, happiness* and *sadness*. Another novel Resistant value is also introduced, which enables our emotion model to simulate vividly the negative emotions *sadness, fear, disgust* and *anger*, and the transitions among them. A RPG-based test environment is developed to represent agents' interactions and emotional changes, with PAD values, Emotion Intensity (EI) values, and facial expressions representing current emotions displayed and updated clearly in real time. Eight experiments are conducted to simulate different emotional responses under different stimuli with different personality traits. Results from the first six experiments demonstrate that our personality model is able to reflect how personalities greatly influence the emotional responses when subjected the same stimulus or same set of stimuli, and the effect of EI. The seventh experiment shows the emotional changes under repeated negative stimuli and the effect of the Resistant value. The last experiment shows personalities can also influence agents' choice when they have options. They can decide whether or not to respond certain stimuli.

In Chapter 2, a review of relevant affective computing models and personality models is provided. Emotion models such as OCC, EM, FLAME are discussed in details. They have played important roles in simulating human emotions. However their limitations are also obvious. Many emotion models can only provide a final emotional state without a clear emotional change process. Emotional intensity is missing from many existed work too. Virtual agents in most of the emotion models passively accept various stimuli with very limited self-protection. The biggest problem among these models is that they treat all agents the same with no individuality. Even though some latest work take personality

into consideration, their experiments are way too simple. Two personality models are introduced in the chapter. Out of the two we have chosen the NEO PI-R personality as the basis of our proposed model, since it provide a more detailed description and measurement of personality, comparing to the crude Big Five personality.

In Chapter 3, the basic components of our emotion model are discussed, including emotion, mood and stimulus. As most other emotion models, emotion is represented as PAD values at any time in our model. Mood reflects a relatively long-term effect, which is more related to Pleasure value. It is classified as good mood, neutral and bad mood. Additionally, stimulus is categorized into instantaneous stimulus and duration stimulus. Basic stimulus elements such as *Intensity, Effect, Likelihood* and *Desire* are discussed. In this thesis, both the instantaneous and the duration stimuli are considered, as shown in the many experiments conducted in Chapter 5. More experiments are carried out for duration stimuli since they are generally more complicated than instantaneous stimuli.

In Chapter 4, we propose an improved emotion model which incorporates NEO PI-R personality into the basic emotion model, and includes two novel parameters: Emotional Intensity and Resistant. Among the 30 NEO PI-R personality facets, 11 of them, namely, *Anxiety, Angry Hostility, Depression, Self-consciousness, Vulnerability, Warmth, Positive Emotion, Altruism, Compliance, Tender Mindedness* and *Dutifulness*, are more related to emotional changes, and are incorporated into the improved emotion model. The novel parameters, Emotional Intensity and Resistant, are also discussed in this chapter. Emotional changes based on current emotion, mood, stimulus, and the above 11 NEO PI-R personality facets are represented by the change of the PAD values. The changed PAD values are then mapped into the emotion space to determine the new emotional status with the help of the proposed Emotional Intensity and the Resistant parameter. With the improved emotion model, not only the emotional type, but also the level of emotion in that type can be determined dynamically, with distinctions on different personalities. Self-protection is represented by Resistant. It makes virtual agents become *angry* and try to against the stimuli through Arousal and Dominant rise.

Chapter 5 describes eight experiments, with their results analysed and discussed in detail. It is shown by the experiments that personalities greatly affect agents' emotional changes, but not necessarily dictate such changes. Personality often works like a magnifier, amplifying certain aspects of the environment while ignoring others when people interact with the environment. Emotional Intensity indicates the difference when experiments result in an emotional status. Specifically, the seventh experiment demonstrates the performance of the Resistant value and its effect on negative emotional types such as *sadness, fear, anger* and *disgust* and the transition among them. Finally, the last

experiment shows that personalities can also influence agents' choice in terms of whether an agent wants to get involved in certain stimuli.

6.1 Summary of Contributions

The contributions of this thesis include the following:

- An improved emotion model is proposed which incorporated the NEO PI-R personality model used popularly in psychology, but not yet in affective computing. It enables more detailed and individualized emotional responses of virtual intelligent agents towards different kind of external stimuli:

  ≻ Each agent is assigned a set of NEO PI-R personality facets. In reality, people always come with their own personality facets. For examples, a man could become *anger* to others (AH) very easily, while he could be a *excitement-seeking* person at the same time.

  ≻ Agents with different personality facets will have different emotion responses when subjected to the same stimulus/stimuli. Such differences can be successfully simulated by the proposed improved emotion model.

  ≻ Some NEO PI-R personality facets, such as *warmth, altruism, tender mindedness, dutifulness* etc. enable agents' "active thinking". They help to decide whether an agent wants to get involved in a certain event/stimulus. They provide more intelligence to the virtual agent and make them more life-like. This is not implemented in any other existing system.

  ≻ A novel parameter Emotion Intensity (EI) is introduced to reflect the emotional strength of *anger, disgust, happiness, fear* and *sadness*. It changes along with the PAD values in real time during the whole process. During the experiments, EIs of agents can be easily observed through their facial expressions and actions.

- A novel Resistant value is proposed to simulate the response of agents towards negative events/stimuli applied on them. With this value, the subtly different and often confusing negative emotions *sadness, fear, anger* and *disgust* and the transitions among them can be simulated in a more believable manner, which is a big step towards realistic and believable intelligent agents.

  ≻ The Resistant value is proposed to simulate bad feeling from negative stimuli. The bulling case discussed in Section 1.2 is a good example. It is able to simulate the self-protection mechanism which is an instinct of all living form.

  - ≻ The Resistant value quickly decays to neutral if the negative stimuli stop. It also increases very rapidly if negative stimuli continually applies in a very short time interval.

- A test environment in the form of a RPG game is implemented to monitor emotional changes of agents represented by NPCs in the game.
  - ≻ The change of PAD values can be observed via graphs, charts and digital numbers in real time.
  - ≻ Emotional status and intensity are presented by NPCs' facial expressions.
  - ≻ A 2D facial expression animation system is developed to demonstrate agents' emotional changes through facial expressions dynamically with proper intensity level.

In summary, this thesis proposed an improved emotion model. 11 NEO PI-R personality facets are implemented into this proposed model, together with the basic components in all emotion models: emotion, mood and stimuli. External stimuli are generally used whose characteristics include Intensity, Effect, Likelihood and Desire. The popular PAD model is used to represent emotional changes under the influences of the current emotion, mood, stimulus and personality. Two novel parameters: Emotion intensity (EI), and Resistant are incorporated into the proposed model. A 2D test environment in the form of a RPG is used to conduct experiments and monitor emotional changes of agents, both numerically and visually, in real time. The results of all experiments are very convincing and highly satisfactory.

6.2 Future Work

There are still certain limitations in the proposed emotion model. As discussed in Chapter 3, the proposed model can only generate five basic emotions such as *anger, disgust, happiness, fear* and *sadness*. Ideally more emotional types should be supported in an emotion model. Additionally, this model only considers 11 out of 30 facets of NEO PI-R. In the future, more and more personality facets could be included, even if not directly. Other personal characteristics could also be included, such as age, occupation, relationships etc. An advanced memory model is also desirable to store and maintain all sorts of knowledge and information, such as the relationship between agents, the standard of the agent, agents' experience and so on.

6.2.1 More Emotional Types

Surprise, as one of the six basic emotional types, is not supported in the proposed model. Because *surprise* is a complicated feeling caused by an event or a piece of news

happens unexpectedly. Virtual agents need to know what expected events are first, which is not easy to implement. A memory model with proper decay functions is needed to store/update relevant knowledge in order to implement the emotion of *surprise*.

Besides the six basic emotional types, Paul Ekman has extended his basic emotion theory in (Ekman, 1999). Seven positive emotional types such as *Amusement, Relief, Sensory pleasure, Pride in achievement, Excitement, Satisfaction*, and *Contentment*, four negative emotional types such as *Contempt, Embarrassment, Guilt*, and *Shame* are added. Those emotional types are more complicated than the six basic emotional types, and remain a challenge to be simulated. In fact a virtual social network might be required for their effective implementations.

6.2.2 Virtual Social Network

Social networking makes affective computing even more complicated. When more and more agents and stimuli crossover and interact with each other, agents' emotional statuses and behaviours are much harder to be predicted. In a virtual social network, agents have their own identities. They have families, friends, jobs, hobbies, and social classes etc. All these aspects make the emotion appraisal process even more complex.

First of all, the effect of a single stimulus increased like a ripple in a lake. For instance, when Nick is bullied at school, his family might feel *anger* to the bully and feel *sadness* for what Nick has suffered. Friends of Nick might feel *pity* for him. People who dislike Nick might feel *happiness* for seeing him get hurt. With the implementation of a virtual social network, much more complicated emotional responses and behaviours can be simulated.

6.2.3 Advanced Memory Model

Memory stores and updates all sorts of information which makes it another critical aspect in emotion appraisal progress. With the help of a properly designed memory model, emotion prediction will be much convincing and accurate. Memory is critical for future development of the proposed model.

6.2.4 Fully Support NEO PI–R

The proposed emotion model currently supports only 11 facets in the NEO PI-R model, which includes *anxiety, angry hostility, depression, self-consciousness, vulnerability, warmth, positive emotion, altruism, compliance, tender mindedness* and *dutifulness*. Among them, 4 are behaviour related. They are included since they enable virtual agents to have the ability to make decisions on whether or not to respond certain stimuli. The other

19 NEO PI-R facets are more related to actions, behaviours and experiences. For example, *Excitement seeking* people tend to explore; *Trust* people keep secrets for their friends, *Straightforwardness* people are honest and frank in expression. *Assertiveness* people are more likely to make bold assertions. *Aesthetics* people appreciate arts and beauties. More and more rules derived based on NEO PI-R could enrich the virtual social network, which enable agents to have different reactions and make different decisions. We will consider adding more facets into the model in the future and make the whole personality simulation more complete.

Bibliography

(2009). The (real!) science behind fox's lie to me. http://www.popularmechanics.com/culture/tv/a3960/4300722/. Accessed: 2014-11-20. 28

(2014). Ekman's six basic emotions: List, definitions & quiz. http://education-portal.com/academy/lesson/ekmans-six-basic-emotions-list-definitions-quiz.html. Accessed: 2014-12-10. viii, 29

(2015). Lifeboat foundation bios: Dr. paul ekman. http://lifeboat.com/ex/bios.paul.ekman. Accessed: 2014-11-20. 28

Allen, F. and Schwartz, M. (1940). The effect of stimulation of the senses of vision, hearing, taste, and smell upon the sensibility of the organs of vision. *The Journal of general physiology*, **24**(1), 105–121. 44

Asherman, A. (1986). *The Star Trek Compendium*. Star Trek. 2

Barrett, L. F. (2006). Are emotions natural kinds? *Perspectives on psychological science*, **1**(1), 28–58. 30

Bartneck, C. (2001). How convincing is mr. data's smile: Affective expressions of machines. *User Modeling and User-Adapted Interaction*, **11**(4), 279–295. 15

Bartneck, C. (2002). Integrating the occ model of emotions in embodied characters. In *Workshop on Virtual Conversational Characters*. Citeseer. 12

Bates, J., Loyall, A. B., and Reilly, W. S. (1994). *An architecture for action, emotion, and social behavior*. Springer. vii, 16

Becker, P. (2001). Structural and relational analyses of emotions and personality traits. *Zeitschrift fur Differentielle und Diagnostische Psychologie*, **22**(3), 155–172. 7

Becker-Asano, C. (2008). *WASABI: Affect simulation for agents with believable interactivity*, volume 319. IOS Press. 40

Becker-Asano, C. and Wachsmuth, I. (2010). Affective computing with primary and secondary emotions in a virtual human. *Autonomous Agents and Multi-Agent Systems*, **20**(1), 32–49. 40

Berlyne, D. E. (1971). Aesthetics and psychobiology. 31

Berlyne, D. E. (1974). *Studies in the new experimental aesthetics: Steps toward an objective psychology of aesthetic appreciation*. Hemisphere. 32

Bolles, R. C. and Fanselow, M. S. (1980). A perceptual-defensive-recuperative model of fear and pain. *Behavioral and Brain Sciences*, **3**(02), 291–301. 25

Boyle, G. J., Matthews, G., and Saklofske, D. H. (2008). *The SAGE Handbook of Personality Theory and Assessment: Personality Measurement and Testing*, volume 2. Sage. 36

Briggs, S. R. (1989). The optimal level of measurement for personality constructs. In *Personality Psychology*, pages 246–260. Springer. 33, 36

Briley, D. A. and Tucker-Drob, E. M. (2014). Genetic and environmental continuity in personality development: A meta-analysis. 49

Bui, T. D. (2004). Creating emotions and facial expressions for embodied agents. 41

Cao, J., Wang, H., Hu, P., and Miao, J. (2008). Pad model based facial expression analysis. In *Advances in visual computing*, pages 450–459. Springer. 32

Clore, G. L. (1994). Why emotions vary in intensity. *The nature of emotion: Fundamental questions*, pages 386–393. 31

Cohen, M. M. and Massaro, D. W. (1993). Modeling coarticulation in synthetic visual speech. In *Models and techniques in computer animation*, pages 139–156. Springer. 53

Costa, P. T. and MacCrae, R. R. (1992). *Revised NEO Personality Inventory (NEO PI-R) and NEO Five-Factor Inventory (NEO FFI): Professional Manual*. Psychological Assessment Resources. 33, 36

Costa, P. T. and McCrae, R. R. (1985). *The NEO personality inventory: Manual, form S and form R*. Psychological Assessment Resources. 33, 36

Costa, P. T. and McCrae, R. R. (1992). Neo pi-r professional manual. 34, 52

Darwin, C. (2002). *The expression of the emotions in man and animals*. Oxford University Press. 42

DARWlN, C. (1872). The expression of the emotions in man and animals. 28

Dormann, C. (2006). Cultural representations in web design: Differences in emotions and values. In *People and Computers XIXThe Bigger Picture*, pages 285–299. Springer. 31

Ekman, P. (1957). A methodological discussion of nonverbal behavior. *The Journal of psychology*, **43**(1), 141–149. 28

Ekman, P. (1989). The argument and evidence about universals in facial expres-sions. *Handbook of social psychophysiology*, pages 143–164. 28

Ekman, P. (1992). An argument for basic emotions. *Cognition & emotion*, **6**(3-4), 169–200. 14, 42

Ekman, P. (1999). Facial expressions. *Handbook of cognition and emotion*, pages 301–320. 30, 88

El-Nasr, M. S. and Yen, J. (1998). Agents, emotional intelligence and fuzzy logic. In *Fuzzy Information Processing Society-NAFIPS, 1998 Conference of the North American*, pages 301–305. IEEE. 25, 27

El-Nasr, M. S., Yen, J., and Ioerger, T. R. (2000). Flamefuzzy logic adaptive model of emotions. *Autonomous Agents and Multi-agent systems*, **3**(3), 219–257. vii, 17, 18, 23, 25

Elliott, C. D. (1992). The affective reasoner: A process model of emotions in a multi-agent system. 18

Furnham, A. and Crump, J. (2014). A bright side, facet analysis of schizotypal personality disorder: The relationship between the hds imaginative factor, the neo-pi-r personality trait facets in a large adult sample. *Thinking Skills and Creativity*, **11**, 42–47. 37

Games, E. (2006). Unreal engine 3. *URL: http://www. unrealtechnology. com/html/technology/ue30. shtml*. 65

Gebhard, P. (2005). Alma: a layered model of affect. In *Proceedings of the fourth international joint conference on Autonomous agents and multiagent systems*, pages 29–36. ACM. 40

Gibson, J. J. (2013). *The ecological approach to visual perception*. Psychology Press. 2

Gratch, J. (2000). Emile: Marshalling passions in training and education. In *Proceedings of the fourth international conference on Autonomous agents*, pages 325–332. ACM. 41

Hjemdal, O., Friborg, O., and Stiles, T. C. (2012). Resilience is a good predictor of hopelessness even after accounting for stressful life events, mood and personality (neo-pi-r). *Scandinavian journal of psychology*, **53**(2), 174–180. 37

Hoffmann, J. and Russ, S. (2012). Pretend play, creativity, and emotion regulation in children. *Psychology of Aesthetics, Creativity, and the Arts*, **6**(2), 175. 2

Holden, R. R. and Marjanovic, Z. (2012). A putatively general factor of personality (gfp) is not so general: A demonstration with the neo pi-r. *Personality and Individual Differences*, **52**(1), 37–40. 37

Hudlicka, E. (2008). What are we modeling when we model emotion? In *AAAI spring symposium: emotion, personality, and social behavior*, pages 52–59. 5, 43

Isen, A. M., Daubman, K. A., and Nowicki, G. P. (1987). Positive affect facilitates creative problem solving. *Journal of personality and social psychology*, **52**(6), 1122. 31

Jeronimus, B. F., Riese, H., Sanderman, R., and Ormel, J. (2014). Mutual reinforcement between neuroticism and life experiences: A five-wave, 16-year study to test reciprocal causation. *Journal of personality and social psychology*, **107**(4), 751. 49

Jiang, X. and Qin, S. (2014). Simulating a crowd with dynamic emotional transmission based on hidden markov model. 32

Kanda, T., Miyashita, T., Osada, T., Haikawa, Y., and Ishiguro, H. (2008). Analysis of humanoid appearances in human–robot interaction. *Robotics, IEEE Transactions on*, **24**(3), 725–735. 7

Keltner, D. (1996). Evidence for the distinctness of embarrassment, shame, and guilt: A study of recalled antecedents and facial expressions of emotion. *Cognition & Emotion*, **10**(2), 155–172. 30

Komarraju, M., Karau, S. J., Schmeck, R. R., and Avdic, A. (2011). The big five personality traits, learning styles, and academic achievement. *Personality and Individual Differences*, **51**(4), 472–477. 33, 34

Kopp, S. and Wachsmuth, I. (2004). Synthesizing multimodal utterances for conversational agents. *Computer animation and virtual worlds*, **15**(1), 39–52. 7

Lei, C. W.-D. G. D. and Yu-Geng, X. (2004). Distributed cooperation for multiple mobile robots based on multi-modal interactions. *Acta Automatica Sinica*, **5**, 003. 33

Li, X., Zhou, H., Song, S., Ran, T., and Fu, X. (2005). The reliability and validity of the chinese version of abbreviated pad emotion scales. In *Affective Computing and Intelligent Interaction*, pages 513–518. Springer. 32

Liu, Y. (2003). The aesthetic and the ethic dimensions of human factors and design. *Ergonomics*, **46**(13-14), 1293–1305. 31

Liu, Y., Sourina, O., and Nguyen, M. K. (2011). Real-time eeg-based emotion recognition and its applications. In *Transactions on computational science XII*, pages 256–277. Springer. 60

Loyall, J. B. A. B. and Reilly, S. (1992). Integrating reactivity, goals, and emotion in a broad agent. In *Proc. 14th Ann. Conf. Cognitive Science Soc.* Citeseer. 15

Lucas, R. E. and Baird, B. M. (2004). Extraversion and emotional reactivity. *Journal of personality and social psychology*, **86**(3), 473. 49

Marinier, R. P., Laird, J. E., and Lewis, R. L. (2009). A computational unification of cognitive behavior and emotion. *Cognitive Systems Research*, **10**(1), 48–69. 41

Marsella, S., Gratch, J., and Petta, P. (2010). Computational models of emotion. *A Blueprint for Affective Computing-A sourcebook and manual*, pages 21–46. 40, 41

Marsella, S. C. and Gratch, J. (2009). Ema: A process model of appraisal dynamics. *Cognitive Systems Research*, **10**(1), 70–90. 40, 41

Maurina, E. F. (2006). *The game programmer's guide to Torque: under the hood of the Torque Game Engine*. CRC Press. 65

McCrae, R. R. and John, O. P. (1992). An introduction to the five-factor model and its applications. *Journal of personality*, **60**(2), 175–215. 33

Mead, M. (1963). *Sex and temperament in three primitive societies*, volume 370. Morrow New York. 28

Mehrabian, A. (1970). A semantic space for nonverbal behavior. *Journal of consulting and clinical Psychology*, **35**(2), 248. 32

Mehrabian, A. (1996a). Analysis of the big-five personality factors in terms of the pad temperament model. *Australian Journal of Psychology*, **48**(2), 86–92. 49

Mehrabian, A. (1996b). Pleasure-arousal-dominance: A general framework for describing and measuring individual differences in temperament. *Current Psychology*, **14**(4), 261–292. 31, 32

Mehrabian, A. and Russell, J. A. (1974). *An approach to environmental psychology.* the MIT Press. 30, 31, 32

Michel, W., Shoda, Y., and Smith, R. (2004). Introduction to personality: Toward an integration. 49

Moridis, C. N. and Economides, A. A. (2009). Mood recognition during online self-assessment tests. *Learning Technologies, IEEE Transactions on*, **2**(1), 50–61. 7

Ortony, A. (1990). *The cognitive structure of emotions.* Cambridge university press. vii, 7, 9, 12, 17, 18, 22

Ortony, A. and Clore, G. (1988). A. collins (1988). *The cognitive structure of emotions.* 7

Patel, A. V. and Mohan, B. (2002). Some numerical aspects of center of area defuzzification method. *Fuzzy Sets and Systems*, **132**(3), 401–409. 22

Pettigrew, A. M. (2014). *The politics of organizational decision-making.* Routledge. 2

Picard, R. W. (1995). Affective computing. 7

Picard, R. W. (2000). *Affective computing*. MIT press. 1

Picard, R. W. (2003). Affective computing: challenges. *International Journal of Human-Computer Studies*, **59**(1), 55–64. 1, 2, 3

Picard, R. W., Papert, S., Bender, W., Blumberg, B., Breazeal, C., Cavallo, D., Machover, T., Resnick, M., Roy, D., and Strohecker, C. (2004). Affective learninga manifesto. *BT Technology Journal*, **22**(4), 253–269. 2

Proshansky, H. M., Ittelson, W. H., and Rivlin, L. G. (1970). Freedom of choice and behavior in a physical setting. *Environmental psychology: Man and his physical setting*, pages 173–183. 32

Reilly, W. S. and Bates, J. (1992). Building emotional agents. vii, 17

Revelle, W. (2007). Experimental approaches to the study of personality. *Handbook of research methods in personality psychology*, pages 37–61. 33

Revelle, W. and Scherer, K. R. (2009). Personality and emotion. *Oxford companion to emotion and the affective sciences*, pages 304–306. 33

Roseman, I. J., Spindel, M. S., and Jose, P. E. (1990). Appraisals of emotion-eliciting events: Testing a theory of discrete emotions. *Journal of Personality and Social Psychology*, **59**(5), 899. 18

Russell, J. A. (1980). A circumplex model of affect. *Journal of personality and social psychology*, **39**(6), 1161. 31

Russell, J. A. (2003). Core affect and the psychological construction of emotion. *Psychological review*, **110**(1), 145. 30

Salmeron, J. L. (2012). Fuzzy cognitive maps for artificial emotions forecasting. *Applied Soft Computing*, **12**(12), 3704–3710. 4

Sauter, D. A. and Scott, S. K. (2007). More than one kind of happiness: Can we recognize vocal expressions of different positive states? *Motivation and Emotion*, **31**(3), 192–199. 30

Sauter, D. A., Eisner, F., Ekman, P., and Scott, S. K. (2010). Cross-cultural recognition of basic emotions through nonverbal emotional vocalizations. *Proceedings of the National Academy of Sciences*, **107**(6), 2408–2412. 30

Shi, Z., Wei, J., Wang, Z., Tu, J., and Zhang, Q. (2012). Affective transfer computing model based on attenuation emotion mechanism. *Journal on Multimodal User Interfaces*, **5**(1-2), 3–18. 32, 53

Shiota, M. N., Campos, B., Keltner, D., and Hertenstein, M. J. (2004). Positive emotion and the regulation of interpersonal relationships. *The regulation of emotion*, pages 127–155. 30

Shock, N. W. *et al.* (1984). Normal human aging: The baltimore longitudinal study of aging. 36

Slovic, P. E. (2000). *The perception of risk.* Earthscan Publications. 2

Smith, C. A. and Kirby, L. D. (2001). 4. consequences require antecedents. *Feeling and thinking: The role of affect in social cognition*, page 83. 7

Snider, J. G. and Osgood, C. E. (1969). *Semantic differential technique: A sourcebook.* Aldine Publishing Company Chicago. 31

Steunebrink, B. R., Dastani, M., and Meyer, J.-J. C. (2009). The occ model revisited. In *Proc. of the 4th Workshop on Emotion and Computing.* viii, 10, 15

Stolorow, R. D. (2014). Self psychologya structural psychology. *Reflections on Self Psychology (Psychology Revivals)*, page 287. 2

Tangney, J. P., Miller, R. S., Flicker, L., and Barlow, D. H. (1996). Are shame, guilt, and embarrassment distinct emotions? *Journal of personality and social psychology*, **70**(6), 1256. 30

Tsai, T.-w., Chang, T.-C., Chuang, M.-C., and Wang, D.-M. (2008). Exploration in emotion and visual information uncertainty of websites in culture relations. *International Journal of Design*, **2**(2), 55–66. 31

Velásquez, J. D. (1997). Modeling emotions and other motivations in synthetic agents. In *AAAI/IAAI*, pages 10–15. Citeseer. 27

Vella, C. (2008). Conscript: An embeddable, compiled scripting language for .net. 59

Watson, D. and Tellegen, A. (1985). Toward a consensual structure of mood. *Psychological bulletin*, **98**(2), 219. 28, 30

Wundt, W. (1896). Grundriss der psychologie, trans. *CH Judd.* 31

Xiao, Q., Ding, G., and Liu, Y. (2014). An emotional model based on multiple factors. In *Proceedings of International Conference on Soft Computing Techniques and Engineering Application*, pages 43–53. Springer. 40

Yaghoubzadeh, R., Kramer, M., Pitsch, K., and Kopp, S. (2013). Virtual agents as daily assistants for elderly or cognitively impaired people. In *Intelligent Virtual Agents*, pages 79–91. Springer. 1

Yen, J. and Langari, R. (1998). *Fuzzy logic: intelligence, control, and information*. Prentice-Hall, Inc. 21

Zhang, J., Zheng, J., and Magnenat-Thalmann, N. (2015). Pcmd: personality-characterized mood dynamics model toward personalized virtual characters. *Computer Animation and Virtual Worlds*, **26**(3-4), 237–245. 40