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A Comparative Framework for Emotion Driven Agent Based Modelling

Dreama Jain
University of Windsor

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Dreama Jain

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by

Dreama Jain

APPROVED BY:

Dr. Gokul Bhandari
Odette School of Business

Dr. Xiaobu Yuan
School of Computer Science

Dr. Ziad Kobti, Advisor
School of Computer Science

Dr. Robert D. Kent, Chair of Defense
School of Computer Science

April 18, 2011

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ABSTRACT

Emotions are an integral part of human decision making so it is important to integrate emotions into artificial agents to make them more realistic. In this thesis we intend to design and implement an artificial emotional response agent simulation using three psychological models for emotions and develop a corresponding algorithm for each depicting its process in order to find a suitable algorithm.

After comparing the performance of the three algorithms we use Ortony, Clore and Collins(OCC) theory to generate emotions in a case study of a basic Hospital Simulation System. In this, there are patient and nurse agents who trigger emotions due to interaction with each other.

Results show that OCC algorithm is advantageous when specific emotion has to be generated and is more accurate than other algorithms. Also from the experiments performed for the case study show that an increase in emotional stress leads to higher error rates in nurse task performance when their logical performance is compared with emotional performance.

DEDICATION

To my loving parents whose immense patience and faith in me have got me this far in my life.

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Chapter 1

Introduction

Emotions are complex and difficult to interpret. Emotions have many facets such as, feelings, experience, behaviour, cognition and so on. Emotions are psycho-physiological experience of an individual’s state of mind [Myers, 2004]. There has been a growing interest in Computer Science to depict emotions and its role in human cognition and social interaction. Neuroscience and studies in psychology show that emotions have impact on the decision making in humans [Bechara, 2004]. Emotions have been depicted in artificial intelligence especially in Robotics and Human Computer Interaction in the past few years. Agent based modelling systems (ABMS) is one of the areas of Artificial Intelligence(AI) research, which deals with interactions of intelligent agents in an environment. ABMS are complex systems which are used in decision support systems. In decision making emotions play an important role. It is essential to take emotions into account while agents interact with one another in an environment to make them capable of reacting and making more realistic decisions.

1.1 Artificial emotions

Emotions are felt by humans. In Computer Science, an intelligent emotional agent is one that strives to mimic human emotions. They acquire knowledge about their environment as well as reflect changes in their emotional states; which is why they can be used in a Decision Support System. Emotions are an integral part of human decision making which is now becoming part of artificial agents as well. Concepts of emotion and various theories of emotion can be found in psychology books such as [Frijda, 1986], [Ortony, Clore and Collins, 1988] and [Lazarus, 1991]. The relationship between AI and psychology (emotion) has been very well described in the work of Sloman, [1990] and Rusell and Norvig, [1995]. The doctoral thesis by [Reilly, 1996] supports the merging of AI with emotion and social adaptation. Bates, Loyall and Reilly [1992] introduce the Tok architecture in the Oz project which implements emotional agents. In this, the authors' aim is to imbibe emotions and reactivity with other capabilities of the agent which have goal-directed behaviour. In [El-nasr, Yen and Iorger, 2000] the authors, discuss the use of fuzzy logic in generating emotions. The researchers describe how they have mapped events to emotions and emotions to behaviours using fuzzy logic and used learning techniques to make agents adaptive.

Lisetti [2002] discusses the emotions and personality of an agent. The authors in their research develop a hierarchical model of personality, affect, mood, and emotion and use emotion components to describe the current emotional state and also to predict the next emotional state of the agent. Gratch and Marsella [2004] implemented a domain independent framework of emotion and adaptation. They developed event appraisal and coping process from the emotion in a situation. Recent efforts in building emotional agents have been done by Adam et al. [2009] who discusses logical formalization of emotional theories. In the latter, the authors develop a logical framework based upon Belief, Desire and Intention (BDI) logic and formalize emotion theories of OCC [Ortony, Clore and Collins, 1988].

1.2 Current research motivation

Design and implementation of emotional agents is closely linked to psychology. There are a number of psychologists who argue about the process of emotion generation in humans. In response to this there have been a lot of theories which explain the emotional process. The question arises whether these theories can be used in Computer Science to generate emotions for artificial agents or not. In order to make artificial agents capable of decision making similar to humans it is necessary to follow the same procedure of generating emotions in agents as it is in humans. If psychological theories can be used for agents, then the best theory to closely link with Computer Science needs to be decided as well. There has been no previous work which compares the various psychological theories for use in artificial agents.

Moreover, most of the previous work revolves around a single reactive agent. There has been not much work done in generating emotions from interactions between two or more agents. Emotions naturally occur due to reactions to events interactions with others; so it is important that in artificial agents the emotions are also generated from in reaction to other agents. There has been no study which takes into account the effect of emotional stress on the performance of the agents. This is another important aspect of emotions which play an essential role in reasoning and decision making situations. For reference, the artificial agents described in this thesis represent mature human subjects as depicted in the psychological models referenced in the context.

1.3 Thesis contribution

In this research we aim to design and implement computer algorithms for each of the three different psychological theories in order to compare their performances. The three theories that we use are OCC (Ortony, Clore and Collins) [1988], Frijda [1986] and Scherer [1984a]. These three theories are closely linked to Computer Science in a way that these can be applied to artificial agents to trigger emotions. With the help of a general artificial agent simulation, we compare the performance of the three algorithms to understand their suitability for selecting them for an artificial agent simulation. Moreover we also implement the behaviour of the agents under the influence of emotions and compare their emotional behaviour to logical behaviour.

After comparing the performance of the three algorithms we use OCC to generate emotions in a case study of a basic Hospital Simulation System.

The main goals of this study are:

- To develop algorithms for each of the three psychological theories and implement them in a general artificial agent based simulation.
- To compare the outcomes of each algorithm to understand their suitability for selecting them for artificial agent model.
- To compare the behaviour of social agents under emotional stress to their logical behavior.
- And to implement a case study to test the general agent emotion model in a hospital simulation system.

1.4 Thesis outline

The main aim of this research is to compare the performance of three psychological theories, implement them in a general artificial agent simulation and implement a case study. In order to discuss this we divide the thesis into following chapters.

In chapter 2 a literature review and survey is presented on emotional agents with goal-directed behaviour, emotions in behavioural animation, use of fuzzy logic in modelling emotions, and emotions integrated with personality and building emotions with logical framework of emotional theories.

Chapter 3 describes the three psychological theories, corresponding algorithm for each and their implementation.

Chapter 4 describes the comparative study for the three theories detailing on the test platform, methodology and discussion of the results of the comparison.

Chapter 5 presents the case study of the hospital simulation system explaining all the details of its implementation.

Finally in the last chapter we outline the conclusion and future directions for this research study.

Chapter 2

Literature Review: Affective computing

This chapter includes a literature review on affective computing. The work that has been done till now in the sphere of emotion generation among agents can be classified into different methods researchers used to implement emotional agents. These methods are integrating emotional agents with reactivity and goals, developing emotions in behavioural animation, emotions and other motivations, use of fuzzy logic in modelling emotions, integrating emotions with personality, modelling emotions using a domain independent framework, building emotional agents using logical formalization of emotional theories.

2.1 Emotional agents integrated with reactivity and goals

The work of [Bates, Reilly and Loyall, 1992], [Reilly and Bates, 1992] and [Bates, Reilly and Loyall, 1998] can be viewed as the initial efforts made by researchers in implementing emotions for Artificial agents. The researchers were working at Carnegie Mellon University on Oz project [Bates, 1992] which is a simulated environment with a set of autonomous agents, a user interface with the help of which people participate in the Oz world. They have capabilities of reactivity and goal-driven behaviour.

2.1.1 Integrating Reactivity, Goals, and Emotion in a Broad Agent

Bates, Reilly and Loyall, [1992] begin by stating that no existing architecture is able to integrate the capabilities of emotions and "goal-directed reactive behaviour" in agents for the Oz project. The Oz world is a simulation with an environment and agents. The purpose of the authors in writing this paper is to explain about the Tok architecture, which is an agent architecture and which has the capabilities of handling emotions, reacting and performing goal directed actions. The authors propose a new architecture for building broad agents with capabilities of emotion handling, and goal-directed behaviour. The architecture is called Tok. It has a simulated world from which agents sense data and, with their perception, uses the data to think emotionally and react accordingly. Another component of Tok is Hap (Action), which has the ability to choose an action for the agent depending upon the goals and emotions of the agent and its perception of the world. Em is another component of Tok which develops emotions of the agent corresponding to the social relationships around it, previous goals of the agent, with the help of which next goal of the agent is determined. Furthermore all the components of Tok are integrated with each other so that they can communicate and perform actions. Hap, after performing an action and achieving a goal, informs Em about what has happened enabling Em to generate emotions. There are some behavioural features which are used by Hap to achieve goals and by Em to express emotions. With the help of this integration, actions are performed on the basis of previous goals achieved, emotions generated, and behavioural features of the agent. The authors claim that the agent architecture that they have developed is reactive towards emotions, explicit goals and different characterizations of the world. Moreover, the authors claim that Hap is able to create independent behaviours for an agent depending upon context conditions and success tests. The authors also claim that the idea of behavioural features can be used to model different personalities of the agent instead of building agents from scratch.

2.1.2 Building emotional agents.

Reilly and Bates, [1992] appear to be the first to identify the problem that emotion-based reaction is required in the agents of the Oz world. The agents should be able to react to the events and act according to their emotions and beliefs, and should have goal-directed behaviour. Moreover, the authors state that there is no existing architecture that can deal with the emotions and behavioural features in Tok, an architecture developed by the authors which works on “sense-think-act cycle”. The authors propose what they claim to be a new architecture for representing emotions in agents and integrating emotions with behaviours of agents. The authors have described previous work on emotions by Ortony, Collins and Clore [1988] and the model which they developed, and also mention the differences between this model and the Em model. The authors have developed the Tok architecture in which Hap developed by Loyall and Bates, [1991] keeps track of goals of the agent and Em checks upon the outcomes of the goals to find out the emotions of the agents. There are two kind of goals, current active which are recorded by Hap and permanent passive recorded by Em. Depending upon the failure or success of the goal, Em records emotion of joy or distress. Moreover Hap updates Em with new success or failure of the goals, with the help of which Em tries to find out the reason behind the success or failure of the goal. Every agent has some objects with respect to which they have emotions which lead to particular attitude towards the object. With the help of these emotions and attitudes recorded by Em the behaviour of the agent is affected. Moreover Em also keeps track of social knowledge and interpersonal relationship of agents with other agents as it is one of the important cause of emotions and vice versa. The authors state that the Em model is an extension of the work of Ortony, Collins and Clore [1988]. The authors claim that Em is able to model not only emotions but relationships, personality and attitudes of agents, and that the complete framework of an agent is influenced by Em and vice versa. The authors claim that Em can be used to model emotions in the agents of the Oz [Bates, 1992] project.

2.1.3 An architecture for action, emotion, and social behaviour.

Bates, Reilly and Loyall, [1998] begin by stating that no existing agent architecture exists for the Oz project [Bates, 1992] which can exhibit goal-directed, emotional and social behaviour. The authors' objective for writing this paper is to explain their Tok architecture, which is an agent with many capabilities which earlier agent architectures do not have. The authors introduce the agent architecture, Tok, which has the capability of sensing the outer world, reacting to that and exhibiting goal-directed, emotional and social behaviour. Firstly the authors explain the simulated world with which agents interact. They have a perception system with the help of which agent senses data from the world and records it. Using this data, an action is chosen for the agent to perform depending upon the goals, emotional state of the agent, and other aspects. For this, the Hap architecture of Loyall and Bates, 1991 is used. Depending upon the emotional state and social relationships all the goals of the agent have a set priority. Moreover, the emotions of the agent change depending upon the success or failure of the goal. The Em model of Reilly and Bates, 1992 is used for representing emotions of the agent with respect to goals and social relationships. With the help of Hap, the action performed, and Em, the emotional influence, behavioural features of the agent are adjusted. The authors claim that their architecture is able to perform actions based on emotions and agent has goal-directed behaviour. They also claim that they have improved Hap in terms of speed, multiple actions, etc. These changes have eventually improved the Hap architecture from what it was previously.

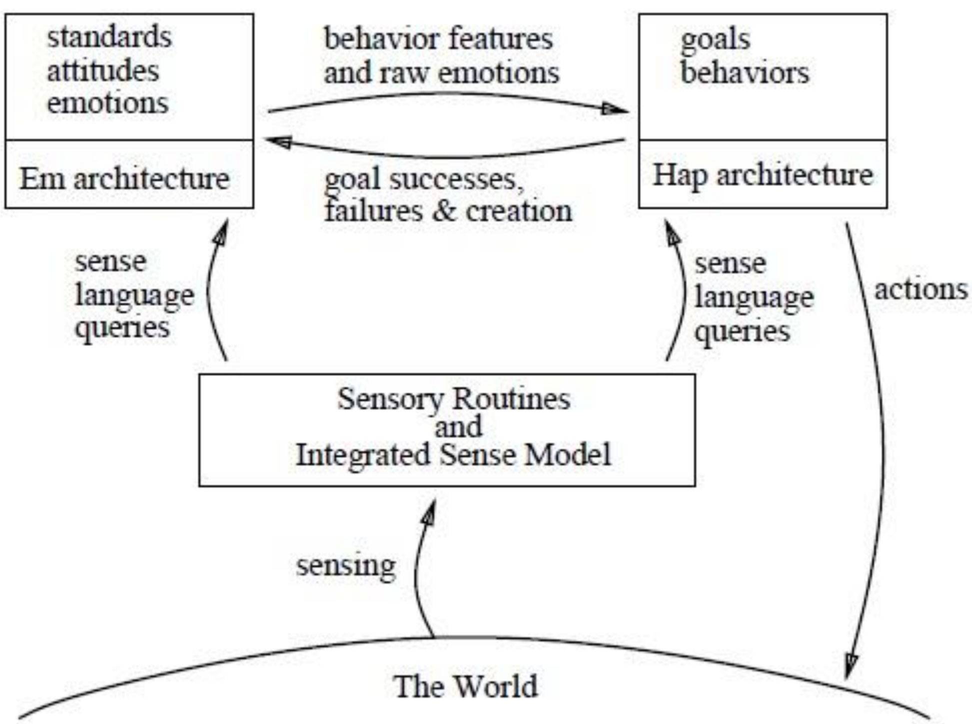

Figure 1: Tok architecture (Bates, Reilly and Loyall, [1998] page 56)

2.2 Developing emotions in behavioural animation

The work of Costa, Feijo and Schwabe, [1995] and [Costa and Feijo, [1996] focuses on developing emotions in agents which are used in animation. The authors state that a deliberative approach in developing agents is not enough and their architecture is reactive as well as deliberative, a hybrid architecture.

2.2.1 Reactive Agents in Behavioural Animation.

Costa, Feijo and Schwabe, [1995] begin by stating that earlier AI implementations of building agents are not reactive and deliberative architecture has been used for designing agents, which is not that good in representing agents' interaction completely with other agents. The authors state that earlier implementations require detailed knowledge which is not possible in such systems due to its complexity. The main objective of the authors in writing their paper is to introduce a new hybrid architecture which combines deliberative and reactive agents. The new architecture introduced by the authors is an architecture for reactive agents in behavioural animation, which has a sensory centre, whose main functions are receiving and sending messages, and a perception function. Messages are exchanged between the agents, and the perception function is used for detecting events that are taking place in the environment. The sensory centre has a cognition centre, an LTM and a body. The LTM is Large Term Memory in which facts or knowledge is stored which have been initially specified by the designer or eventually learnt by the agent from the environment. The cognition centre basically processes the facts in a controlled and automatic way, in order to make decisions. The body describes the structure of the agent.

The authors claim that the architecture they have built for the reactive agents is innovative for behavioural animation systems, and is efficient and supports most of the properties required by agents that deal with their interaction with each other. They also indicate the future work that can be done in improving and making agents more complex and formal methods such as procedural logic can be used.

2.2.2 Agents with emotions in behavioural animation.

Costa and Feijo, [1996] begin by stating that there has not been much work done in behavioural animation other than the work of Costa, Feijo and Schwabe [1995]. The authors claim to be the first to identify the problem of handling emotions in agents in behavioural animation. The main purpose of the authors in writing this paper is to introduce the Reactive Emotional Response Architecture, which has been used to generate emotions and behaviour corresponding to those emotions in agents. The authors propose a new architecture for reactive emotional response which is a complement to the work of Costa et al [1995]. The agent structure consists of a Sensory Centre which has functions of sending/receiving messages and perception functions. There is a Large Term Memory (LTM) which stores the facts that exist in the environment. These facts are acted upon by processes in the Cognition Centre which is a part of Sensory Centre. The external events which are stored as facts in LTM activate propositional network. Based upon the current emotional state, a decision is taken for the action to be performed such as “go_to”, “follow_path”, “move”, etc., the task is to reach a position by avoiding obstacles. The authors claim that their architecture is innovative for dealing with emotions in behavioural animation in reactive agents, which satisfies all the principles of reactive agents (cognition, emergence, situatedness, recursion and cooperation). The authors also state that their work deals with emergence, generic behaviour, emotion models, and is appropriate for reuse technology and parallel processing which, they claim, has not been done by anyone else till now. However, the authors give little evidence or argument to support these claims.

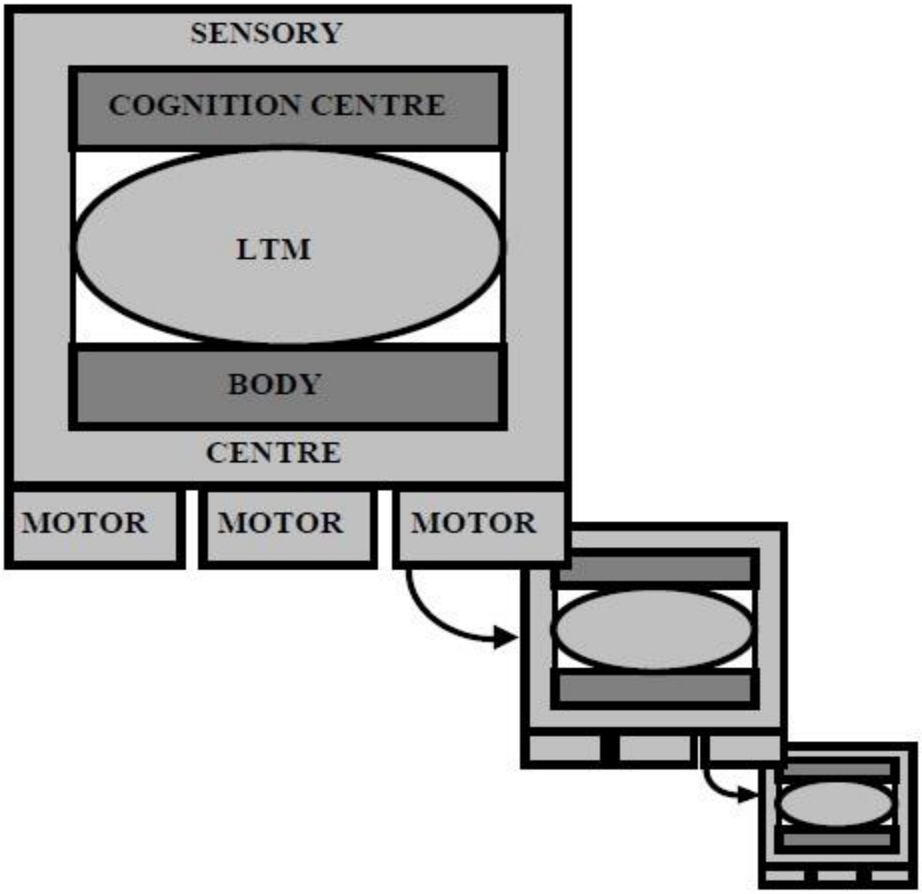

Figure 2. Actor Structure (Costa and Feijo, [1996], page 378)

2.3 Emotions and other motivations

2.3.1 Modelling Emotions and Other Motivations in Synthetic Agents

Velasquez, [1997] states that his purpose of writing this paper is to present Cathexis model, which models emotion and behaviour in autonomous agents. The authors state that till date there have been very few implementations of generation of emotion in synthetic agent, so they present a computational model which generates emotion using various aspects of emotion and then depicts the behaviour of these agents due to influence of emotions. The author refers to the work of Ekman [1992] and indicates that his model includes the basic emotions as described by [Ekman, 1992]. The author introduces what he claims to be a novel idea, the Cathexis Model. The emotion generation system consists of a network of proto-specialist agents which have their own sensors to recognize a particular kind of emotion, so each proto-specialist represents a different emotion. Each proto-specialist has two threshold values: first controls the activation of emotion, and second specifies level of saturation for that emotion. Another threshold is decay function. Cathexis includes basic emotions such as: anger, fear, distress/sadness, enjoyment/happiness, disgust, and surprise. Cathexis can also produce mixed or emotion blends when more than one proto-specialist is active at the same time. Cathexis takes into account cognitive as well as non-cognitive elicitors of emotion, which are, neural, sensorimotor, motivational, and cognitive, which includes, appraisals, comparisons, attributions, beliefs, etc. Cathexis differentiates moods from emotions. Emotion intensity is dependent on various factors such as, mood, interaction of emotions, etc. in Cathexis model. Every proto-specialist has its own decay function which may be time dependent or driven by a complex function. The Behaviour system in Cathexis model consists of network of behaviours, which consists of two components: Expressive component, it contemplates prototypical facial expression, body posture, and vocal expression. Experiential component, which considers motivation and action tendency. The selection behaviour is dependent upon releasers, which include emotions, moods, etc, and external stimuli.

In order to test Cathexis, the author used a testbed environment, Simon the Toddler. It includes five drive proto-specialists such as hunger, thirst, etc., six emotion proto-specialists. A number of behaviours, with expressive component of facial expressions and experiential component of motivations and specific actions. Interaction with Simon is done with the help of some parameters which act as external stimuli for Simon on the basis of which Simon responds to the actions by giving different facial expressions and behaviours.

The author states that his model considers both cognitive as well as non-cognitive elicitors of emotion. It also models influence of emotion on agent's behaviour and takes into account expressive as well as experiential component of emotion. The author claims that Cathexis model includes cognitive and non-cognitive elicitors of emotion which has not been used in any other previous models. The author also claims that there are some improvements that can be made in Cathexis model such as memory-based elicitors, which may affect memory, learning and decision-making processes.

2.4 Use of fuzzy logic in modelling emotions

2.4.1 PETEEI: A PET with Evolving Emotional Intelligence

El-Nasr, Yen and Ioerger, [1999] begin by stating that memory and experience play an important role in emotion generation process, so learning is essential to be incorporated in computer simulations which model emotional process. The purpose of the authors to write this paper is to introduce a PETEEI (a PET with Evolving Emotional Intelligence), which uses fuzzy logic to model emotions and learning techniques to make the agent adapt to the events with the help of its own experience. The authors introduce a new model of emotions which consists of learning mechanisms such as: learning about events for which desirability of specific events is measured by identifying the link between events and goals. This is done with the help of a reinforcement learning algorithm, Q-learning. The second learning is about the user by learning the sequence of actions a user takes in form of patterns to be learnt with the help of a probabilistic method. Next is learning about pleasing and displeasing actions which is learnt by external feedback. The recent action will be learned as the action evaluated. Last is the pavlovian conditioning, an object is associated with an emotion, which is then learnt by the agent. The learning about events is used in event predictions and event evaluation, which results in expectations and desirability of the event respectively, event predictions also use learning about user's actions. Expectations and desirability is then used in generating emotion which also takes into account pavlovian conditioning and event-emotion association. When an emotional state is generated behaviour selection is done which also takes into account learning about pleasing and displeasing actions. Agent's behaviour not only depends upon emotional state but motivational state and the current situation. The authors have used fuzzy rules to map emotions to behaviours.

The authors implement a PET which interacts with the user with the help of a graphical user interface displaying various scenes and various actions. The authors use three different models in their experiment to emphasize on the role of learning. The first model produces random emotions and behaviours. Second model includes simulated emotions without learning and finally a third model with simulated emotions and learning mechanisms. The authors chose participants to interact with these models and capture their feedback using a questionnaire. The authors claim that learning is an important factor to be included in modelling of emotions which induces dynamic nature of emotional process. The authors also claim that their model can be used in various applications, like training applications, character animation, etc. The authors also claim that one of the limitations of their model is lack of personality component which is considered important in emotional process.

2.4.2 Flame – Fuzzy Logic Adaptive Model of Emotions

El-Nasr, Yen and Ioerger, [2000] begin by stating that no existing models of emotions are able to incorporate adaptability in the agents and behave dynamically to events. The authors state that already existing models are able to generate emotions but do not provide learning of the events to the agents. The purpose of the authors to write this paper is to introduce what they claim a novel idea of using fuzzy logic to represent emotions, and to map events to emotional states and behaviours, and using machine learning methods to incorporate adaptability and learning features in the agent to respond dynamically to situations.

The authors propose new agent architecture for modelling emotions called FLAME – Fuzzy Logic Adaptive Model of Emotions. The model consists of three main components: an emotional component, a learning component and a decision-making component. The agent perceives external events, which are passed to learning and emotional component. The learning component passes event-goal expectations according to the events perceived to the emotional component, which in turn uses perceptions and event-goal expectations to generate emotional behaviour. This emotional behaviour is passed to decision making component which generates action. In the emotional component the event perceived by the agent is evaluated by the importance of the goals affected by the event and the degree up to which these goals are affected by the event. Here the fuzzy rules are used to determine desirability of the event which is then passed to an appraisal process to determine the change in emotional state, which is done by calculating intensities of emotions. A mixture of emotions is triggered which is then filtered by inhibiting motivational and emotional states and calculating the mood. Next behaviour of the agent is selected again by using fuzzy logic. In the end decay of the emotion is done by providing feedback to the system and using a constant for decaying the emotions.

To incorporate learning and adaptability in their model the authors induced different learning techniques: classical conditioning to associate an emotion with an object, this is done by using a formula by averaging the intensity of emotion in the events where the object was used. Next learning technique is reinforcement learning used to assess events according to the goal, this is done using non-deterministic method of Q-learning. Next is probabilistic approach to learn patterns of the events based on the frequency of the actions performed. Last is the heuristic approach to learn the actions that please or displease the agent, this is done by using a learning algorithm which averages feedback and calculates the expected value of the actions. The authors claim that their model of emotions can be enhanced and used in various applications, such as responsive tutor agent training simulations, and human-computer interfaces. The authors claim to have some limitations in their model. The authors state that the parameters they have used in the model can be constrained to specific values before using the model for different applications. The authors state that FLAME does not incorporate personality which is regarded as an important factor in simulating emotional behaviour. Moreover authors state that their model is capable of interacting with the user but not with other agents in the simulation which is important in order to accomplish tasks.

2.5 Emotions integrated with personality in a rational agent

[Lisetti, 1997], [Lisetti, 2002] and [Lisetti and Gmytrasiewicz, 2002] use a hierarchical model of personality, affect, mood, and emotion to describe how emotional states and personality can lead to decision-making.

2.5.1 Motives for intelligent agents: computational scripts for emotion concepts.

Lisetti, [1997] begins by stating that emotions are a very essential part of human intelligence and decision making, but emotions being very complex it becomes difficult to imbibe them in computer agents, as computers initiate actions on the command of the user. The author states that in order to display behaviour of humans in intelligent agents there is requirement of introducing emotion states in agents which motivates them to take decisions and perform actions. The author introduces computational scripts as a method to depict emotion concepts in agents. The author firstly defines some cognitive and bodily components of emotions, which according to the author act as parameters for defining the emotion state of the agent. These components are: time frame and planning, belief modality and goal generation, involvement and focus, intensity and salience determination, comparison and discrepancy detection, tempo and salience, criteria and attribution and size and chunking. With the help of these components emotion of the agent is obtained. The author states that almost every emotion acts as a signal, which is treated as the functional attribute of the emotion, as it generates some motive. The author uses five primitives which are helpful in characterizing functional attributes. These primitives are: prioritize, re-evaluate, release, search and chunk down, these are used in case of negative emotions such as guilt, anxiety, feeling overwhelmed, anger, frustration, feeling stuck, disappointment, which signals that agents' motive at this point is to use appropriate primitive and take action. In case of positive emotions, agent will keep on working on its present task as it is imbibing positivity to the agent. The author uses semantic meta-definitions of emotion terms to define computational scripts.

Computational scripts consist of causal chain, which is series of processes which take place in arousing of an emotion, and open roles which has the values for emotion components which lead to instantiation of a script. The author claims that computational scripts as described in the paper can be used to represent emotion concepts and generation of particular action with respective to the signal produced by the emotion, in other words, the functional attribute.

2.5.2 Emotions and Personality in Agent Design and Modelling.

Lisetti and Gmytrasiewicz, [2002] begin by stating that there are two different areas: cognitive science and artificial intelligence, the problem is combining the two and creating artificial agents which can deal with emotions. The authors' purpose of writing this paper is to introduce a decision-theoretic model which consists of utility functions and behavioural features which, on the basis of probabilities, can recognize emotions and lead to decision making. Another issue that the authors raise is personality and emotions of the agents which are to be understood by other agents, and, depending upon that, these agents make decision. The authors propose, what they claim to be, a new architecture for agents in multi-agent systems which handle emotions for decision making purposes. Each agent has a set of actions or behaviours, and a set of states that are achieved when some action is performed. The state of the agent is determined by a probability distribution. A projection function is used which determines the next state of the agent with the help of the current state and the action or behaviour performed. In addition, there is a utility function which determines which state is more desirable. The authors define decision making as a quadruple of 1) the agent's knowledge about the environment, 2) the agent's actions, 3) the results of the actions, and 4) the desirability of these results. Emotions are also associated with decision making. The authors regard personality as a set of emotional states of an agent, which is further defined as a finite state machine consisting of a set of emotional states, a set of environmental inputs, an emotional transformation function and an initial emotional state. Furthermore, they define a personality model of an agent which is capable of predicting the emotional state of the another agent, whose initial emotional state is given. The transformation of an action takes place depending upon the new emotional state developed by the agent. The utility functions are also transformed by emotional states, depending upon positive or negative feelings, to states that are desirable. The transformation of probabilities of states is achieved by changing probabilities and moving to the most likely state. The authors claim that they have been successful in merging the two areas of artificial intelligence and psychology and have been able to define how agents behave and make decisions depending upon emotions and personality. However, the authors give little evidence to support their claims.

2.5.3 Personality, Affect and Emotion Taxonomy for Socially Intelligent Agents.

Lisetti, [2002] begins by referring to the work of Murphi, Lisetti et al [2002] and the problem identified by [Murphi, Lisetti et al, 2002]: emotions play a very important role in socially intelligent agents who are dependent upon their environment, which is complex and unpredictable, and do not have complete access to their resources. The author states that the problem is to develop a framework which takes into account the "external behaviour" and "internal motivational goal-based abilities" of the agents. The author introduces a new framework known as Affective Knowledge Representation (AKR) which is used in representing emotions in various socially intelligent agents. AKR is derived using emotion theories of [Frijda, 1986], [Ortony, Clore and Collins, 1988] and [Wierzbicka, 1992]. Firstly, the author introduces a hierarchical model of Personality, Affect, Mood and Emotion. Personality of an autonomous agent being at the top of the hierarchy allows different type of agents to experience all kinds of emotions. Affect comes next in the hierarchy which can be positive or negative depending upon the personality of the agent. Next in the hierarchy are mood and emotion which are caused by some event. In order to find out the emotion aroused by the event there are various emotional components which differentiate one emotion from another. These components and their expected value are described here: facial expression (happy, sad, surprised, disgusted, angry, fearful, neutral), valence (positive, negative), intensity (very high, high, medium, low, very low), duration (lifetime, days, minutes), focality (global, event, object), agency (self, other), novelty (match, mismatch), intentionality (other, self), controllabitliy (high, medium, low, none), modifiability (high, medium, low, none), certainty (certain, uncertain, non-uncertain), legitimacy (yes, no), external (social) norm (compatible, incompatible), internal (self) standard (compatible, incompatible), action tendency and causal chain. The author defines functional attributes and action tendencies that are used to identify action to be taken from the previous state and emotion obtained. The author defines causal chain as a description of the emotion achieved by the agent, its belief and the corresponding goal. The author also describes a dynamic model of emotional states which is used to generate emotional states while the current state is provided and there is some input, in case of autonomous agents and multimodal affective interface agents. The author claims that in their approach each emotion is described by a number of emotion components. The author also claims that their approach takes into consideration action tendency which is used to describe that the emotion experienced leads to this particular action to be performed.

2.5.4 Can a Rational Agent Afford to be Affectless? A Formal Approach.

Lisetti and Gmytrasiewicz, [2002] begin by stating various transformations which emotions can bring to decision-making situations, with the help of which authors state that emotions and rationality are closely linked in humans and need to be included in designing of artificial agents. The authors state that modelling of agents cannot be completely dependent upon just goal driven and task-solving concepts, there has to be emotive reasons behind the decision making situation of the agents. The authors introduce a new approach of designing rational agents called Affective Knowledge Representation (AKR). In this architecture authors first define the Affect Taxonomy which is a hierarchical model of personality, affect, mood and emotion. It depicts the personality of the agent as characteristics of the agent which can be negative or positive. Further authors describe some emotion components: facial expression, valence, intensity, duration, focality, agency, novelty, intentionality, controllability, modifiability, certainty, legitimacy, external norm, internal standard, action tendency and causal chain. The authors use probabilistic frames to describe emotion using slots and facets. The authors also describe Markov model of emotional state dynamics. It is used in identifying agents' current state as well as predicting agents' most probable future state. The authors claim that they have modeled agents such that in the decision making process role of affect is also included. They also claim that they have described emotional transformations which indeed are formalization of these roles.

2.6 Modelling emotions using domain independent framework

[Gratch and Marsella, 2004] and [Gratch and Marsella, 2005] introduces a domain independent framework of emotion known as Emotion and Adaptation (EMA) which not only implements appraisal of events but also generates coping process for the event and the emotion generated.

2.6.1 A Domain-independent Framework for Modelling Emotion

Gratch and Marsella, [2004] begin by stating that there have been a numerous work done in computational models for modelling emotions with the help of appraisal theory but their work not only uses appraisal theory to model emotions but their work also implements a general and domain independent algorithm for appraisal, with the implementation of appraisal variables in Computer Science. The authors state that their framework also include model of coping, which consists of coping strategies, coping process and decision-making. The authors purpose to write this paper is to introduce their framework what they claim to be a extension of some previous work [Elliot, 1992], [Moffat and Frijda, 1995] but they are the first one to introduce coping. The authors introduce what they claim to be a novel idea of coping and appraisal theories as EMA, Emotion and Adaptation, which is a computational model of human emotional behaviour.

The authors state that EMA algorithm has 5 stages. First is a causal interpretation which is recognized as agent's current mental state and has three parts: causal history, current world description and task network, which link to past actions of the agent that has lead to this state, interpretation of the environment and future plans respectively. The mechanism for updating the mental state or as the authors say causal interpretations, are the cognitive operators that is, planning, dialogue, execution, and monitoring operators. Second stage is of appraisal frames and variables, which are formed due to change in causal interpretations. In order to generate these appraisals there are some rules of perspective, agent's interpretation for an event, relevance, significance of the event for an agent, desirability, preference of the event for the agent, likelihood, causal attribution, controllability and changeability. Next stage is to map appraisal frames to instances of emotion, which is done with the help of some basic rules using intensity and category of emotion. In the next stage emotional instances are aggregated to a emotional state, which is done using emotional focus approach. The overall mood of the agent is also generated by aggregating the emotional state. In the final step a coping strategy is adopted for the emotional state. This is done by following the coping process, which consists of the following steps: identifying the coping opportunity with the help of focus-agency, cause of provocation, interpretation-object, agency-max and max-interpretation. Next step is to elaborate coping situation followed by proposal of alternative coping strategies and then assessing the coping potential and finally selecting one strategy. The authors define some of the coping strategies: planning, positive reinterpretation, acceptance, denial/wishful thinking, mental disengagement, and shift blame. The authors claim that EMA is a domain independent framework which models emotions using appraisals and also inhibits coping strategies and can be used with Natural language processing and intelligent agents. The authors claim to have some limitations of the model such as, lack of unexpectedness, reasoning of causal attributions. The authors claim that EMA is able to maintain a balance between emotional instances and causal interpretation which conforms to behavioural consistency. The authors claim to have some differentiation between their model and Classical Decision Theory, such as difference in combining utility values with behaviour.

2.6.2 Evaluating a Computational Model of Emotion

Gratch and Marsella, [2005] state that their aim of writing this paper is to compare the behaviour of their model EMA (Emotion and Adaptation) [Gratch and Marsella, 2004] against the actual human behaviour. The authors state that their model aims to be used in applications for people to interact with virtual humans which can provide decision-making skills. The authors also state that their model is capable of generating emotion as well as coping strategies for that emotion. The authors give an overview of their model EMA which has been better explained in Gratch and Marsella [2004]. The authors state that the agent in their model perceives the environment as causal interpretations which consist of goals, beliefs, causal relations, plans and intentions. Appraisal of these causal interpretations is done on the basis of some appraisal variables: perspective, desirability, likelihood, causal attribution, temporal status, controllability and changeability. The appraised events are mapped to emotional instance. Next step is coping which depends upon the significance of appraised event. The strategies used by the authors in their model are: action, planning, seek instrumental support, procrastination, positive reinterpretation, acceptance, denial, mental disengagement, shift blame, and seek/suppress information. The authors claim that their model has responded fairly close to the human behaviour. The authors claim that since they have used an outside source for evaluating human behaviour, so it proves that they have used a fair system to evaluate the model and the use of this system also considers emotional dynamics. But the authors also claim that the encoding of scenarios was done by them which are being bias with the model.

2.7 Emotional agents

2.7.1 Emotional agents: A modelling and an application.

Maria and Zitar, [2007]'s main purpose to write this paper is to introduce a new model for multiagent system which uses emotions as part of decision making. The authors state that there is a very important role of emotions in artificial agents such as action selection, adaptation, learning, goal management, etc,. According to the authors there has been no such implementation in multi-agents which depicts emotion and relative decision making.

The authors introduce their new model which consists of two agents one is a regular intelligence agent (RIA) and the other is emotional intelligence agent (EIA). The authors have used benchmark problem of "the Orphanage Care problem". In this an agent has main goal of taking care of the Orphanage. It has other goals of working to earn money for the care of Orphanage, to improve its skills at an Academy and to socialize at club etc. The authors have explained the thinking process of both the agents. EIA has emotions parameters: Event-based emotions, Attribution emotions and Attraction emotions. The authors also describe the conditions and rules for the RIA to take decisions and behave towards a goal. For EIA also there are some conditions and rules to behave towards the goal but it also has emotion generation and normalization. Every time the emotions are checked it is checked on the basis of the goal and standard of EIA. The three kinds of emotions are linked with different goals and objects in the model. EIA depicts the intensity of the emotions but there is no such observation of how the emotions influence behaviour of EIA. Personality of EIA is influenced by the emotions which in turn influences appraisal hence leading to the behaviour of EIA. So if the intensity of emotions is on the happy state then EIA would work on the bright side of the life and vice versa. The authors perform experiments to compare the performance of RIA and EIA. They have used 3 different settings for the world and the agents, to test and verify their performance. In the first setting the average values of the salary, social and working capacities which are generated randomly are maximized. The second setting is an easy setting which increases the gains for the agents and reduces their expenses. In the third and final setting the world is made harder for the agents by decreasing the gains and increasing the expenses.

The authors state that, in the first setting EIA agent performs better than RIA, EIA is happier and is able to maintain its main goal, which is more stable than RIA. In the second settings both the agents are able to perform extremely well and achieve their goals better because of the easy setting. The results of final settings show that RIA agent's performance is acceptable as it is able to earn money but unable to keep up with social capacity level. But in case of EIA agent, it fails after some iteration because it does not work rationally towards making money but emotionally by spending more time in the

Orphanage and hence runs out of money. The authors claim that emotional agent can outperform a regular agent in real world applications also. The authors also claim that if the emotional agents have the capability of learning then it can enhance the behaviour of the agents and their decision-making skills.

2.8 Building emotional agents using logical formalization of emotional theories

2.8.1 A logical framework for an emotionally aware intelligent environment.

Adam, Gaudou, Herzig and Longin, [2006 a] begin by referring to the work of Aarts, Harwing and Shuurmans [2002] on Ambient Intelligence and the problem of applying emotional abilities in intelligent agents. The authors indicate that the problem is to manipulate emotions of the agents in an intelligent environment, in this case in an Ambient Intelligent System. The main purpose of the authors in writing this paper is to introduce the framework which they have developed which is based on BDI modal logic and deals with the emotional abilities in the intelligent environment.

The authors introduce a logical framework based on BDI modal logic which represents the emotions of the agents. In this framework, the agents have an initial knowledge base which includes factual knowledge and epistemic knowledge. The framework consists of a set of agents, a set of actions, and a set of atomic formulae. There is a set of axioms which define the operators used in the framework. These are Full belief, Probability, Choice, Like/Dislike, Action and Time. With the help of these axioms, the authors have deduced some inference rules which are used in the formalization of emotions. The authors formalize the emotions using appraisal criteria based upon agreement and probability. The emotions of the agents are only dependent upon the events that have occurred. The emotions can be Joy/Sadness, Hope/Fear and Satisfaction/Fear-confirmed/Relief/Disappointment based upon the event that has occurred and the way the agents appraise the events.

The authors present a formal analysis of their framework using a case study. This case study consists of four different scenarios. The first case is "appraisal of an external event from the user's point of view", in this case the agent is able to figure out the emotion of the human by knowing the event that has occurred.

The second case is "pre-evaluation of the emotional effect of an agent's action on the user". In this case, if the agent knows that the human has some emotion of sadness because of some event but actually the event has not taken place then the agent can inform the human about that. Also if the agent knows that the human is happy because he was expecting an event but now that event will not take place because of another event that has to take place before that event, and now the agent knows that the event that human was happy about can take place but with another event to take place before it then the agent should inform the human about it.

The third case is "observation and explanation of behaviour". In this case, a human is afraid about some event which will take place and can have positive reward or negative reward. The agent does not know why human is afraid but with its world knowledge and knowledge about human agent can find out the reason why human is stressed and how can he be happy or sad by the next event that will occur. So the agent is able to deduce the emotions of the human and is able to explain how these emotions can vary depending upon the event.

The last case is “observation, and explanation hypothesis”. In this case, the agent finds out that the human is sad but he does not know the reason. He will infer that the human is sad because of some event that was to take place and has not resulted in something good.

The authors state that their framework is able to deal with four different scenarios. The authors mention that they have not depicted the results clearly in their paper. The authors claim that their framework deals with emotions and intelligent environments. The authors also claim that their model is simple to manipulate and is not complex. They also state that due to its construction it can be easily extended by adding more emotions, which can make it complex.

2.8.2 OCC's emotions: a formalization in a BDI logic.

Adam, Gaudou, Herzig and Longin, [2006 b] begin by stating that in recent times agents have incorporated emotional abilities, but not many emotions have been implemented in them. The current models do not handle as many as twenty-two emotions as proposed by [Ortony, Clore and Collins, 1988] and they use semi-formal methods to implement emotions. The purpose of the authors work is to use a formal method to extend BDI logic in order to incorporate more number of emotions as depicted by OCC. The authors developed a framework which is an extension of BDI logic and builds on the work of Herzig and Longin [2004]. This framework consists of a set of agents, a set of actions, and a set of atomic formulas and complex formulas. A model consists of set of possible worlds, truth assignment and a tuple of structures which consist of associations of agents and actions to the world. The authors define the belief and probability relation and other operators of which desirable and undesirable operators are important. With the help of these operators and mappings the authors extend the emotions built by [Ortony, Clore and Collins, 1988].The first branch being event-based emotions. The authors claim that, in this branch, there is well-being emotion which has concern with the agent's joy or sadness depending upon the desirability of the event that happened. In prospect-based emotions, there is emotion attached to the likelihood of an event to happen, the prospect being that the event will be desirable. The fortune-of-others emotions have concern with an agent having liking, desirability or deservingness of an event for another agent. The second branch is agent-based emotions. In branch, the first kind is attribution emotions, which is concerned with approving of an agent's action by itself and by other agents. The second kind is composed emotions, combination of well-being emotions and attribution emotions. The authors claim that they have depicted twenty emotions. However, they state that their framework does not provide fine-grained differentiation between similar kinds of emotions and the emotions exist until a condition is true which is not realistic as emotions change with time and do not remain the same forever.

2.8.3 A logical formalization of the OCC theory of emotions.

Adam, Herzig and Longin, [2009] state that OCC theory [Ortony, Clore and Collins, 1988] does not represent different components of emotions and relationship between agents' emotions and actions. The authors state that work has been done in triggering mental states from emotions, but the modelling of triggering of emotions from a given mental state of an intelligent agent has not been done, and that this is an important problem that needs to be solved before using emotions to trigger mental states. The authors address this problem by introducing a logic of mental states to model emotions. The authors propose a new architecture for modelling emotions using modal logic, based upon the BDI framework and represent twenty emotions out of twenty-two emotions as described in the psychological review of OCC [Ortony, Clore and Collins, 1988]. In this paper, the authors first define the theories that exist which can be used for modelling emotional agents. Then they state that they have used the OCC theory in their paper because of its concepts and logic, which are implementable using computers. The authors state that in their paper they work on the variables of desirability and praiseworthiness as described by [Ortony, Clore and Collins, 1988]. The authors define syntax and semantics that have been used in generating the logical model of emotions. In this, they define Action, Belief, Time, Probability, Desirability, Ideals, and Mix Axioms. [Ortony, Clore and Collins, 1988] defines three kinds of emotions: even-based, agent-based, and object-based. The authors use event-based and agent-based emotions in their paper. Firstly, event-based emotions, which are related to desirability of an event, have three kinds. First well-being emotions, by which agent feels joy for a pleased event and distress for an unpleased event. Next, prospect-based emotions, which have a likelihood attached with the event, corresponding to which an agent may feel hope, fear, satisfaction, disappointment, relief or fear-confirmed. Third, being fortune-of-others emotions, this uses three intensity variables of desirability for other, deservingness and liking, corresponding to which an agent may feel happy, sorry, resentment or a gloating emotion. Next being agent-based emotions, in this first category is attribution emotions. If this emotion is triggered for self in terms of pride or shame, and for others admiration or reproach depending upon praiseworthy or blameworthy action. Next is compound emotion which consists of attribution and well-being emotions and hence corresponds to gratitude and admiration, anger and reproach, gratification and pride, or remorse and shame. With the help of these, the authors give various theorems and their proofs. The authors claim that their model has clear semantics, retains BDI logics, and that their model very well expresses mental states hence validating BDI logics. The authors claim their model can be a useful tool for psychologists. The authors claim that they have implemented a BDI framework for agent appraisal and coping strategies. The authors also claim that their model implements twenty emotions from the OCC theory and they will implement other theories of emotions in the future as well.

Also [Adam, 2007] a doctoral thesis describes logical formalization of emotions by defining semantics and axiomatics used in this framework, formal definitions of emotions, and formal properties of emotions.

2.9 Concluding comments

[Bates, Reilly and Loyall, 1992] appear to be the first to identify the problem of developing emotional agents. They developed the Tok architecture which integrates reactivity, goals, and emotion. The authors state that there is need for improvement and changes in the architecture which includes speed, sensing, multiple actions, etc. Moreover the authors believe that Tok needs to be extended.

The papers [Costa, Feijo and Schwabe, 1995] and [Costa and Feijo, 1996] discuss emotional agents in behavioural animation. The authors designed the Reactive Agent Structure which satisfies various agent principles such as cognition, emergence, and situatedness. The authors state that their architecture is the only one at that time which satisfies such principles in animation. The authors also state that improvement can be done in order to create more complex agents.

The papers [Velasquez, 1997] and [Velasquez and Maes, 1997] identify emotions as well as other motivations of emotions such as moods and implement a Cathexis model which in a flexible way generates emotions using proto-specialists and model the influence of emotion on the behaviour of synthetic agents. Moreover [Velasquez, 1997] also takes into account cognitive and non-cognitive elicitors of emotion, emotion intensity and decay of emotion with time.

The papers [El-Nasr, Yen and Ioerger, [1999] and El-Nasr, Yen and Ioerger [2000] introduce FLAME generation of emotions using fuzzy logic. In this mapping of events to the emotions is done using fuzzy logic. The authors also take into account memory and experience of the agent which is implemented using various learning techniques. The authors claim that their model can be used in a number of applications to generate emotions with learning experience but the authors also claim that they have not considered role of personality in their model, which can be done in the improvement of their work.

The papers [Lisetti, 1997], [Lisetti, 2002] and [Lisetti and Gmytrasiewicz, 2002] describe personality and emotional states. The authors state that with the help of the definitions they have found out that decision making can be modified if there is small number of behaviours and time constraint, agents are able to know the emotional state of other agents which is helpful in decision making, and if agents have well-defined emotional states it can lead to better human-computer interaction. The authors claim that they have been successful in merging the two areas of artificial intelligence and psychology and have been able to define how the agents behave and make decisions depending upon emotions and personality. The authors state that in their future work they will use the definitions to design more personalities of agents and will find out the effect on abilities of agents in accomplishing their goals by modifying decision-making model.

The papers [Gratch and Marsella, 2004] and [Gratch and Marsella, 2005] introduce a domain-independent framework which models emotion and adaptation. According to the authors their framework is able to appraise events and generate emotions using emotional instances. Moreover their framework also has the ability to produce coping strategies. The model is able to generate a coping process which produces some coping strategies out of which, one of the coping strategy is used. In [Gratch and Marsella, 2005], the authors have evaluated their model in comparison to the human behaviour with the help of stress and coping questionnaire. The authors claim that their model responded fairly close to that of human behaviour but there are some limitations which may lead to some different results. The authors also claim that their model can be used in various applications on Natural Language processing and intelligent agents.

The papers [Adam, Gaudou, Herzig and Longin, 2006] and [Adam, Herzig and Longin, 2009] all used a logical framework for formalizing emotional theories using BDI logic. The authors state that their model is domain-independent and covers almost twenty emotions of the OCC emotional theory. The authors state that their future work may consist of more psychological theories, and they would like to add object-based emotions which will use modal predicate logic. Moreover they might work on formalization of events and actions by moving to theories of agency.

Chapter 3

Psychological theories

In this research we compare three psychological theories to be implemented in artificial agents and select the best theory for generating emotions in artificial agents. The theories we used are OCC theory [Ortony, Clore, and Collins 1988], Frijda's theory [Frijda 1986] and Scherer's theory [Scherer, 1984a]. We chose these theories due to their close link with computer science in a way that they can be converted into algorithms. So we designed algorithms for each of the theory and then implemented them in a general artificial agent simulation.

3.1 Theory of Ortony, Clore and Collins (OCC)

Ortony, Clore and Collins [1988] developed a cognitive structure of emotions. Their main aim of developing this theory was to be used in computer science. According to OCC emotions develop in consequence of certain cognitions and interpretations. The classes of emotions due to which the emotions are generated are: events, agents and objects. Reaction to these cognitions lead to some kind of emotion, in case of event either pleased or displeased, for agents approving or disapproving, and for objects liking or disliking. According to OCC a person's appraisal of emotion inducing situation is based on three central variables: desirability, praiseworthiness, and appealingness. There are some global variables that affect to all emotion categories. These variables are sense of reality, proximity, unexpectedness, and arousal. Figure 3 shows the structure of emotion types according to OCC.

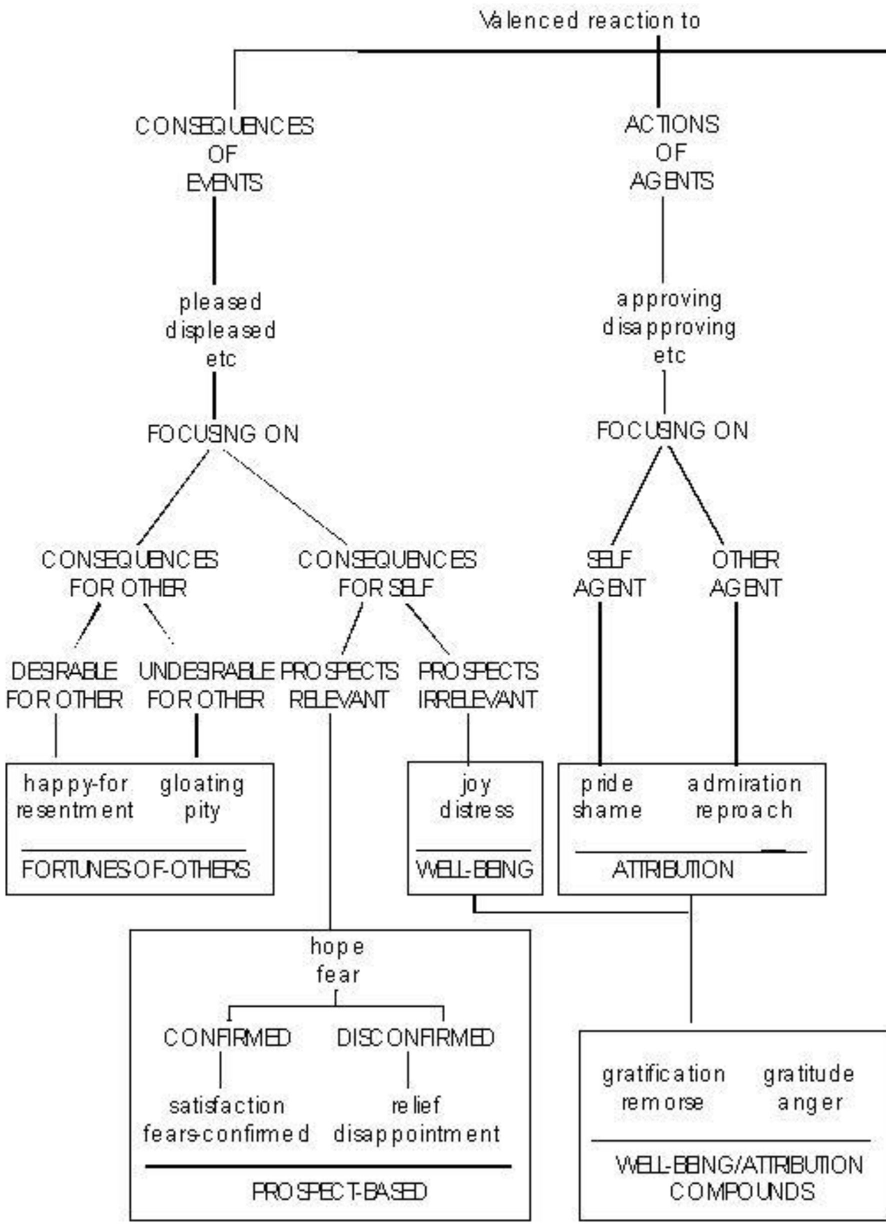

Figure 3: Global structure of emotion types (Ortony, Clore and Collins, [1988], page 19)

The first category of emotions is reactions to events. The sub categories for this are classified according to well-being emotions, fortunes-of-others emotions, and prospect based emotions. Well-being emotions are the emotions where an agent is either pleased or displeased with the event that has occurred. Desirability variable is used to see how desirable the event was for the agent and whether the agent is pleased or displeased by it. Fortune-of-others emotion takes into account whether an agent is pleased or displeased for another agent when some event occurs. Now if the agent is of good-will then he will be pleased for a desirable event that has occurred to another agent or displeased for an undesirable event and this will satisfy his goal. If the agent is of ill-will, that is, the event does not satisfies his goal then he will be pleased if the event was undesirable by the other agent and displeased if it was desirable. In this case desirability and goal satisfaction variables are used. Prospect-based emotions consist of two parts. First when an event is expected to happen, the agent will have hope for a good event and fear emotions for a bad event to happen. In the second part, when the event has occurred, depending on hope or fear, confirmation or disconfirmation of prospect, emotions like satisfaction, fears-confirmed, relief or disappointment occur. We use a probability variable according to which prospect based emotions are generated.

The second category of emotion is reactions to agents. In this, there are attribution emotions for oneself and for other agents which are generated according to the action performed by the agents. If an agent approves of one's own praiseworthy action, then he is pleased and generates gratification emotion. If the agent disapproves of one's own blameworthy action and is displeased then it generates remorse emotion. In case of other agent's actions, if the agent is pleased and approves someone else's praiseworthy action then it generates gratitude emotion. If the agent is displeased and disapproves someone else's blameworthy action then it generates anger emotion. Finally agents generate emotion of liking or disliking in reaction to objects. The algorithm we generated for this theory is shown in Figure 4. The Table I shows the definitions used for this algorithm.

Table I: OCC Algorithm Definitions

Em_c	Current emotional state
N	Set of agent's needs
min, max	Minimum and maximum threshold of a need that is required to please and agent
Des	Checks whether the event is desirable (1) or not (0)
G_{sat}	Checks if the event or action is towards the goal (1) or not (0)
Prob(e)	Defines the probability of an event *e*

```
Start
Set initial world
Populate agents list
Set Emc for all agents Ag in agent list Aglist
Call step function for every time step.
For time = 1, time < totaltime, time++
 Step()
  Update world
  Call step function for every agent
  Foreach Ag in Aglist
   Agentstep()
    Trigger event = e
    Well being emotions
    Check for agent needs
    Foreach n in N
     If min<= n <= max, then
      Emc = pleased
     Else
      Emc = displeased
     Update history
    Fortune of others emotions
     Check desirability of event for other agent
     If des = 1, then
      If Gsat = 1, then
       Emc = pleased
      Else
       Emc = displeased.
     Else if des = 0, then
      If Gsat = 1, then
       Emc = pleased
      Else
       Emc = displeased
     Update history
    Prospect emotions
     If prob(e) > 0, then
```

```
      If Gsat = 1, then
       Emc = hope
      Else
       Emc = fear
     If prob(e)>= 50%, then
      If Emc = hope, then
       Emc = satisfaction
      Else
       Emc = fearsconfirmed
     Else if prob(e) < 50%, then
      If Emc = hope, then
       Emc = disappointment
      Else
       Emc = relief
     Update history
    Attribution emotions
     Update agents’ own action
     If Gsat = 1, then
      Emc = approve/gratification
     Else
      Emc = disapprove/remorse
     Update other agents’ action
     If Gsat = 1, then
      Emc = approve/gratitude
     Else
      Emc = disapprove/anger
     Update history
Stop
```

Figure 4: OCC Algorithm

3.2 Frijda's theory

According to Frijda [1986], more than just emotion, it's the process of emergence of emotion that is important. Frijda describes six substantial characteristics of the emotion system which describe its function. These are concern relevance detection, appraisal, control precedence, action readiness change, regulation and social nature of environment. The core process of emotion generation has some components which combine to form a functioning emotional system. These components are as follows:

Analyzer: When the agent comes across a stimulus event, the input, in this case event, is scanned by analyzer and is checked if the event is one of the known types or the event gives some clue about its cause or consequence.

Comparator: In order to check the relevance of the event to the agent, comparator has the function to generate relevance signals. According to the relevance of the event it is classified as pleasure, pain, wonder or desire. We update the emotion of the agent according to the relevance of the event.

Diagnoser: The relevance signals from the comparator are passed on to diagnoser, which has the function to generate coping potential of the agent for that event. The coping potential generated the action possibilities for the event.

Evaluator: The output of diagnoser is used by evaluator to evaluate urgency, difficulty and seriousness of the event. These values combine to form control precedence signals.

Action proposer: The function of action proposer is to generate action readiness change using the output from evaluator and finally one action is generated and performed by the agent.

Figure 5 shows the emotion process, while Figure 6 is the algorithm designed for this theory with definitions in Table II. In the algorithm we concentrate just till the part where emotion generation takes place, the other components do not have much role to play in this implementation.

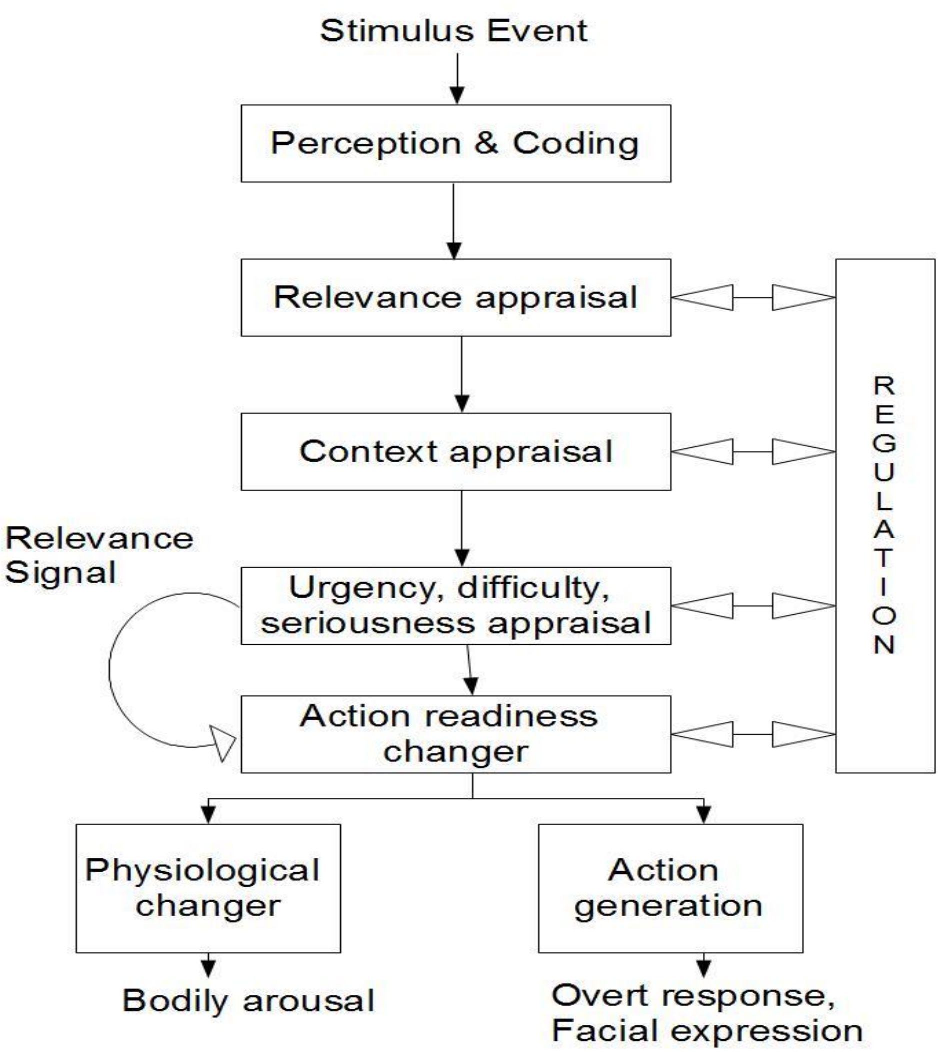

Figure 5: The emotion process (Frijda, [1986], page 454)

Table II: Frijda Algorithm Definitions

Em_c	Current emotional state
rel	Relevance evaluation which varies from 0 to 6, where rel=0 means irrelevant
Coping	Tells whether an agent is able to cope up with the event or not. 0=cannot cope, 1=can cope
Action	Defines what the agent will do. Two defined actions: 1=move to a new location or, 0=stay at the same place

```
Agentstep()
 Agent moves
 Trigger event
 Analyzer()
  Get neighbours of the agent
  Checks for the event type in history
  If the event is present in the history
   update the emotion and move to next step
  Else
   For every neighbour agent
    generate emotion and action
  Call Comparator()
 Comparator()
  Check for relevance evaluation for the agent
  If(rel==0)
   Exit
  If event==0 and rel>1, then
   Emc= wonder
  If event<20, then
   Emc=pleasure
  If event<40, then
   Emc = desire
  Else
   Emc = pain
     Call diagnoser and pass relevance
 Diagnoser()
  Find if agent can cope up and
  what action it can perform
  If rel<=3, then
   If coping==1, then
    Action=1
  Else
   If coping == 1, then
    Action =0
   Else
    Action = 1
 Update history
```

```
 Evaluator()
  Computes  urgency,  difficulty  and  seriousness  of  the  event
according to the value of the event or the object placed.
  Call action proposer
  Generates Control precedence signal
 Action proposer()
  Store action to related relevance
  Generates action readiness change
```

Figure 6: Frijda Algorithm

3.3 Scherer's theory

According to Scherer [1984a], there are five functionally defined subsystems in an organism which are involved in an emotional process.

The first subsystem is an information processing subsystem which has the function to perceive a stimulus event and generate some stimulus evaluation checks (SECs). The stimulus event is evaluated through perception, memory, forecast and evaluation of available information. The SECs are checks or variables which are used to generate emotion. In this research we concentrate just on emotion generation so we designed and implemented only the information processing system.

The second subsystem is a supporting subsystem which deals with the internal regulation of the tasks and controls neuroendocrine, somatic and autonomic states. The executive subsystem has the task of decision making in order to take an action. Next the action subsystem actually controls the behaviour and expressions while an action is performed. Lastly the monitoring subsystem is responsible for controlling all the subsystems and their states.

SECs play an important role in labelling or differentiating the emotions generated. First check is the novelty check, which determines if the event occurred is novel or an old one and has been processed. Intrinsic pleasantness check determines whether the event occurred is pleasant or unpleasant. Goal/need significance check, checks whether the event supports the goal of the agent or not, using relevance, expectation and conduciveness sub-check. Next, coping potential check determines if the person is able to cope with the event or not with the help of control, power and adjustment sub-check. Finally norm/self compatibility check has the function to check if internal and external standards of a person are met or not. Combination of SECs is useful in determining every emotion.

Figure 7 shows the algorithm designed for this theory and Table III shows the definitions for the variables used.

Table III: Scherer Algorithm Definitions

exp	expectation sub-check. Its value can be either unexpected (1) or slightly unexpected (0)
inpl	intrinsic pleasantness subcheck. Its value can be either unpleasant (0) or pleasant (1)
goal	goal significance subcheck. Its value can be either goal unsatisfied(0) or satisfied(1).
cop	coping potential subcheck. Its value can be either cope (1) or cannot cope (0).

```
Agentstep()
 Agent moves
 Trigger event
 Generate neighbour agents
 Check for event in the history
 If the event is present in the history
  update the emotion
 Else
  For every neighbour agent
   generate emotion using evaluation checks
     Generate values for all the subchecks
  if(inpl==0)
   if(goal==0)
    if(cop==0)
     emo="disgust"
    else
     emo="anger"
   else
    if(cop==0)
     if(exp==1)
      emo="fear"
     else
      emo="sadness"
    else
     emo="despair"
  else
   if(goal==0)
    emo="joy"
   else
```

```
    emo="satisfaction"
Update history
```

Figure 7: Scherer Algorithm

Chapter 4

Comparative study

4.1 General artificial emotional multi-agent model

The multi-agent system implemented in this research aims at a generic model and not a particular application. The aim of designing this general model is to compare the suitability of the three algorithms explained in previous chapter. We used Java platform and RepastJ library for multi-agent simulation.

4.1.1 Test platform

The model consists of agents and objects placed randomly on a two dimensional grid, which represents the world, during the initialization of the simulation. The objects retain a value varying from -10 to +10 which is generated randomly. This value is used as a parameter to test the liking or disliking of the object by the agent. The locations of the objects are managed in an array so that in future if any agent reaches the same location it may generate emotion in response to the object. The goal of the agents is to interact with other agents and to do this they move on the grid every time step. The parameters used to initialize the model, which can be changed during the initialization of the simulation, are given as following:

1. **Numofagents**: this represents the number of agents that will be placed on the grid for that simulation run.
2. **Numofobjects**: this represents the number of objects that are placed on the grid.

3. **Commdist**: this represents the communication distance of the agents, the radius around the agent in which it interacts with the neighbour agents.
4. **Movespeed**: this represents the pixels the agent would move on the Cartesian grid world.
5. **Worldsizex**: this represents the size of the world to be initialized for the simulation run towards X-axis of the grid.
6. **Worldsizey**: this represents the size of the world to be initialized for the simulation run towards Y-axis of the grid.
7. **Theory**: this is drop down box used to select the algorithm to be used representing which theory for the particular simulation run.

For every time step, an agent moves on the grid with the move speed and randomly in any direction in order to interact with its neighbour agents and exchange emotions. An event is triggered for every agent every time step. According to this stimulus event agents generate emotions, taking into account emotions of neighbour agents as well. In general we assume that all the events have a constant impact on all the agents. Also we assume every agent knows what is desirable for other agents. When agent step is performed, the motive is to update emotion of the agent for that time step taking into account the event that has been triggered, neighbours around the agent and intensity of the emotion.

4.1.1 Neighbour impact

According to the communication distance the Moore neighbours of the agents are retrieved in a list. But an important thing is the agent to agent interaction. In general humans do not interact with every other neighbour around them. So we assume that not all the neighbours of the agent are close to the agent, as a result the agent would generate emotions for only those neighbours with whom it is close. So for every neighbour we generate a random impact according to which the agent will generate emotions. If the neighbour does not have any impact on the agent then it will not change its emotional state or remain neutral.

4.1.2 Impact of event

When an event occurs for the first time for an agent, the impact of the event will be highest. In order to store the events occurred the agents have a memory represented as a stack of events. For every event occurred it stores the corresponding emotion generated for that event and number of times that event has occurred. So every time step when an event is triggered, first of all the memory of the agent is checked, which is able to store last 10 events occurred. If the event is present in the memory then according to the occurrence of the event the impact of the event is calculated. Supposedly if the event has occurred for more than 10 times then the agent will not generate the same emotion as the repeated occurrence of the event makes the agent used to the same event.

4.1.3 Emotion intensity and mixture of emotions

While generating emotion for every neighbour in the same time step, there is a possibility that agent would have more than one emotion. For example, agent can be happy for the event triggered but maybe sad or angry due to some neighbour for the same time step. In this case it becomes hard to update the emotional state with one emotion when actually agent generates blend of emotions. So we attach emotion intensity with each emotion varying between low, medium and high. Now at the end of the time step the emotion with highest intensity can be updated as current emotional state. If there are two emotions of same intensity and same valence that is either positive or negative, then the recent emotion is updated. In case the emotions with same intensity are of different valence positive and negative then we assume that negative emotion is dominating and hence it is updated as current emotional state.

4.1.4 Update history

Whenever an emotional state for the agent is updated, it is stored in the history or in this case memory of the agent, so that in the next time steps when the agent comes across same event it can check in its memory for its impact. If the impact is still high then the same emotion can be updated and there wouldn't be any need to go through the process of emotion update again for same event.

4.2 Methodology

After the description of the general artificial emotional agent model, we describe the methodology used to generate emotions in the agents. We explained the three theories used to design algorithms and for comparison in the previous chapter. In this section we explain the implementation of each theory in the general model.

4.2.1 Implementation of OCC theory

According to this theory there are 22 emotions which are classified according to reactions to events, agents and objects. For objects we check, if there is any object in the proximity of the agent's location. If an object is found then the value for that object is checked. According to the value the emotion of the agent is updated as pleased or displeased in case object is liked or disliked by the agent. After the object has been checked the event triggered during that time step is checked for its impact. During the first few runs of the simulation the events will have high impact as they are triggered for the first time. The neighbours around the agent are retrieved and according to their impact emotion for the agent is updated. There are some global variables such as proximity, sense of reality, unexpectedness and arousal, these variables are updated randomly. In case there are no neighbours around the agent then well-being emotions, prospect based emotions or attribution emotions for oneself are generated. If there are neighbours then either of fortune-of-others or attribution emotions for other agents is generated.

Well-being emotions: with global variables, a desirability variable is randomly updated and used to update emotion as pleased or displeased for event was desirable or not respectively.

Prospect-based emotions: in this case the probability of the event to occur is generated. Then according to desirability or goal satisfaction of the event the emotion of the agent is updated to hope or fear. Next in case the event occurs whose probability was generated then according to hope or fear emotion of agent and desirability the emotional state is updated to satisfaction, relief, fears-confirmed or disappointment.

Attribution emotions for oneself: here we randomly generate goal satisfaction/ praiseworthiness or blameworthiness of the action performed by the agent itself. According to global variables and this variable the emotion of the agent is updated as gratification or remorse.

Fortune-of-others emotions: deservingness and goal satisfaction variables are updated randomly on the basis of which the agent feels either pleased or displeased for neighbour agent.

Attribution emotions for other agents: goal satisfaction/degree of praiseworthiness or blameworthiness is updated randomly and according to that the emotional state of the agent is updated as gratitude or anger for a neighbour agent.

The above methods are used to update the emotional state in case of OCC theory.

4.2.2 Implementation of Frijda's theory

According to Frijda the emotion generation is a process with a number of components. We have implemented these components as described in the algorithm in previous chapter. First of all when the event is triggered it is checked for its impact in the history. Then the current location of the object is checked for objects. If any object is present then according to the value of the object emotion is updated as pain, pleasure, wonder or desire. Next the neighbours of the agent are retrieved and according to their impact emotion will be updated. These all functions are performed by the analyzer.

Comparator: Next after retrieving the neighbour agents and their impact, comparator checks the relevance of the event triggered. In this case relevance is a random integer. In case there is no relevance for the event then the emotional state remains neutral else according to the event and relevance emotional state is updated to pain, pleasure, wonder or desire.

Diagnoser: In this method the coping potential for the event is generated, which in turn is used to generate action.

Evaluator: This method is used to compute urgency, difficulty and seriousness of the event which combine to form control precedence signal.

Action proposer: This method generated the final action to be performed. In this case we do not generate any action as our main focus is to update the current emotional state.

4.2.3 Implementation of Scherer's theory

According to Scherer there are Stimulus Evaluation Checks (SECs), combination of which is used to update emotional state of the agent. In our implementation we perform the check for impact of the event triggered and retrieve neighbours and their impact on the agent. According to the object value, if any object present at the location emotion is updated as joy or sad. The value for SECs is generated randomly. The SECs used are intrinsic pleasantness check, goal relevance sub check, expectation sub check, and coping potential check. If an event is unpleasant, does not satisfy goal and does not have coping potential then the event generates disgust emotion. If it has coping potential then anger emotion is updated. If an unpleasant event satisfies goal but was expected generates fear emotion. If the event was unexpected then is generates sadness. If the unpleasant event has coping potential then despair emotion is generated. If a pleasant event does not satisfy goal, it updates joy emotion and if it satisfies goal then satisfaction is updated as emotional state.

Using this criterion the emotional state of the agent is updated as disgust, sadness, fear, despair, anger, joy or satisfaction.

4.3 Experiments

4.3.1 Experimental setup without emotional intensity

In order to see the suitability of the algorithms we perform some experiments. We define 50 arbitrary events as numerals from 0 to 49 which initiate emotions. We target event 0 to be matched with pleased emotion (pleasure in case of Frijda and joy in case of Scherer) for the test case. We trigger event 0 for fifty percent of each simulation run. The remaining 49 events occur rest fifty percent of the times. Each simulation is run for 1000 time steps and we track how many times event 0 occurred and for that how many times pleased emotion is generated. We also perform experiment by switching on and off update history, that is, once when agent is able to store events and once when agent cannot store. We calculate a percent match for the number of times pleased emotion occurs with respect to number of times event 0 is triggered for every theory and with and without history.

4.3.2 Results

The Tables IV and V show the result of the percent match for all the three algorithms with and without history respectively. We ran the simulation for different number of agents and objects every time. The results look very consistence as the tables show the mean of all the actual results. Figure 8 shows statistical variance of the percent match for 100 agents. We see a drastic increase in variance when history is enabled but in all the three methods still don’t show a big difference.

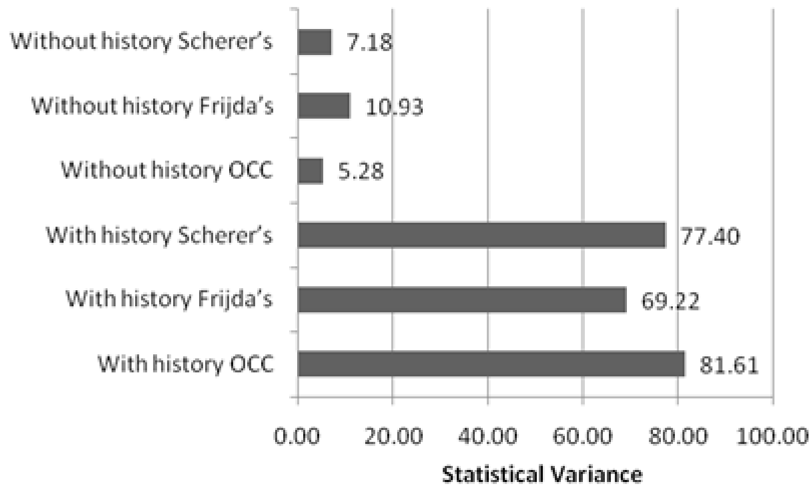

Figure 8: Statistical variance of the percent match for the pleased emotion for 100 agents.

Table IV: Experiments with history and event impact enabled

Method used	**#agents**	**#objects**	**# Event$_0$**	**# pleased emotion**	**% match**
OCC	10	10	506	293	57.6
Frijda			506	239	47.0
Scherer			497	262	52.0
OCC		100	505	236	46.0
Frijda			503	240	47.0
Scherer			496	260	52.0
OCC	50	50	501	259	51.0
Frijda			498	245	49.0
Scherer			499	245	49.0
OCC		500	500	256	51.0
Frijda			500	233	46.0
Scherer			498	248	49.0
OCC	100	100	497	240	48.0
Frijda			500	252	50.0
Scherer			497	251	50.0
OCC		1000	498	248	49.0
Frijda			501	239	47.0
Scherer			503	256	50.0

Table V: Experiments without history and event impact disabled

Method used	#agents	#objects	# Event$_0$	# pleased emotion	% match
OCC	10	10	493	244	49.0
Frijda			500	253	50.0
Scherer			502	245	48.0
OCC		100	493	246	49.0
Frijda			505	254	50.0
Scherer			495	251	50.0
OCC	50	50	499	248	49.0
Frijda			500	254	50.0
Scherer			499	249	49.0
OCC		500	499	248	49.0
Frijda			499	245	49.0
Scherer			499	249	49.0
OCC	100	100	501	248	49.0
Frijda			500	245	49.0
Scherer			501	250	50.0
OCC		1000	499	248	49.0
Frijda			501	234	46.0
Scherer			500	251	50.0

4.3.3 Conclusion

The results show consistency among the percent match for all the three algorithms so it can be suggested that any of the three algorithms can be used for artificial agent simulation. But it is interesting to note that OCC can generate up to 22 emotions while Frijda's theory generates only 4 general emotions and using Scherer's theory 7 emotions have been generated. So in order to generate more variety of emotions OCC should be preferred.

4.3.4 Experimental setup with emotional intensity

In this experiment we take into account emotional intensity of every emotion generated, that is, during a single time step an agent may generate more than one emotion and the emotion updated as current emotion according to the intensity of each emotion. In previous experimental setup the last emotion updated during that time step was set as current emotion for that time step.

4.3.5 Results

Tables VI and VII show results of the experiments. In the first experiment event 0 is matched to pleased emotion and triggered 50-75 times. A number of experiments are performed with each theory and different parameters, such as increasing the number of agents and objects to 50 and 500 respectively, and increasing the communication distance from 10 to 20. In the second experiment event 49 is targeted to generate displeased emotion with change in parameters. The results show the percentage match of targeted emotion generated with respect to event triggered.

Table VI: Experiment results with emotional intensity for pleased emotion.

Method used	**#agents**	**#objects**	**Comm dist**	**%of $Event_0$ occurred**	**#$Event_0$**	**# pleased emotion**	**% match**
OCC	10	100	10	50	509	370	72.7
Frijda					504	166	32.9
Scherer					499	168	33.9
OCC	10	100	20	50	505	370	73.2
Frijda					502	159	31.8
Scherer					494	156	31.6
OCC	50	500	10	50	497	363	73.0
Frijda					500	165	32.9
Scherer					497	164	33.0
OCC	50	500	20	50	500	370	74.0
Frijda					501	168	33.5
Scherer					500	166	33.4
OCC	50	500	20	75	748	505	67.5
Frijda					752	259	34.5
Scherer					750	189	25.3

Table VII: Experiment results with emotional intensity for displeased emotion.

Method used	#agents	#objects	Comm dist	%of Event$_{49}$ occurred	#Event$_{49}$	# displeased emotion	% match
OCC	10	100	10	50	498	415	83.4
Frijda					499	260	52.2
Scherer					494	158	31.9
OCC	10	100	20	50	489	420	86.0
Frijda					502	259	51.8
Scherer					494	164	33.3
OCC	50	500	10	50	501	426	85.2
Frijda					505	256	50.8
Scherer					502	163	32.4
OCC	50	500	20	50	502	426	84.9
Frijda					499	254	51.0
Scherer					503	163	32.4
OCC	50	500	20	75	750	591	78.8
Frijda					751	399	53.1
Scherer					752	194	25.9

4.3.6 Conclusion

From the above results we can conclude that the performance of OCC theory in recognizing a particular emotion is more accurate than Frijda’s and Scherer’s theory. Almost 75% of times correct emotion is generated by OCC theory whereas in case of Frijda the recognition of correct emotion varies a lot for pleased and displeased emotion. Pleased emotion is recognized around 30% of times while displeased/pain emotion is recognized 50% of times. This suggests that Frijda’s theory is not a good solution in case of generating particular emotions. Moreover Frijda’s theory can generate only four general emotions which do not give a clear understanding of the emotion of the agent. In case of Scherer’s theory recognition of emotion varies from 25 to 30%, which shows that

Scherer's theory cannot be a good choice when a particular emotion has to be generated for the agent.

Table VIII summarizes the performance of the three algorithms and where they can be used.

Table VIII: Summary of the three algorithms and their application in AI.

Features	**OCC theory**	**Frijda's theory**	**Scherer's theory**
Specific Emotion recognition	70-75% accurate	30-50% accurate	25-30% accurate
Maximum number of emotions	22 basic emotions	4 general emotions	7 specific emotions
Specific to event	accurate	Performs well for some cases	Not specific to event
Number of positive emotions	11	2	2
Number of negative emotions	11	2	5
Emotion generation technique	Takes into account neighbours or self well being	Checks relevance for the events	Stimulus evaluation checks
Reliable in emotion generation	Highly reliable	Moderately reliable	Moderately reliable
Specific emotions for neighbours or other agents	yes	no	no
Application in AI	Highly recommended for specific emotion generation and classification of emotion	Can be used in cases with no specific emotions	Can be used in cases with specific emotions but the number of emotions can be varied according to the application.

Chapter 5

Case study: Hospital system

5.1 Introduction

In a base hospital system described in [Bhandari et al., 2011] there are patient agents and nurse agents. Initially they are allocated patient rooms and nurse rooms respectively. The actual floor plan of the Leamington General Hospital is used as hospital floor plan with all the rooms and hallways. The nurses move from one room to another in order to serve the patients when the patients buzz for nurse. Using the floor plan various graphs are generated connecting rooms and hallways in order to generate shortest path between nurse room and patient room. These are weighted directed graphs in which nodes represent a particular area and edges are ability to traverse between two adjacent areas. With the help of these paths nurse agents move taking the shortest path and servicing the patient. The nurses serve only those patients who are assigned to them during the beginning of the simulation. Moreover nurse being reputation conscious interacts with other nurses whom they see while traversing their path to patient room. The simulation runs for different time steps where one time step is equivalent to 12.5 seconds in real time.

5.2 Emotion integration

In order to see the performance of the generic model as described in chapter 4 we integrate emotion generation in patients and nurses in the hospital system. In this case we use OCC theory to generate emotions bearing in mind the fact that OCC theory is able to generate up to 22 emotions. Initially all the patients have some emotion which depends upon the severity of the patient. A patient agent with high severity may tend to be displeased or disappointed that is may have negative feelings. When a nurse agent serves a patient agent, it may generate emotion for the nurse as well. Like, if a nurse sees a patient disappointed and in pain, nurse may feel sad and displeased about the patient's condition. Following this the nurse when talks or interacts with other nurses, its emotion may transfer to other nurses. This leads to exchange in emotions first between nurse and patient then among two or more nurses. For example if a nurse interacts with other nurse and tells about a patient in serious condition, the other nurse will also feel sad, or if the nurse did something wrong, the other nurse may get angry.

5.3 Behaviour of the nurse agent

While a nurse generates positive or negative emotions, it may have effect on their behaviour while they perform other tasks such as, medication administration, documentation, etc. [Naqvi, Baba Shiv and Bechara, 2006]. In order to test the performance of the nurse agents under the influence of emotions, we derive two functions: logical and emotional performance.

5.3.1 Task

A task is defined as a process comprising of a sequence of steps. Each step performed constitutes to completion of the task. The task is represented by a weighted directed graph where each node is a step with a weight associated with it, which is summed in order to check the completion of the task. A task for instance can have around 4 to 10 steps.

5.3.2 Attention factor

The weight attached to each step (node) of the task is the attention factor or the attention required to perform that step. The total attention factor of the task is sum of the individual weight of each node. A step can have attention factor varying from 0 to 100.

5.3.3 Logical performance

A task is said to be performed by traversing through the graph and summing the weights/attention factor attached to the node/step of the task being traversed. Logically a task is said to be complete if all the steps of the task are performed. At the end of the task completed logically we get final sum of the measure of attention factors of each step. A task is performed logically when the agent has positive emotions or is neutral.

5.3.4 Emotional performance

When the emotional state of the agent is on the negative side, then the agent tends to make mistakes or perform the task in a different manner than performing it logically. Under the influence of negative emotion humans tend to make mistakes and sometimes skip a step while performing a task or make decisions emotionally which are not logical [Dijksterhuis, 2004] and [Bechara, 2004]. With this motivation in mind, in our simulation if the agent is under the influence of negative emotion then it tends to miss a step or more while performing the task according to its current emotional state. When the agent misses one or more steps, the total sum of the weight of the task is different from that expected or would have occurred when performed logically. We plot this difference of the task completion logically and emotionally on a graph to observe the behaviour of the agents. The average of the task attention for all nurses achieved logically and emotionally is plotted on the graph. The Figure 9 shows an example of a task performance logically and emotionally, which shows that due to heightened emotional stress, likelihood of an agent missing a step is increased.

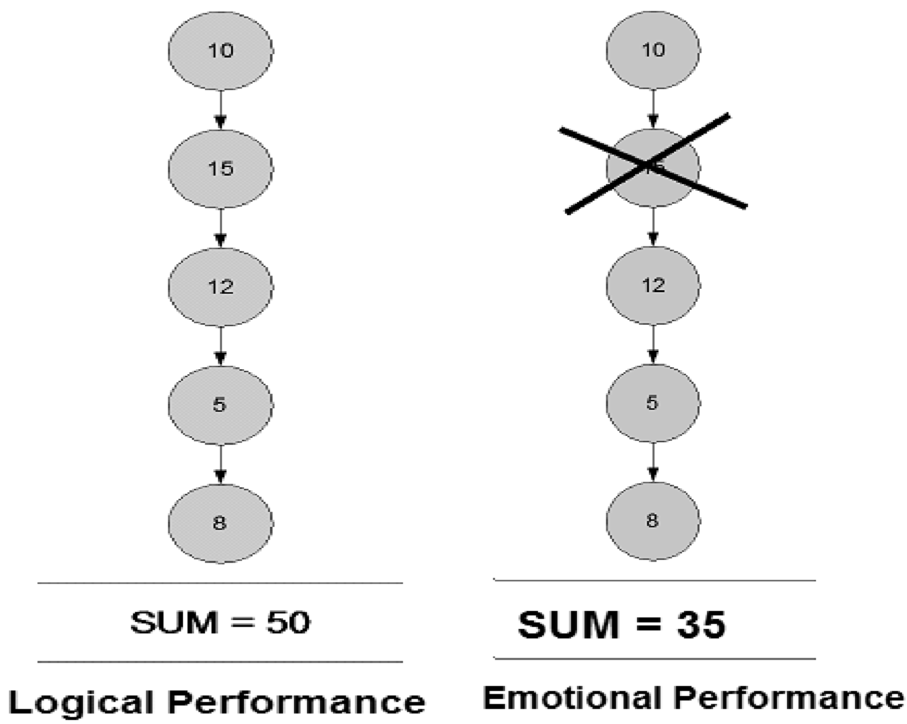

Figure 9: An example task showing the comparison of logical and emotional performance.

Figure 10 shows the algorithm used to miss a step when emotional state is on the negative side, where, Em_c is the current emotional state of the agent.

```
If Emc = displeased or pain or sadness
     50% chance of missing one step of the task
If Emc = anger or disgust
     50% chance of missing more than one step of the  task
If Emc = disappointment or despair
     75% chance of missing one step of the task
If Emc = fear or fears-confirmed
     75% chance of missing more than one step of the  task
If Emc = remorse
     25% chance of missing one step of the task
Else
     Does not miss step
```

Figure 10: Algorithm used to miss a step while performing a task under the influence of negative emotions

5.4 Experimental Setup

We have used three different settings to perform experiments with the simulation. We ran the simulation for 10 times with each setting.

5.4.1 Setting 1

The patient agent's emotion is fixed and the nurse does not interact with other nurses. These are the basic settings for the simulation. When the model is built the emotions of the patients are initialized according to their severity. Throughout the simulation run the patient agents do not change their emotion. When the nurse agent serves the patient, they are affected by the patient's emotion. But the nurses do not talk to other nurses, so other nurses do not change their emotions. With the changed emotional state, nurses perform their task differently. To see the difference between the performances we compare emotional against the pure logical performance of the task. In this setting, not many nurses interact with the patients, and they don't interact with each other as well; so the comparison shows that whenever there are more nurses with a negative state of emotion like displeased, then the nurses tend to skip some step in their tasks. But this does not happen frequently as the patient's emotion state is constant and more nurses have positive emotional state. Figure 11 shows number of nurses with various negative emotions with time. Figure 12 shows the difference between the logical and emotional performance of the nurse for the first setting.

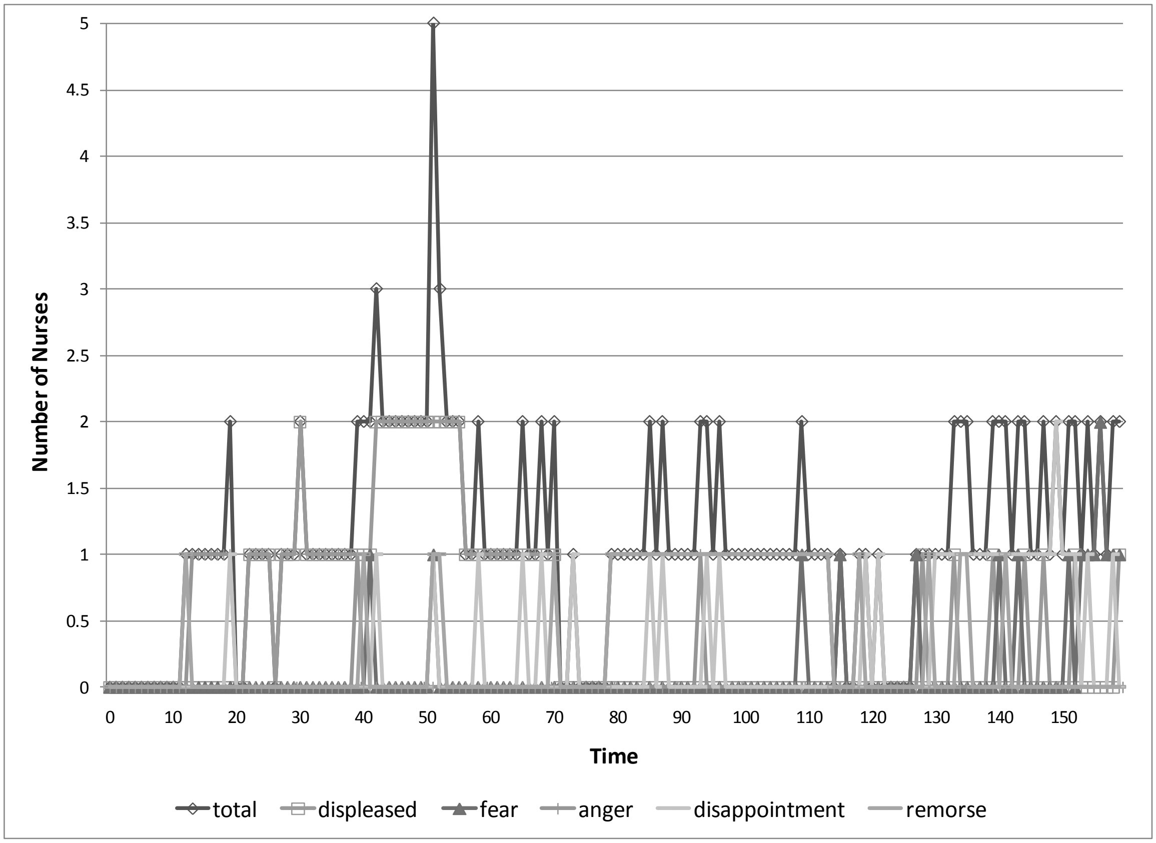

Figure 11: Graph shows the number of nurses with negative emotions for every time step for Setting 1. X-axis represents time step and Y-axis represents number of nurses.

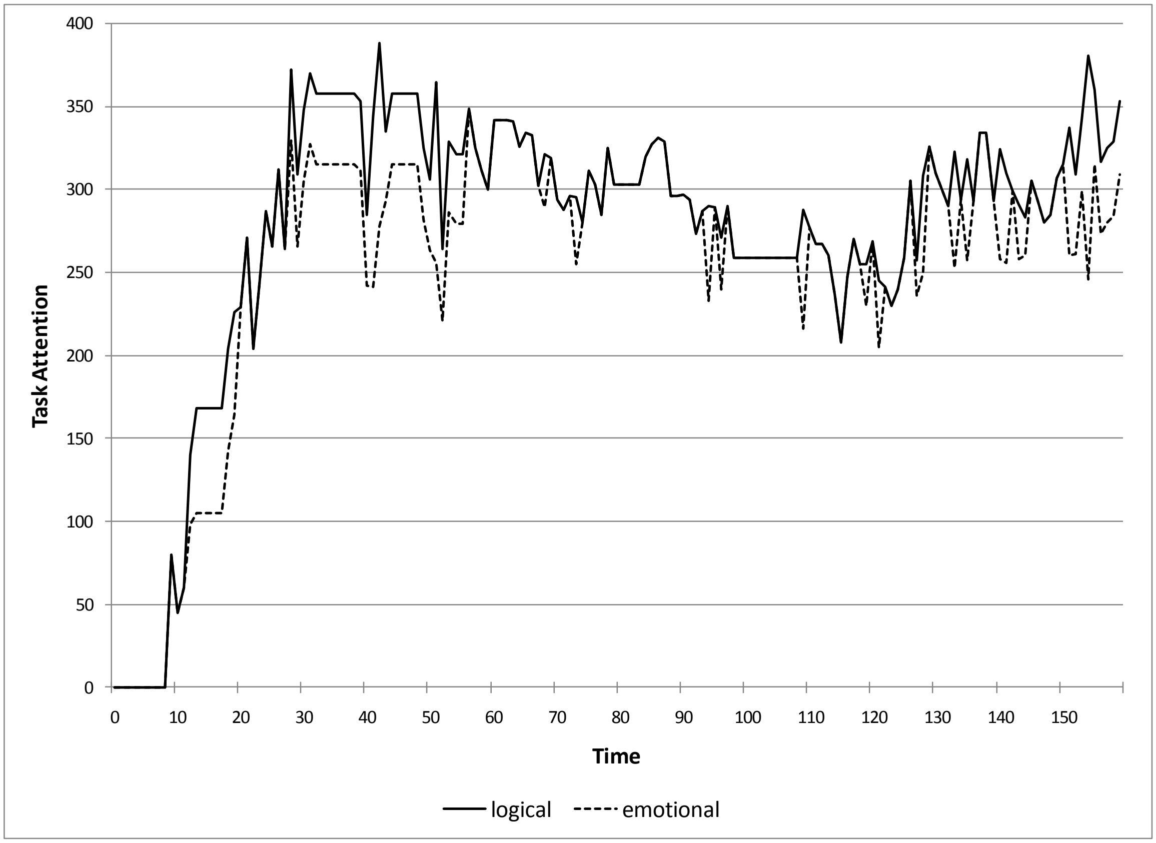

Figure 12. Graph showing task attention vs. time for logical and emotional performance of the nurse for Setting 1.

5.4.2 Setting 2

Nurses interact with other nurses while the patient's emotion is fixed. In this setting, the nurses communicate with each other if they are in the same room. When they talk their emotional state also changes. Now as more nurses interact, their emotional state changes more often. If they have negative emotional state then they tend to skip a step or more while performing their tasks. The comparison between pure logical way of performing a task and emotionally performed task, in this case, show a lot of difference. More nurses interact, their emotional state changes more often and they tend to make mistakes more often. Since the patient's emotion is constant, when negative emotion is generated and tends to multiply among nurses when the nurses influence each other. A large pattern of mistakes being made by nurses is seen. Figure 13 shows number of nurses with negative emotions with time. Figure 14 shows the difference between logical and emotional performance of the nurses.

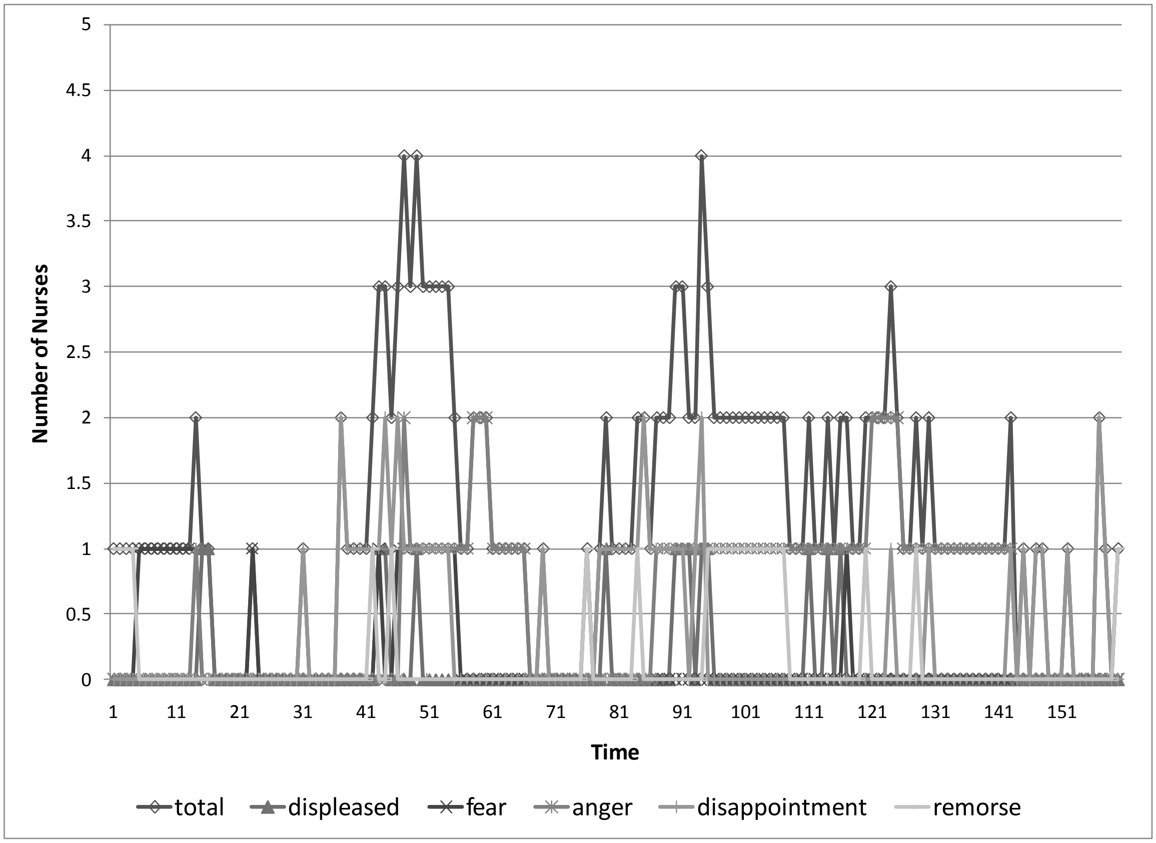

Figure 13: Graph shows the number of nurses with negative emotions for every time step for Setting 2. X-axis represents time step and Y-axis represents number of nurses.

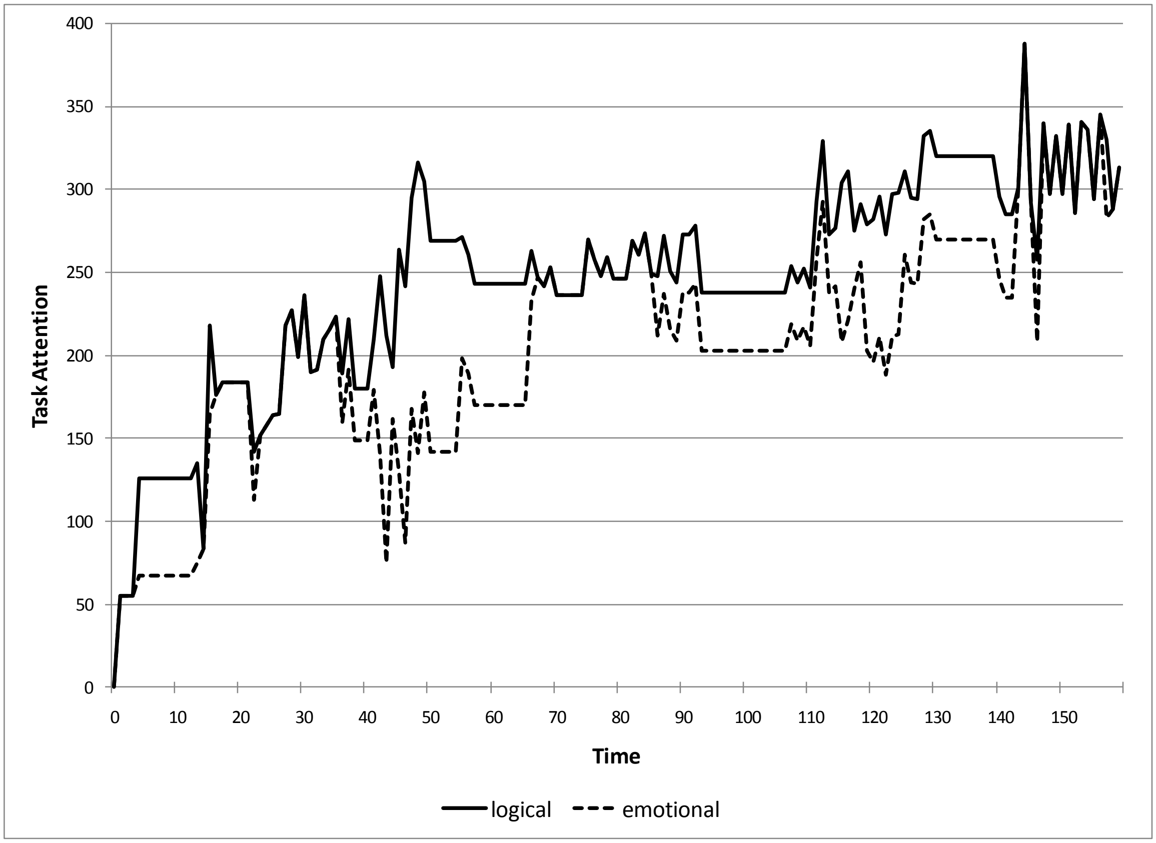

Figure 14: Graph showing task attention vs. time for logical and emotional performance of the nurse for Setting 2.

5.4.3 Setting 3

Patient's emotional state changes with time. In this setting, when the patient's emotion also changes when the nurses' visit them, the continuity of making mistakes decreases. We see a pattern, when there is increase of unhappy patients, unhappy nurses also increase and task performance is affected. When the number of unhappy patients decreases, there are less unhappy nurses and consequently more tasks are performed logically. Figure 15 and 16 shows number of patients and number of nurses with negative emotions with time. In case for Setting 1 and 2 number of patients with negative emotions remain constant. Figure 17 shows task performance of the nurses, logically and emotionally.

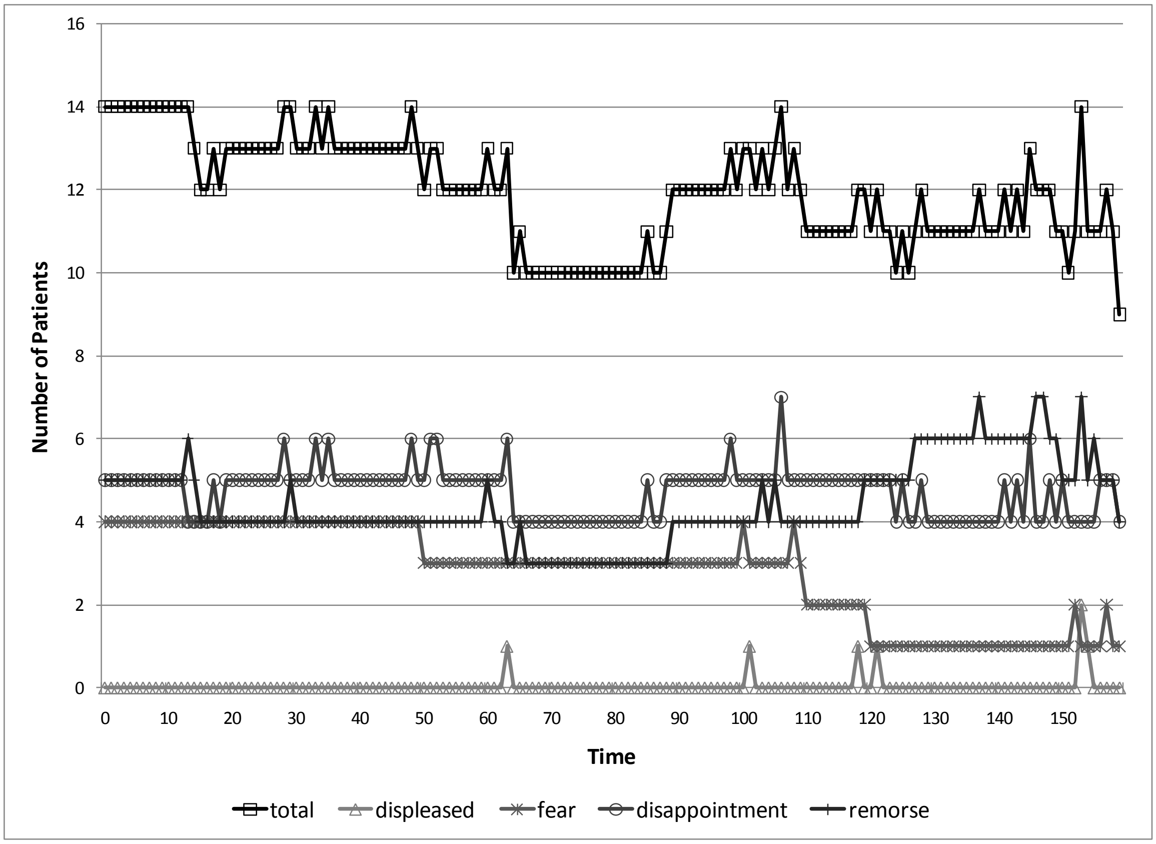

Figure 15: Graph shows the number of patients with negative emotions for every time step for Setting 3. X-axis represents time step and Y-axis represents number of patients.

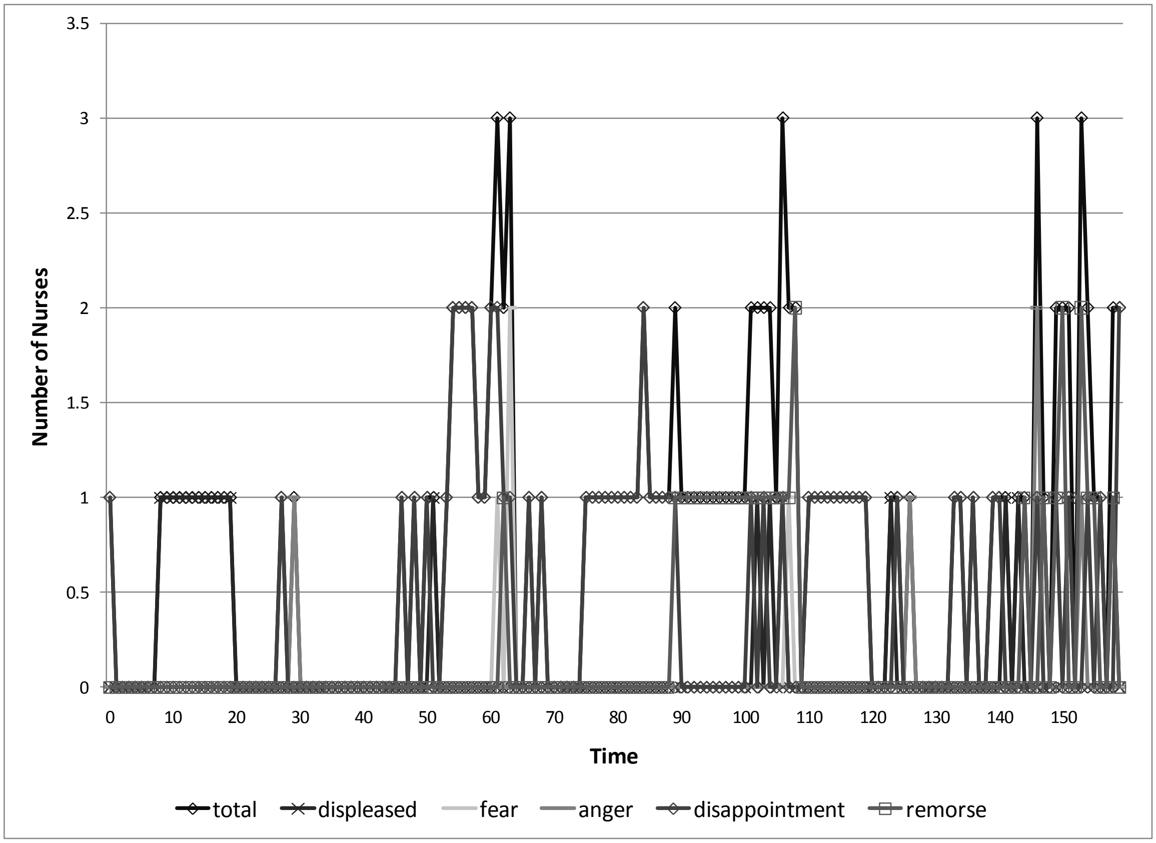

Figure 16: Graph shows the number of nurses with negative emotions for every time step for Setting 3. X-axis represents time step and Y-axis represents number of nurses.

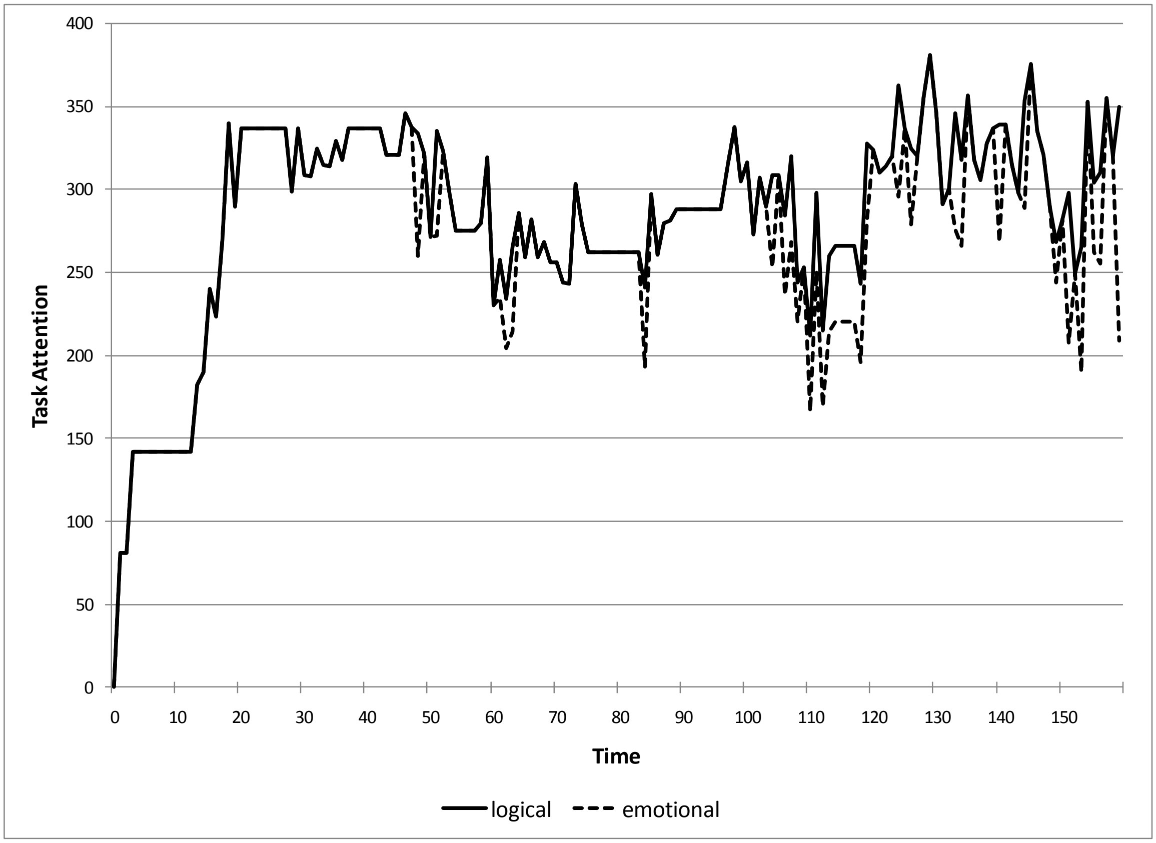

Figure 17: Graph showing task attention vs. time for logical and emotional performance of the nurse for Setting 3.

5.4.4 Results

In the first setting since there was no interaction between the nurses and patients' emotions remain constant, the nurses performed well and did not skip many steps. In the second setting, after the nurses' start interacting with each other we observe a major downfall in the performance of the nurses. In the third setting patients change emotion, which changes nurses' emotions more frequently and hence nurses' performance also changes frequently from missing steps to performing well, while their emotional state changes to happy from unhappy.

Chapter 6

Conclusion and future work

In this thesis we developed the generic algorithms from psychology to generate emotions in artificial autonomous agents. The three theories used are of the great psychologists Ortony, Clore and Collins's Cognitive structure of emotions, Frijda's emotions and Scherer's theory of emotion. In chapter 2 we discussed the different researches done in AI for exhibiting emotions in agents. In chapter 3 we described the three algorithms developed from the three theories. In chapter 4 we discussed the generic model developed in order to test the performance of the three theories using a neighbour interaction simulation. Emotions are very complex and it is not possible to consider every aspect of emotion in a single study, so this research also has some limitations. Firstly we used a two dimensional grid in the generic model to perform experiments and see interactions among agents, instead of which a more general network of agents could have been used, like graphs, but for this case a two dimensional grid has all the elements required for Multi-agents simulation. Then we use the update history function which has been designed as per the requirement of this model and can be upgraded according to a particular application. Moreover we assume that objects and events have a similar impact on all the agents and this impact is a part of the environment perceived which is visible to the other agents as well.

The results from various experiments performed show that when a specific emotion has to be generated among emotions, using the OCC algorithm is advantageous as it has around 22 emotions classified according to neighbour interaction, object liking and disliking, and personal well being of the agents. Moreover it has equal number of negative and positive emotions covering all the basic emotions experienced by individuals according to stimulus events. In the case of Frijda's theory it has only four emotions which are too general to define the emotional state of an individual and in this case, artificial agents. While Scherer's theory does not have defined emotions but can generate as many as 40 to 50 emotions with varying the value of stimulus evaluation checks, but this theory can be considered in applications where very specific emotions are to be generated with the knowledge of how the stimulus event will affect the various checks. We can conclude that OCC recognizes emotions more accurate than the other two theories and can be used for a number of applications where basic emotions have to be generated using interaction among agents and events. In chapter 5 we discuss a Hospital Simulation System case study, in which we see the performance of OCC theory in generating emotions among patients and nurses, and the reaction of the emotion generated on the performance and behaviour of the nurses. We can conclude that depiction of emotion is done quite accurately, while the change in patient emotion is reflected with change in nurses' emotion and hence affecting their performance while under the influence of negative emotions.

A future extension of this work would be to add learning and adaptation capabilities in the agents. Like if a nurse sees the same kind of situation again and again, she/he would not respond with the same emotion after some occurrences of that event. Moreover personality of an agent can be useful in emotion generation and task performance.

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VITA AUCTORIS

Dreama Jain was born in 1988 in Patiala, Punjab, India. She completed her Bachelor degree in Computer Science in 2009. Currently she is a Master's Candidate under Dr. Kobti's supervision at the School of Computer Science in University of Windsor, Ontario. She is expected to graduate in June 2011.