Modeling the Acquisition of Knowledge that Affects Agents' Emotions

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ABSTRACT

Emotions play an important role in decision-making. Intelligent agents can exhibit emotions using systems based on modal logic. This survey is concerned with research on implementing emotions in agents. One approach is by integrating reactivity, goals, and emotions. Another approach is using cognitive as well as non-cognitive elicitors in generating emotion. Using fuzzy logic and learning techniques for mapping events to emotions. Personality consisting of emotional states can also play a part in modeling emotional agents. Appraisal of events and coping strategies is another method for emotion generation in agents with memory and experience. Logical formalization of emotion theories using Belief, Desire and Intention (BDI) logic is another approach. This survey contains annotations of the research publications describing these approaches which will help in better understanding of the research.

Keywords: intelligent agents, emotion, decision-making, modal logic.

CONTENTS

1. INTRODUCTION

Emotions are felt by humans. In Computer Science, an intelligent agent is one of the parts of AI which can be used to create an emotional component. They not only acquire knowledge about their environment but also reflect changes in their emotional states which, as a result, can be used in a Decision Support System. Frijda, [1986], Ortony, Clore and Collins, [1988] and Lazarus, [1991] are some of the important works which deal with the basic concepts of emotions.

One of the methods of modeling emotions in intelligent agents is the use of modal logic. Bates, Loyall and Reilly [1992] were the first to develop emotion in agents using modal logic. This survey summarizes the work done by various researchers in modeling emotions using modal logic. The research papers for this survey have been identified using Google Scholar, ACM and LNCS. There are 9 milestone papers and 9 important papers out of which 8 are conference papers, 9 are journal papers and 1 is a technical report. There is a doctoral dissertation [Elliot, 1992] which models emotions in Multi-agent systems. Another doctoral dissertation [Adam, 2007], is another milestone for this survey.

There are 3 research papers identified as early efforts made in building emotional agents which introduce the Tok architecture in the Oz project and were described between 1992 and 1998. In these, the authors aim is to imbibe emotions and reactivity with other capabilities of the agent which have goal-directed behavior. Next, there are 2 research papers which have implemented emotions in behavioral animation using a reactive agent structure described between 1995 and 1996. In these, the authors create an agent which is actually the actor of the animation and has the function of performing various tasks in order to reach a particular goal with exhibiting emotions, desires and beliefs. Next, there is a research paper which implements emotions and some other motivations which lead to generation of emotions and behaviors which are influenced by emotions, which has been written in 1997. In the next set of research papers there are 2 papers which discuss about use of fuzzy logic in generating emotions. These papers have been written in 1999 and 2000. The researchers in these papers describe how they have mapped events to emotions and emotions to behaviors using fuzzy logic and used learning techniques to make agents adaptive.

In the next set of research papers there are 4 papers which discuss the emotions and personality of an agent described between 1997 and 2002. 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. Next, there are 2 research papers which have implemented a domain independent framework of emotion and adaptation. These papers have been written in 2004 and 2005. In these papers, the researchers have developed event appraisal and coping process from the emotion in a situation. Next, there is a research paper which implements a model and a application for a emotional agent, written in 2007. This paper compares the behavior of rational agent to the emotional agent using Orphanage care problem. Lastly, recent efforts in building emotional agents are described in 3 papers which discuss logical formalization of emotional theories described between 2006 and 2009. In this research, 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].

2. BACKGROUND

2.1 Artificial Intelligence and Emotions

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 Artificial Intelligence 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] also supports the merging of Artificial Intelligence with emotion and social adaptation.

2.2 Overview of Survey

2.2.1 Early efforts in building emotional agents using Tok architecture

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 in 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 behavior. In order to imbibe emotions in the agents, which help them in decision-making situations, the authors introduce the Tok architecture. This architecture is used to integrate emotion, reactivity and goals. With the help of this integration, firstly data is sensed then actions are performed on the basis of previous goals achieved, emotions generated, and behavioral features of the agent. [Bates, Reilly and Loyall, 1992] describes this integration and the Tok architecture. [Reilly and Bates, 1992] describes the Em emotion model, its integration with behavioral features and social knowledge. [Bates, Reilly and Loyall, 1998] describes all of the components of the Tok architecture starting from the simulated world, perception, action (Hap), emotion and social relationships (Em), and behavioral features.

2.2.2 Developing emotions in behavioral 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. The authors describe the Reactive Agent Structure which has a Sensory Centre which consists of Large Term memory and a Cognition Centre.

Each Sensory Centre termed as motor is an agent which store facts in LTM and based upon these facts emotions are generated by cognition centre using processes. Another function of the Sensory Centre is to send and receive messages. Depending on the current emotional state some decision is taken and a task is performed in order to achieve some goal.

2.2.3 Modeling emotions and other motivations

The work of Velasquez, [1997] describes Cathexis model, which uses a proto-specialist for each emotion. The author differentiates between emotions and other motivations such as moods. In this paper cognitive as well as non-cognitive elicitors of emotions are used. Moreover mixed emotions and emotion blends have also been implemented with emotion intensity and decay of emotion. The behavior system consists of expressive and experiential component and again out of the network of behaviors, the behavior with highest value is chosen by the agent to act upon.

2.2.4 Emotion generation using fuzzy logic.

The work of El-Nasr, Yen and Ioerger [2000] introduces a new computational model known as FLAME (Fuzzy Logic Adaptive Model of Emotions). In this fuzzy logic is used to map events to emotions and then emotions to behaviors. They also use learning techniques in order to make an agent adaptive to the events, learn from its experience and hence implements memory of agent. [El-Nasr, Yen and Ioerger, 1999] describes PETEEI, an application which uses FLAME implemented in a pet with evolving emotional intelligence. In this the users are able to interact with a virtual environment which acts as a pet and displays emotions and behaviors influenced by emotions.

2.2.5 Personality and emotions

[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. The work of Lisetti, [1997] describes computational scripts of emotions derived from semantic meta-definitions which give a database of emotion concepts. [Lisetti and Gmytrasiewicz, 2002] provide formal definitions of decision-making situation, emotional state, agent’s personality, and personality model. They also describe probabilistic transformations which are used in transition of emotional states and lead to a decision. [Lisetti, 2002] describes the Affective Knowledge Representation (AKR) scheme which consists of a hierarchical model of personality, affect, mood, and emotion. It uses emotion components which are used to analyze particular emotions at a particular state. Using functional attributes, emotions are mapped to actions. The author also describes Emotional State Dynamics.

2.2.6 Domain-independent framework of emotion

[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. The authors used a doctor's example to generate emotions for a child patient and then generate coping strategies in order to cope from that situation. In [Gratch and Marsella, 2005] the authors have generated a method to evaluate their EMA model by comparing it with human behavior, using stress and coping questionnaire. The authors conclude that their work is very close to the results of the questionnaire, with some limitations.

2.2.7 Emotional agent

[Maria and Zitar, 2007] implements a model and an application for a multi-agent system. In this there are two agents: Rational agent and Emotional agent. A rational agent performs all the functions logically, where as emotional agent takes into account emotions while performing its functions. A set of experiments are performed to compare emotional agent with the rational agent, with the conclusion that emotional agent has the ability to perform better than a rational agent.

2.2.8 Recent work on building emotional agents using logical formalization

[Adam, Gaudou, Herzig and Longin, 2006] and [Adam, Herzig and Longin, 2009] describe the recent work done in building emotional agents with the help of BDI logic and the formalization of emotional theories as described by OCC [Ortony, Clore and Collins, 1988]. The work of Adam, Gaudou, Herzig and Longin, [2006] introduces a logical framework based on BDI (Belief, Desire and Intention) which consists of agents, actions and atomic formulae. With the help of full belief, probability, choice, and like/dislike, various emotions are formalized and a task is performed after decision-making. The authors conducted a case study related to Ambient Intelligence. The work of Adam et al., 2006 describes a logical framework which is based on OCC emotion theories. The authors define operators and event-based emotions and agent-based emotions. [Adam, Herzig and Longin, 2009] develop a logical formalization of twenty two emotions as described by OCC. The authors state that modeling of triggering of emotions from mental states has been done in their research.

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.

3 SURVEY OF RESEARCH

3.1 Emotional agents integrated with reactivity and goals.

The research papers in this section deal with the problem of developing emotions in agents, which can also display reactivity and goal-directed behavior. All papers use the Tok architecture to implement emotional capabilities in agents. The first paper was written in 1992 and the last in 1998. All of the researchers worked at Carnegie Mellon University on the Oz project which is basically a simulated world with agents which interact with each other and their environment.

3.1.1 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 behavior" 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 refer to the work of [Bates, Loyall and Reilly, 1991] and indicate that they use the theory of Broad agents as the basis of their work. The authors also refer to the work of [Loyall and Bates, 1991] and indicate that they have used the same theory for the Hap architecture as [Loyall and Bates, 1991]. The authors do not directly identify the shortcomings of the previous work but instead used it as their basis of work.

The authors propose a new architecture for building broad agents with capabilities of emotion handling, and goal-directed behavior. 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 behavioral 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 behavioral features of the agent.

The authors have used Lyotard, a cat, as their agent. It has goals such as finding food, searching for a place to sit, etc which can make him happy. Another set of goals is generated depending upon the emotional state of Lyotard and the previous goal achieved. The authors also explain the relationship between Lyotard and humans and how this affects its emotions and the next set of goals. Depending upon this, Lyotard may have the emotion of fear or hate which can lead to an aggressive behavior and the actions corresponding to this will be somewhat harmful for humans but may provide satisfaction to Lyotard.

The authors state that their architecture is able to exhibit different kinds of emotions in the agent depending upon the outside world, social relationships, previous goals achieved and behavioral features. This in turn leads to another set of goals for the agents which arise from the emotions of the agent at that time. These emotions can be happy or content emotions or sad or disgust feelings. Furthermore, the agent behaves according to the new emotions it has perceived.

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 behaviors for an agent depending upon context conditions and success tests. The authors also claim that the idea of behavioral features can be used to model different personalities of the agent instead of building agents from scratch.

3.*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 behavior. Moreover, the authors state that there is no existing architecture that can deal with the emotions and behavioral features in Tok, an architecture developed by the authors which works on "sense-think-act cycle".

The authors refer to the work of Ortony, Collins and Clore [1988] and indicate that they use their model of emotion as the basis of their own Em model. The authors also highlight the differences between the model of Ortony, Collins and Clore [1988] and their own model.

The authors state that the work of Ortony, Collins and Clore [1988] could not deal with social knowledge which the authors are able to do in the Em model. The authors state that the work of Ortony, Collins and Clore [1988] is not flexible enough to identify emotions and behaviors and there are not many interactions with the emotions.

The authors propose what they claim to be a new architecture for representing emotions in agents and integrating emotions with behaviors 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 behavior 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 explain the functioning of the Em model with the help of an agent Lyotard, which is a cat. It has emotions towards humans and corresponding to those emotions it has an attitude towards the human, which depends upon the behavior of the human towards the cat. The authors give examples of various events which can make Lyotard happy or sad and what all goals it has. If the goals succeed or fail Lyotard will have corresponding behavior. Em records all the emotions, events and goals of Lyotard and depicts its emotion towards humans.

The authors state that the Em framework is able to generate emotions of agents as well as performing some other functions of emotion decay and tracking of events that will produce emotions in the agent. The authors claim that Em captures the attitude of the agent towards objects and generates emotions related to the object. Em integrates with behavioral features of the Tok, it also keeps track of social knowledge. The authors claim that Em is flexible in nature as it is simple to add emotions into it.

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.

3.1.3 An architecture for action, emotion, and social behavior.

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 behavior. 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 refer to the work of Loyall and Bates [1991] and the work of Ortony, Clore and Collins [1988] and use their theory of Hap for goal-directed action in the agents and Em to model emotional aspect of the agents respectively. The authors also refer to the work of Bates, Loyall and Reilly [1992] and indicate that they have used the theory of Bates et al as the basis of their agent architecture. They do not directly state the shortcomings of the previous work, but instead use their work to integrate their work with the previous work done in Oz project [Bates, 1992].

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 behavior. 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, behavioral features of the agent are adjusted.

The authors conducted an experiment by building a Tok agent which is a cat called Lyotard. This agent has sensory routines and an integrated sense model with the help of which Lyotard senses the outside world. Lyotard has several emotions which have been programmed using Em. Corresponding to these emotions it has a certain kind of behavior. He has a list of goals which he has to accomplish. Depending upon the priority of the goal, his emotions and relationship to other agents or the world, he has some behavioral features. The authors provide an example of how Lyotard behaves when he comes across a human he dislikes, or when he is hungry and looks for food. Moreover, when he finishes some goal successfully, it makes him happy and again the emotional state is updated which has an effect on forthcoming goals.

The authors state that the Tok architecture is able to integrate perception, goal-reacted behavior, emotions and social relationships. Lyotard, a Tok agent, is able to exhibit a behavior which is dependent upon emotions and social relationships. Lyotard is able to achieve goals by prioritizing them and every action is chosen with the help of Hap architecture.

The authors claim that their architecture is able to perform actions based on emotions and agent has goal-directed behavior. 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.

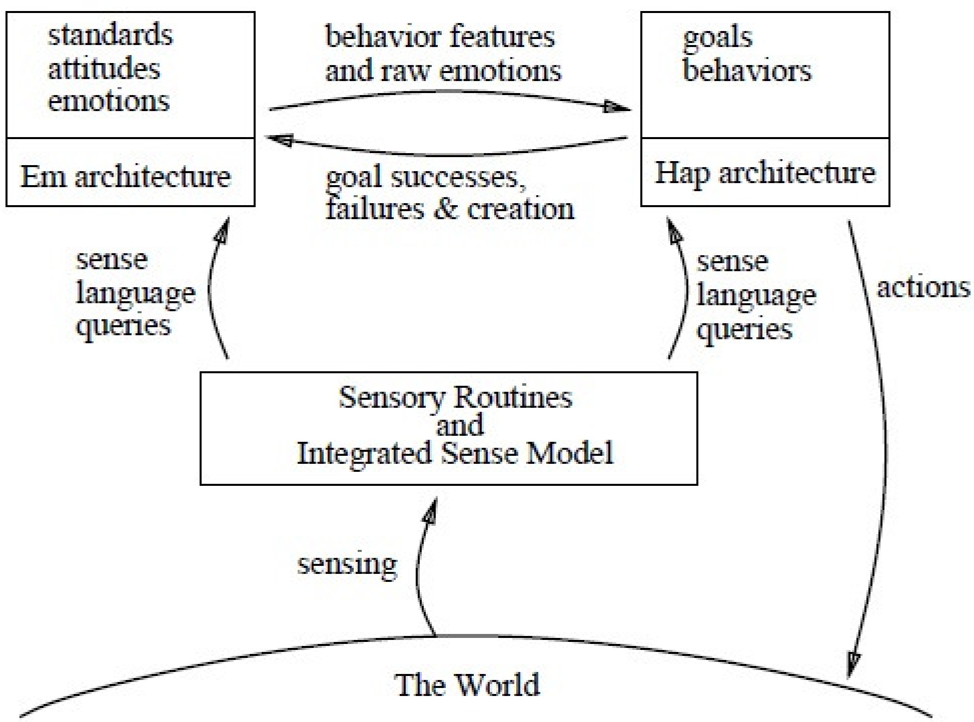

Figure 1: Tok architecture (Bates, Reilly and Loyall, [1998] page 56)

Year	Authors	Title	Contribution
1992	Bates, Reilly and Loyall	Integrating Reactivity, Goals, and Emotion in a Broad Agent.	Introduces Tok architecture which has capabilities of handling emotions, reactivity and performing goal-directed actions.
1992	Reilly and Bates	Building Emotional Agents	Integrates behavioral features and emotions in Tok architecture.
1998	Bates, Reilly and Loyall	An Architecture of Action, Emotion, and Social Behavior	Explains the Hap model for action, and the Em model emotion in Tok.

Table I: Major contributions in Tok Architecture

3.2 Developing emotions in behavioral animation

In this section we review the research papers which deal with the problem of developing emotional characters in behavioral animation. The researchers introduced a new architecture called reactive agent structure to implement emotions in agents. These papers were written in 1995 and 1996 by the researchers working at Laboratorio de CAD Inteligente, Departmento de Informatica, PUC-Rio. The authors argue that there has not been any reactive architecture for building agents in AI and their architecture is deliberative as well as reactive.

3.2.1 Reactive Agents in Behavioral 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 authors refer to the work of Zeltzer [1985] in animation, which acts as the basis for behavioral animation. They also refer to the work of Rodney Brooks and indicate that they use the theory of [Brooks, 1991] as a basis for their work. The authors state that [Brooks, 1991] talks about the principles of an agent which are required in a reactive agent so that it is able to interact with the environment. The authors point out some of the problems with earlier deliberative architecture of agents, which they claim can be overcome by using a hybrid architecture. These problems are inefficiency, coping with unpredictable events, requires detail plans which in general are not possible.

The new architecture introduced by the authors is an architecture for reactive agents in behavioral 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 are 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 performed an experiment in which a character has to move in a house. The simulation involves a number of agents which help the agent to move from one position to another while avoiding collision with obstacles. With the help of a script language, the authors illustrate their approach by simulating the movement of a child moving from one room of the house to another by avoiding a toy placed on the floor.

The authors state that the reactive agents built by them are able to perform their tasks such as moving from one place to another in the house, transforming messages, etc. The authors claim that the agents were able to generate a plan for the character to move from one position to another, avoiding collision. Their agents use logical procedures and learned procedures for decision making.

The authors claim that the architecture they have built for the reactive agents is innovative for behavioral 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.

3.2.2 Agents with emotions in behavioral animation.

Costa and Feijo, [1996] begin by stating that there has not been much work done in behavioral 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 behavioral 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 behavior corresponding to those emotions in agents.

The authors refer to the work of Brooks [1991], which deals with reactive architecture for building agents and the authors indicate that they use principles of reactive agents laid by Brooks in their work and hence their work is a hybrid architecture of classical and reactive architecture. The authors also refer to the work of Costa, Feijo and Schwabe [1995] and indicate that they implement emotional actors based on that work. The authors do not mention any shortcomings in previous work, but use the previous work as the basis of their work.

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 create an actor which is a child who moves inside a house from one place to another, avoiding obstacles. The child comes across a mouse which generates emotion of fear in the child and, corresponding to that the movement of the child becomes faster in order to escape. Similarly when the child comes across a toy it generates another path to reach its destination by avoiding the obstacle.

The authors state that in the architecture they have developed, emotions are generated by the procedures of the cognition centre and are not based upon representation of the world. The authors state that their approach is consistent with principles of reactive agents and is a simple method of generating emotions.

The authors claim that their architecture is innovative for dealing with emotions in behavioral 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 behavior, 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.

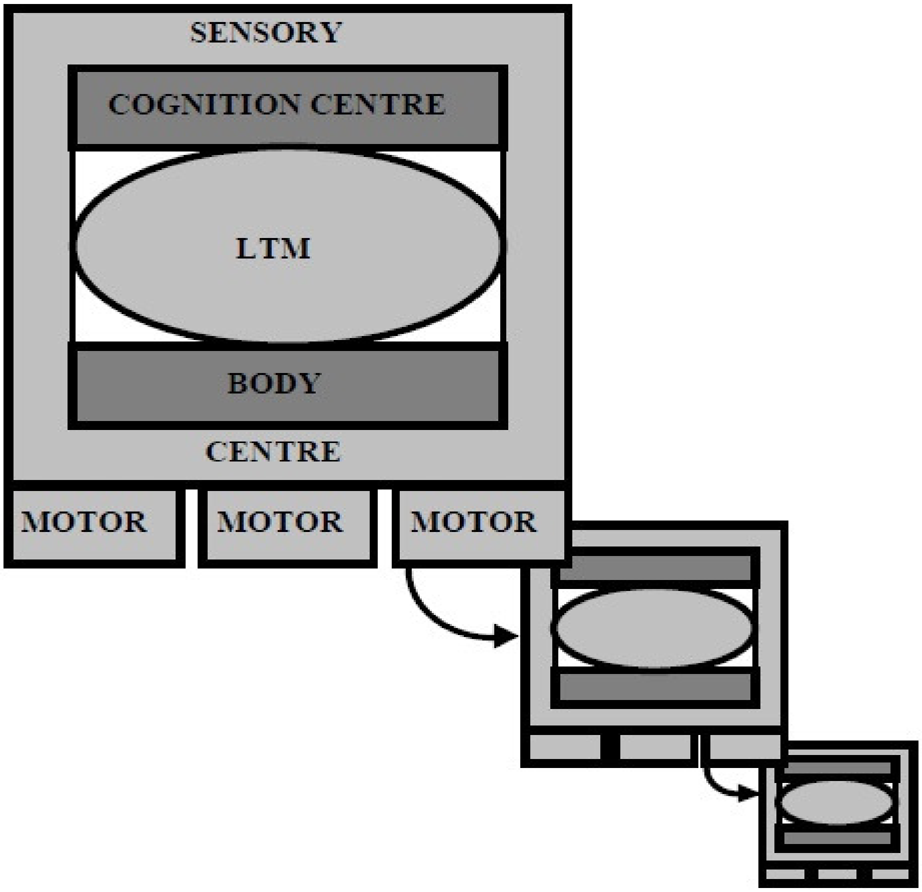

Figure 2. Actor Structure (Costa and Feijo, [1996], page 378)

Year	Authors	Title	Contribution
1995	Costa, Feijo and Schwabe	Reactive Agents in Behavioral Animation.	Introduces a Reactive Agent Structure for Behavioral Animation
1996	Costa and Feijo	Agents with emotions in behavioral animation.	Introduces the Reactive Emotional Response Architecture.

Table II. Major Contributions in Behavioral Animation

3.3 Emotions and other motivations

The research paper discussed in this section discusses Cathexis model, which uses a network of emotions and a network of behaviors. The paper was written in 1997, there is another paper related to the same work which has not been discussed here to avoid repetition.

3.3.1 Modeling 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 behavior 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 behavior 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 Behavior system in Cathexis model consists of network of behaviors, 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 behavior is dependent upon releasers, which includes 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 behaviors, 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 behaviors.

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 behavior 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.

Year	Authors	Title	Contribution
1997	Velasquez	Modeling Emotions and Other Motivations in Synthetic Agents	Introduces Cathexis model, which generates emotions and corresponding behaviors in synthetic agents.

Table III. Major Contribution in Modeling emotion and other motivations.

3.4 Use of fuzzy logic in modeling emotions

The research papers in this section use fuzzy logic to generate emotions by mapping events to various emotions and applying learning methods for agent to adapt to the events. The first paper in this section was written in 1999 by the researchers from Northwestern University and Texas A&M University, which deals with the implementation of FLAME in a pet. The second paper was written in 2000 by the same researchers and it describes the complete implementation of FLAME.

3.4.1 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 refer to the work of Reilly [1996], which describes the OZ project, in which there is a simulation world in which events take place. The events are evaluated according to the goals and attitudes of the agent and is then mapped to some emotional state using [Ortony et al., 1988]'s theory of emotions. According to the authors the OZ project has some shortcomings. It lacks evaluation of expectations and emotions rely on events that affect agent's goals and attitudes without any concept of partial success or failure.

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 behavior selection is done which also takes into account learning about pleasing and displeasing actions. Agent's behavior not only depends upon emotional state but motivational state and the current situation. The authors have used fuzzy rules to map emotions to behaviors.

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 behaviors. 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 state that after evaluating the questionnaires of the participants they learn that the rating for the first two models, the ones without learning is very low comparative to the ratings of the third model. According to the participants agent learning is way higher in the third model than in the first two. Next the behavior of the agent is also improved in the third model than model 1 and 2.

The authors claim that learning is an important factor to be included in modeling 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.

3.4.2 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 behaviors, and using machine learning methods to incorporate adaptability and learning features in the agent to respond dynamically to situations.

The authors refer to the work of Bolles and Fanselow [1980] and indicate that [Bolles and Fanselow, 1980] proposed a model which inhibits motivational states as part of emotional process and their work includes an aspect of Bolles and Fanselow [1980]'s model. The authors refer to the work of Ortony et al. [1988] and Roseman et al. [1990] and indicate that they use the theory of Ortony et al. [1988] and Roseman et al. [1990] as a basis for their work.

[Ortony et al., 1988] and [Roseman et al., 1990] demonstrate event-appraisal methos for generating emotions. The authors indicate the shortcoming of Ortony et al. [1988] and Roseman et al. [1990] that their models do not display expectations and its link with the intensity of emotions. The authors refer to the work of Bates et al. [1992] and indicate that [Bates et al., 1992] worked on the OZ project, which has believable agents in simulation world. The authors bring out the shortcoming of the work of Bates et al. [1992] stating that their model could not simulate dynamic nature of expectations, which authors claim to have incorporated in their work. The authors also refer to the work of Velasquez [1997] and indicate that the model of Velasquez [1997] captured various aspects of emotional process but could not incorporate influence of motivational states and adaptation in modeling emotions, which has been incorporated by the authors in their work. The authors also refer to the work of Elliot [1994] and indicate that [Elliot, 1994] developed a model called Affective Reasoner, which builds on Ortony et al [1988]'s psychological model of 24 emotions, but this model does not address impact of learning on emotions, filtering emotions and relation to motivational states. The authors claim to have addressed these issues in their work.

The authors propose new agent architecture for modeling 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 behavior. This emotional behavior 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 behavior 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 implemented FLAME using an interactive simulation of a pet called PETEEI- a PET with Evolving Emotional Intelligence. It is implemented using a graphical user interface with the help of which user is able to perform actions such as: walk to different scenes, object manipulation, talk aloud, opening and closing doors, look at, and touch and hit. Feedback from pet can be barking, growling, sniffing, etc., pet's actions and internal emotional levels are displayed. In order to evaluate the model, the authors chose user assessment method, by allowing users to walk through different scenes and then get their feedback using a questionnaire. They chose participants as undergraduate students most of them from first year. The experimental procedure followed was to gather criticism from the participants for the improvement of the simulation. The simulation was provided in four different versions: in the first one the pet was simulated to produce random emotions and random behaviors. The second version was not random but dint use fuzzy logic or learning either, but some interval mapping. In the third version fuzzy logic was used but without learning. Lastly the final version used both fuzzy logic and learning methods.

The authors used questionnaire to collect the feedback of the participants. Firstly intelligence of the pet was explored. According to the ratings for the four different versions of the model by the participants for intelligence the random model was like a baseline, with increase in intelligence for non-fuzzy and non-learning model. The addition of fuzzy logic dint bring much increase in the ratings but the final version with learning and fuzzy logic brought significant increase in the intelligent ratings. Next learning of the model was assessed using questionnaire. The response to these questions clearly stated that learning was achieved only when the learning component was introduced that is in the final version of the simulation. Next behavior of the pet was rated. The random model did not give a realistic behavior, non-fuzzy and non-learning method still increased the ratings, fuzzy model induced a slight improvement but a considerable and significant improvement was seen in fuzzy and learning model. The authors conclude that fuzzy logic did not contribute much but is still a better means of modeling emotions, but learning methods play an important role in the simulation inducing adaptability, intelligence and realistic behavior.

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 behavior. 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.

Year	Authors	Title	Contribution
1999	El-Nasr, Yen and Ioerger	PETEEI: A PET with Evolving Emotional	Introduces a application with emotional

		Intelligence.	intelligence which uses fuzzy logic
2000	El-Nasr, Yen and Ioerger	Flame – Fuzzy Logic Adaptive Model of Emotions	Introduces the Fuzzy Logic Adaptive Model of Emotions (FLAME).

Table IV. Major contributions in use of fuzzy logic for generating emotions.

3.5 Emotions integrated with personality in a rational agent

The research papers discussed in this section deal with the problem of implementing emotions in agents which is an essential part of human intelligence and decision making. The authors have used personality as an important factor of an agent and have used the method of Affective Knowledge Representation for decision making situation in emotional agents. The first paper was written in 1997 and rests of the papers were written in 2002. Three of these papers were written by researchers working at University of Central Florida, all of the other papers were written by researchers at various unrelated institutions.

3.5.1 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 behavior 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 refers to the work of Schank and Abelson [1977] and indicates that they have used computational scripts for emotion concepts which are similar to the scripts of [Schank and Abelson, 1977]. The author refers to the work of Wierzbicka [1992] and indicates that they have used primitives from the work of Wierzbicka [1992] in order to describe emotion components.

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 uses semantic meta-definitions to generate some computational scripts which consist of causal chain and emotional components. First pleased script is generated in which criteria is good hence there is no functional attribute and no action is taken. Second script is for newness in which criteria is unspecified so no functional attribute is generated for it. Next script is for frustration in which criteria is bad and functional attribute to re-evaluate is set. In the disappointed script functional attribute is set to release and in discouraged script functional attribute is set to chunk down.

The author states that using semantic meta-definitions, computational scripts for emotion concepts can be generated which are useful in directing the agent to perform specific action in case of arousing of negative emotion. A causal chain is generated which shows all the processes of emotion which is involved during the generation of particular emotion.

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.

3.5.2 Emotions and Personality in Agent Design and Modeling.

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 behavioral 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 makes decision.

The authors refer to the work of [Boutilier, Dean and Hanks, 1999] and indicate that they have used Boutilier et al theory for decision making in their work. The authors also state that they have used the emotional states differentiated by [Ortony, Clore and Collins, 1988] and some concepts of [O'Neill, 2000] for cognition.

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 behaviors, 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 behavior 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 created a simple personality model which has a Boolean transformation function and the agent has only three states: cooperative, slightly annoyed, and angry. The environmental inputs categorize the transitions as being cooperative or uncooperative. If an agent is in cooperative state and given an uncooperative input it can move into the slightly annoyed state, and if uncooperative input is given again, it moves to an angry state.

The authors state that a change in emotional state leads to a change in the action of the agent. Moreover, emotions also change the desirability of the state hence modifying utility functions. Probabilities of states also transforms with change in probabilities and moving to the most likely state. 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 behaviors 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 agents behave and make decisions depending upon emotions and personality. However, the authors give little evidence to support their claims.

3.5.3 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 behavior" and "internal motivational goal-based abilities" of the agents.

The author refers to the work of Frijda [1986] and Ortony, Clore and Collins [1988] and indicates that they have used the theory developed by [Frijda, 1986] and [Ortony, Clore and Collins, 1988] in order to define various emotion components which are used to differentiate between emotions. The author refers to the work of Wierzbicka [1992] and indicates that they have used emotion concepts of [Wierzbicka, 1992] to create causal chains in their approach. The author does not specify any shortcomings of the previous work.

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), certainity (certain, uncertain, non-uncertain), legitimacy (yes, no), external (social) norm (compatible, uncompatible), internal (self) standard (compatible, uncompatible), 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 uses two kinds of input which are provided to the agent depending upon which a new emotional state is achieved by the agent. The first kind of input is external event which influences an agent at neutral state to move to happy state if the input is positive otherwise moves to concerned state if input is negative. If again negative input is given it moves to frustrated state and for positive it moves back to concerned or happy state. In the second kind of input which is internal belief, an agent develops some emotion not because of the external event but by their own efforts. If an agent feels “I can’t do this” he moves to a discouraged state and if the agent starts feeling “I can do this” he can move to hopefulness state. The application of this framework is in Emotion-Based Architecture for Autonomous Robots, MultiModal Affective User Interface Agent and Game Theoretic Agents.

The author states that their approach is able to generate emotions and the agent is able to move from one emotional state to another given some external event as input or internal belief as input. The author states that their framework has been implemented in Emotion-Based Architecture for Autonomous Robots, MultiModal Affective User Interface Agent and Game Theoretic 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.

3.5.4 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 modeling 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 refer to the work of Johnson-Laird and Shafir, [1993] and discuss reasoning and decision making in Normative Rational Agent Modeling. The author also refers to the work of Lisetti and Gmytrasiewicz, [2000] and points out that the emotional transformations introduced by Lisetti and Gmytrasiewicz are described in their paper.

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 use driver's safety and patient's telemedicine application to depict the change of emotional state. Firstly taking into account is external event as input, due to the stress of driving in New York city, a frustrated driver becomes angry. Another input is internal belief, in this agent have some beliefs depending upon which their emotional state changes, these are the feeling which they experience on their own but are maybe due to effect of some external event.

The authors state that they have developed an architecture of rational agents Affective Knowledge Representation which uses emotion components with the help of which current emotion state is identified and next state is also predicted.

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.

Year	Authors	Title	Contribution
1997	Lisetti	Motives for intelligent agents: computational scripts	Introduces computational scripts as a method to depict emotion

		for emotion concepts.	concepts in agents.
2002	Lisetti and Gmytrasiewicz	Emotions and Personality in Agent Design and Modeling.	Introduces a decision-theoretic model which consists of utility functions and behavioral features which, on the basis of probabilities, can recognize emotions and lead to decision making.
2002	Lisetti	Personality, Affect and Emotion Taxonomy for Socially Intelligent Agents	Develops a framework which takes into account the "external behavior" and "internal motivational goal-based abilities" of the agents.
2002	Lisetti and Gmytrasiewicz	Can a Rational Agent Afford to be Affectless? A Formal Approach.	Describes normative rational agent modeling and related concepts with emotions and rationality

Table V. Major Contributions Personality and Emotions

3.6 Modeling emotions using domain independent framework

The research papers in this section introduce a domain-independent framework of emotions, which deals with appraisal of events and coping process. The first paper was written in 2004 by researchers working in University of Southern California. The second paper was written in 2005 by the same researchers. The first paper describes the complete framework and the second paper mostly deals with the application of the framework.

3.6.1 A Domain-independent Framework for Modeling Emotion

Gratch and Marsella, [2004] begin by stating that there have been a numerous work done in computational models for modeling 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 refer to the work of Elliot [1992] and indicate that their work uses some features of Elliot [1992]'s model that is, use of appraisal frames and appraising of event from multiple perspectives in order to characterize events to appraisal variables. The authors also refer to the work of Moffat and Frijda [1995] and indicate that [Moffat and Frijda, 1995]'s architecture uses appraisal variables to capture causal relationships but lack attributions of blame and credit and coping behavior, which authors state to have included in their work while extending the work of Moffat and Frijda [1995].

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 behavior. The authors state that EMA algorithm has 5 stages. First is causal interpretations 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 use a medical example to test their computational model of appraisal and coping. In this there is a doctor, Dr. Tom, and a patient Jimmy, suffering from inoperable cancer, who is in pain. The only way to reduce his pain is to approve of giving him morphine treatment, which may hasten death of Jimmy. Dr. Tom hopes that Jimmy's mother would not approve of morphine treatment and if she does, she will be charged blameworthy for this action. Dr. Tom is sympathetic to Jimmy and wants to end his pain but this may lead to unfortunate consequences of Jimmy's death. The model shows appraisals from the perspective of Dr. Tom who generates emotions of hope, fear, anger and distress. In the end he comes up with the coping strategy of denial which reduces the intensity of Dr. Tom's emotions.

The authors state that the model behaves in the manner they expected it to, by generating appraisals to the situation and corresponding emotions, and finally a coping strategy which reduces the emotion intensity. The authors state that their work has been used in the application of Mission Rehearsal Exercise, as a single mechanism for designing its components.

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 behavioral consistency. The authors claim to have some differentiation between their model and Classical Decision Theory, such as difference in combining utility values with behavior.

3.6.2 Evaluating a Computational Model of Emotion

Gratch and Marsella, [2005] state that their aim of writing this paper is to compare the behavior of their model EMA (Emotion and Adaptation) [Gratch and Marsella, 2004] against the actual human behavior. 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 refer to the work of Elliot [1992], El Nasr et al. [2000] and Moffat and Frijda [1995] and indicate that their work has been built on these previous works with better enhancement on appraisals and coping strategies. The authors state some shortcomings of the previous work such as, not enough transitions for emotional state in the work of El Nasr et al. [2000] which develops on Markov Decision Process, lack of blame and credit attributions and interpretation of coping in the work of Moffat and Frijda [1995].

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 use Stress and Coping Process Questionnaire (SCPQ), a clinical instrument, to measure the actual human behavior and coping process in some typical situations, in order to compare it with the performance of their model. Then for the evaluation of EMA model, the situations and scenarios as provided in SCPQ are encoded in the model. The model is evaluated for aversive condition and loss condition. To measure the good and bad aspects of an event the authors have used an aggregate measure which sums intensities of undesirable appraisals and subtracts from intensities of desirable appraisals.

The authors state that the model behaves according to the results of SCPQ, but varies I some cases. Like in the loss condition the sadness produced should have been more than the sadness produced in aversive condition, but the opposite occurred. Moreover in the loss condition zero control is achieved which differs from the human behavior which authors state that is because of encoding variations.

The authors claim that their model has responded fairly close to the human behavior. The authors claim that since they have used an outside source for evaluating human behavior, 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.

Year	Authors	Title	Contribution
2004	Gratch and Marsella	A Domain-independent Framework for Modeling Emotion.	Introduces EMA (Emotion and Adaptation), a domain-independent framework for modeling emotions in agents.
2005	Gratch and Marsella	Evaluating a Computational Model of Emotion	Compares the behavior of EMA with actual human behavior.

Table VI. Major Contributions of modeling emotions using domain-independent framework.

3.7 Emotional agents

The research paper discussed in this section is a standalone paper and indicates about the implementation the authors have done in multi-agent system using NetLogo. The paper compares the implementation of a rational agent with an emotional agent using “Orphanage Care problem”.

3.7.1 Emotional agents: A modeling 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 refer to the work of Ortony et al. [1988] and use their work as a base to categorize emotions in their framework. The authors have used NetLogo to develop their model. The authors have pointed out some related work but claim that their work is a novel idea and is not similar to or extension of any of the previous works.

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 behavior of EIA. Personality of EIA is influenced by the emotions which in turn influences appraisal hence leading to the behavior 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 behavior of the agents and their decision-making skills.

Year	Authors	Title	Contribution
2007	Maria and Zitar	Emotional agents: A modeling and an application.	Introduces a model and application which depicts comparison between rational and emotional agent.

3.8 Building emotional agents using logical formalization of emotional theories

The research papers discussed in this section deal with the problem of implementing emotional abilities in intelligent agents. The first paper was written in 2006 and the last in 2009. The authors have introduced a logical framework based on emotional theories and extend BDI logic.

3.8.1 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 refer to the work of Prendinger and Ishizuka [2005] and indicate the shortcoming in their work that it can detect emotions but is not appropriate for ambient intelligence. The authors also refer to the work of Lee and Narayanan [2003] and state that they have used fuzzy inference rules for detecting emotions. The authors indicate that the shortcoming of the work of Lee and Narayanan [2003] is that they do not explain the causes of the emotions detected. Another work that the authors refer to is that of Jaques et al. [2004] and indicates that this work has been able to detect the emotions and anticipate them according to ambient intelligence. The authors refer to the work of Herzig and Longin [2004] and Herzig [2003] and indicate that they use their [Herzig and Longin, 2004] theory of modal logic as the basis of their framework and use the probability operator of Herzig [2003].

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 behavior". 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.

3.8.2 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 use the theory of emotions and typology of emotions as defined by [Ortony, Clore and Collins, 1988]. The authors refer to the work of Herzig [2003] and indicate that they use the modal probability operators as defined by [Herzig, 2003]. The authors use the logic built by [Herzig and Longin, 2004] as their framework for their model. The authors discuss the shortcomings of current models which result from the fact that they are only semi-formal, the fact that the models only accommodate a few emotions. They mention the work of Meyer [2004] which is based on only four emotions and which is limited to a particular context.

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.

Using the various emotions defined by [Ortony, Clore and Collins, 1988], the authors cite examples of emotions and use their framework to depict the logical representations of the emotions. In well-being emotions, "an agent feels joy or distress when he is pleased or displeased by a desirable or undesirable event". In prospect-based emotions, "an agent feels hope or fear if he is pleased or displeased by the prospect of a desirable or undesirable event". It also takes into account hope, fear, satisfaction, disappointment, relief or fear-confirmed emotions. Fortunes-of-others emotions take into account happy for, sorry for another agent or resentment, gloating towards another agent. Attribution emotions have pride or shame for oneself and admiration or reproach for another agent. Composed emotions have gratitude and admiration or anger and reproach for another agent, remorse and shame or gratification and pride for oneself.

The authors state that they have formalized twenty emotions defined by Ortony, Clore and Collins [1988]. Moreover using the examples from the work of Ortony, Clore and Collins, the authors claim that they have have proven the correctness of their framework and depicted the important properties of genericity and verifiability in agents.

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.

3.8.3 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 modeling 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 use the theory of emotions as defined by [Ortony, Clore and Collins, 1988], since, the authors claim, it can be used for designing robust and versatile agents due to its simplicity and implementability as it has well-defined concepts of emotions which pertain to logic of beliefs, desires and standards. The authors use the desirability and praiseworthiness variable from [Ortony, Clore and Collins, 1988]. The authors state that their work is also based upon the BDI framework of Herzig and Longin [2004]. They used the BDI framework to build their logical framework of emotions which is triggered by mental states.

The authors propose a new architecture for modeling 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 modeling emotional agents. Then they state that they have used the OCC theory in their paper because of its concepts and logic, which is 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 use examples from [Ortony, Clore and Collins, 1988] to describe emotions. The authors define logical representations for the twenty emotions using modal operators, axioms, syntax and semantics. The authors also expressed some formal properties in terms of theorems and their proofs, which comprise prospect-based emotions and their confirmation, fortunes-of-other emotions, link between self-agent and other-agent attribution emotions, inconsistencies between some emotions, emotion awareness and emotions and ego-involvement.

The authors state that they have created a logical framework based on the BDI architecture of rational agents, in which mental states trigger emotions. Their model is domain-independent and works on BDI logics, and hence can be used easily for emotional agents as it has a number of emotions captured that is around twenty emotions have been implemented. The authors have formalized almost complete logic of OCC theory of emotions. In their model they have very well depicted twenty emotions of OCC typology. The authors also state that a limitation of their model is a lack of expressivity, intensity degrees of emotions, and emotional dynamics.

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.

Year	Authors	Title	Contribution
2006	Adam, Gaudou, Herzig and Longin	A logical framework for an emotionally aware intelligent environment.	Introduces logical framework based on BDI logic.
2006	Adam, Gaudou, Herzig and Longin	OCC's emotions: a formalization in a BDI logic.	Develops formalization for OOC emotion theories using BDI logic
2009	Adam, Herzig and Longin	A logical formalization of the OCC theory of emotions.	Introduces a logic of mental states to model emotions by formalizing OCC emotions.

Table IV: Major Contribution in Logical Formalization of theory of emotions.

4. 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 behavioral 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 behavior 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 behaviors 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 behavior with the help of stress and coping questionnaire. The authors claim that their model responded fairly close to that of human behavior 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.

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