A Fuzzy Emotional Agent for Decision-Making in a Mobile Robot

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Abstract

Emotions have been shown to have a significant influence on the decision-making process of human beings and, thus, play an important role in intelligent behavior. As a means of providing similar intelligence, we are investigating the use of emotional agents in the decision-making process of a mobile robot. We propose a fuzzy logic model that captures the inherent uncertainty of emotions. The model is used to generate decisions based on both internal and external states and incorporates the use of sensory information to extract environmental conditions. In this way, the agent will react to a changing environment and can take an action according to a mixture of emotions generated by multiple states. As a first step towards addressing the complexity, the model deals with three negative emotions: fear, pain and anger, chosen because of their innate structure. In this paper, we discuss our fuzzy logic model and describe the implementation of an emotional agent on a small mobile robot in which sensory information is used to generate emotions.

1 Introduction

Since the time of the Greeks, we have been conditioned to think that emotion is not a part of human intelligence and that it hinders our thoughts. Demasio refuted this claim with neurological evidence taken from several test cases [5]. Elliot, one of the cases under Demasio's supervision, was observed to be stable and intelligent but had lost his emotional power, resulting in his inability to make basic decisions, to follow a schedule, or even to motivate himself to get dressed in the morning. As a result of his research, Demasio suggested that emotions lead an active role in guiding the decision-making process by providing a selection mechanism for eliminating bad alternatives. Decision-making is then simplified, because there are fewer choices left to be evaluated.

Several psychologists have acknowledged the importance of emotions in the role of thinking and intelligent behavior. Indeed, Minsky concluded that, "the question is not whether intelligent machines can have any emotions, but whether machines can be intelligent without any emotions"[17]. As a means of providing such intelligence, we are investigating the use of emotional agents in the decision-making process of a mobile robot.

Psychology, philosophy and cognitive science have been concerned with modeling the mind and its behavior for many years. Pain has been modeled by Schumacher and Velden [24] and again by Tayrer [28]. Bolles and Fanselow have proposed a model that shows the relation between fear and pain [4]. Price et al have developed a mathematical model that described emotions in terms of intensity and expectation [20].

With the interest in Artificial Intelligence (AI), several computer models have been proposed to simulate the human mind. Many of the proposed emotional models represent significant milestones in the research on human emotions. Pfeifer offers a summary of AI emotional models from the early 1960s to the 1980s [19]. One such model was proposed by Frijda and Swagerman [8]. Dyre simulated a day dreamer [6]. An expert system was proposed as an alternative model for the emotional process in [23].

Japanese researchers have recently become interested in a system (e.g., robot) that can communicate with humans, and emotions are regarded as an important factor. As part of this focus, Masuyma formulated human emotions in terms of rules [15]. An attempt was also made by Sugano and Ogata [27] to simulate the brain priority level through an electrically wired robot. A prototype of a decision-making process using emotion was developed by Inoue et al, using neural networks [11].

Stimulated by the Japanese work, U.S. researchers have also begun working in the area of emotions and believable agents [1,14]. Bates has been building a believable agent for his virtual world, the OZ project [2,3,21], using a model proposed by Ortony, Clore and

Collins [18]. Another model has been built by Velasquez [29]. These two models provide a reasonable starting point for building computer simulations of emotions; however, they describe only basic emotions and their reactions, not their interactions.

In general, the previous research discussed has not addressed the complexity of the human emotional system. The previous work has not adequately modeled the interactions between emotions, how they overlap, or how they may be inhibited. We have attempted to address these limitations and, in Section 2, describe a new model for emotions. In Section 3, we apply our model to three specific emotions, namely anger, pain, and fear, and discuss the resulting behavior. A prototype realization of the model is discussed in Section 4. In Section 5, we conclude and suggest future work.

2 The Model

In the human emotional system, there are instances where the emotions overlap or interact with each other. Human beings usually experience a combination of feelings at one time. We tend to act on only a few feelings at a given time; later, we may act on others. In addition to the emotions, there are motivational states that affect the emotional life and sometimes inhibit emotions. For example, pain is sometimes inhibited by hormones sent by the brain. Our model was built to tackle these problems and to develop a decision-making process that is based on both emotions and goal priority.

Most of the previous models have used mathematical modeling techniques, which require the identification of absolute, numeric parameters. In practice, the setting of such parameters may be difficult to achieve because of the inherent complexity and variability among emotions. In contrast to the other models, we have used fuzzy modeling as a means of capturing the inherent uncertainties. It has been emphasized in the psychology literature that emotions' intensity cannot be modeled with cut-off thresholds but rather it is a matter of degree without sharp boundaries. Also, words like rage and anger describe different intensities of the same emotion (i.e., anger), and thus could be more easily modeled by fuzzy modeling.

As a first step in modeling a complex system like the human emotional system, we have considered three emotions: *fear*, *anger*, and *pain*. These emotions were specifically chosen because of their innate structure and the fact that they tend to be constant through different social groups and cultures.

2.1 Framework

The framework for our model is based on that of the Intelligent Agent (IA) [22]. We have expanded the IA framework to incorporate the emotional or the internal state features, as illustrated in Figure 1.

The agent's internal states are shown in the gray box. The solid lines represent relationships in our model, and the dashed lines represent those in the traditional model. In the traditional IA model, the world belief and goals are the determining factors of actions that the agent takes. However, in our model the goals shape our expectation levels of the events. The expectation levels, along with environmental inputs, determine the mixture of emotions and their intensities.

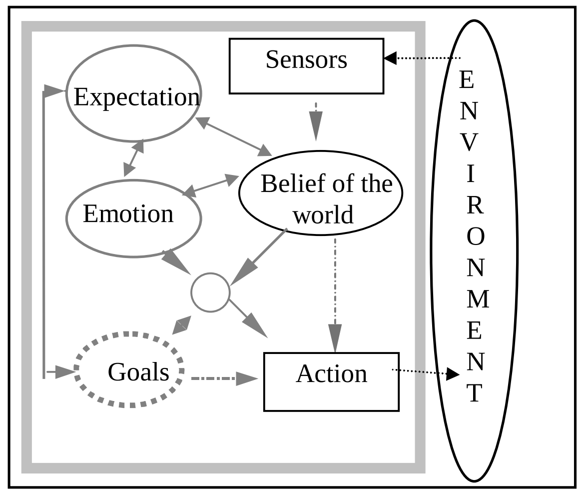

Figure 1. An Extended Intelligent Agent Framework.

Expectation levels can trigger more than one emotion, although they may be triggered at different intensities. As a result, we may end up with different intensities of a mixture of emotions from expectation alone. The mixture of emotions will then be filtered to get one emotion upon which the agent can act.

An action is triggered according to the selected emotion and its intensity. Sometimes emotions can drive the agent to modify its goals. An action could also be triggered without any environmental inputs. Expectations could trigger emotions that will in turn trigger actions that have no environmental inputs.

2.2 Algorithm

Figure 2 illustrates a sketch of our algorithm, with outputs shown for each intermediate step. To begin, the model first senses environmental information such as the degree of brightness and the level of sound. We also input the external state of the agent, which includes being *alone*, *blocked* or *physically damaged*. The information that we get from the environment shapes the agent's view of the world.

The external state *alone* is a binary state that indicates the agent is by himself in the environment. This can affect several behaviors, especially those concerning anger. For example, many people tend to suppress mild anger when they are surrounded by other people. The external state *blocked* is also a binary state and refers to the agent's view of the environment with respect to obstacles. A blocked state means there is no escape route, whereas an unblocked state means escape is accessible. This will influence the behavior of the agent when he is experiencing fear. In an unblocked condition, people tend to run; in a blocked condition they tend to freeze[4]. The external state *physical damage* is a measure of how much tissue damage the agent is experiencing. In contrast to the binary states, we determine a degree of physical damage, which influences the level of pain. These inputs are then normalized to certain degrees (e.g., a level from 1-10).

Another input from the environment is a stimulus, an external event or object, which is used in two ways. First, an expectation level is calculated by measuring the anticipated likelihood of that event to occur according to the agent's world view or memory. Second, a *desirability* is associated with each stimulus as a measure of how desirable the stimulus is according to a specific goal. If a stimulus is perceived as a step toward achieving a certain goal and the goal has a high priority, then the desirability of the stimulus will be high. In contrast, if a stimulus threatens a goal and the goal has high priority then the desirability of the stimulus is low.

Now taking all normalized inputs, plus the expectation level, and the *desirability* of the event, the emotional state inference engine will then produce a mixture of emotions according to the intensity of inputs. From this mixture, the emotion with the highest intensity and the highest priority will be chosen by the priority system. The priority of an emotion is calculated as

$$f(threat(Goal(g), stimulus(x)), \Pr iority(g), \mathrm{int}\, ensity(emotion))$$

where g is the goal that is threatened by stimulus x. *Stimulus(x)* is the stimulus that evoked an emotion. A stimulus that would threaten a goal will illicit a negative emotion. Thus, the priority is biased towards the negative emotions more than the positive emotions. That is due to that fact that negative emotions can have more urgent calls on the Goals than the positive emotions. However, if the emotion elicited from the event x does not threaten any goal, then the intensity and the priority of the goal (the event helps accomplish) will be the prime key factors.

The chosen emotion will then go into the behavioral system that will, according to the chosen emotion's intensity and the state of the agent, recommend an action. The emotions that were not addressed will then be fed back to the system. The active emotion will be decayed by decreasing the emotional level, and the whole process will iterate until the user exits.

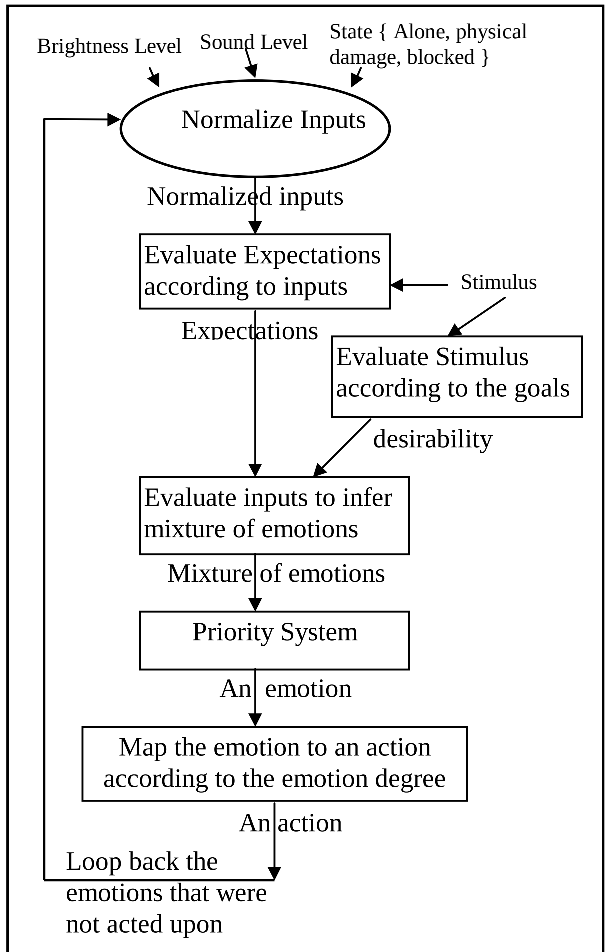

Figure 2. An Algorithm for Emotion-Based Action Section

3 Emotions

In this section, we describe the modeling and behavioral reactions of the three emotions in our prototype system. The emotions of anger, pain, and fear are represented as fuzzy sets, each of which consist of three membership functions, describing the intensity as low, medium, or high.

Normally, an emotion will trigger a reaction; however, sometimes, emotions can be suppressed if they are below a certain level. For example, if all of our emotions are low, then they probably will be suppressed to the unconscious part of our brain. They will pass to consciousness only when they reach a high enough level.

Reactions vary from just being a reflex to building a plan and adding more goals. In this section, we will look at how different emotions may trigger different actions. Moreover, we will look at how different intensities of a given emotion can trigger different actions.

The rules of the system are considered to be the knowledge base for this project. These rules were developed as a cumulative review of interviews, papers, and books in the areas of psychology, computer science, philosophy and cognitive science.

3.1 Anger

Anger is so complex that it cannot be described by external states only but rather requires the interaction of several internal states. Thus, in order to model anger as an emotion we had to incorporate an inner state for the agent. This was the prime reason for adding expectation to our model. Anger depends on multiple states, which Lahaye outlines as the following: memory of old experiences, temperature and body chemistry, personal desires, demands and expectations, positive and negative modeling of family origin, and finally, positive and negative relationships[10].

Of all the above, we are modeling anger according to expectations only. It is also evident that some of the states above trigger more than one emotion. Sadness can be triggered from expectations and demands as well as anger. For example, if you expect to get an A in an exam and instead you get a D, you will probably experience a mixture of sadness and anger.

It is not impossible to incorporate all of the other states, but that will complicate the model by adding a memory and a learning factor. It should be noted that all the states above are internal states. So it is safe to say that it would be impossible to model anger without representing the agent's internal state.

The reaction associated with anger depends on both the intensity level and the presence of other people. For example, if anger is high, a reaction may be directed at other people in the environment. According to the level of anger, the agent can become aggressive; we might even say that he crossed the border of anger to *RAGE*. With this high level of anger the agent will tend to fight any person who is near him. On the other hand, if the anger is not high then most people will tend to suppress anger in the presence of other people.

3.2 Pain

Pain, unlike anger, is triggered mostly from external stimulus, although we sometimes feel hurt because our demands or expectations are not met. However, in our model, pain is considered from the external state only and is modeled through physical damage. Pain that is discussed here is mostly a feeling not an emotion. Some philosophers may refer to this type of pain as a motivational state, since it does affect some other emotions as we shall see later. According to the level of tissue or physical damage, a level of pain is assigned. If the level of pain is greater than the level of fear or anger, then pain will inhibit both [4].

Pain reactions are not very interesting as Fanslow pointed out [4]. However, we describe them in terms of company. If many people are around and the pain is very high (i.e. serious) then the agent will tend to ask for help. This action also depends on whether the other agents are near or far from him. If the pain is high and the people are far away, then the agent might think he will endanger himself more if he travels to the other agents to ask for help, so he will tend to his own wound.

3.3 Fear

Fear, like pain, is mostly concerned with the external state of the agent. Several inputs can trigger fear; our model uses the following: level of darkness, level of sound, and being alone or with others. The rationale is provided by Izard[12], who suggests that we have an innate fear of darkness, being alone, and loud noises. Of course, a person can overcome these fears, but our model does not include a learning component. Rather, our model reacts as a child, experiencing innate emotions. We produce fear according to the levels of the three factors above, and the combination reinforces the fear further.

Fear inhibits pain and anger if they are experienced with the same intensity level. An example of pain inhibition is evident in war. A soldier wounded in an intense battle may continue to fight, even if the same wound experienced without fear would incapacitate him. A hormone called endorphins is responsible for this action. It is secreted into the system when the person feels an intense fear and thus inhibits pain [4].

The idea of one emotion inhibiting the other is based on goal priority. If a given condition threatens a high priority goal, then the agent will act on the emotion triggered by this threat. We assume that survival is one of the highest priority goals. If a person's survival is threatened, then he will normally have a high level of fear; pain will be inhibited unless it is higher than fear. In this case, priority will be given to the pain, because this means the agent must stop the pain or tend to the wound in order to survive.

The behavior of the agent will depend on whether the external state is blocked or unblocked. According to the level of fear, the agent will either freeze, walk or run. If the fear is very high and the environment is blocked, the level of anger will be raised and the agent will not move (i.e., the agent will freeze). The time period used for freezing depends on the universe of discourse for the membership function.

4 Prototype Robot

As a first step towards investigating the applicability in decision-making of mobile robots, a prototype robot was built using our model of the emotional agent. Sensors are used to take information from the environment concerning the brightness, sound and physical damage.

The agent then shapes his internal state with values for the internal structures like expectation.

As discussed previously, pain has more than one meaning. In our model, we assumed that pain is the amount of physical pain; it does not include the hurt feeling which is another form of pain. In this sense, pain is associated with physical damage. If physical damage is high then pain is high.

Anger is stimulated by two factors: one is expectation and the other is the *desirability* of a stimulus. Fuzzy mapping rules are used to determine the degree of anger. We divide anger into ten degrees, and use four fuzzy sets to describe it: NoAnger, Low, Medium and High. Expectation and the desirability of the stimulus are also mapped into membership functions.

Fear is triggered by four inputs: sound, brightness, anxiety and the *alone* external state. We use trapezoidal and triangular membership functions to make the inference efficient.

The emotional system for the robot is divided into two major fuzzy models. The first handles the invocation of the emotions in their different intensities (i.e. low, medium or high). Within this model there are three other models—one for handling each emotion (anger, pain and fear). The second fuzzy model handles the behavior associated with each emotion. The behavior of the robot depends on three major factors: (1) emotion, (2) emotion intensity, and (3) the environment around the robot. The system currently uses 63 rules total. Twenty-one are used for the invocation of the emotional intensity based on internal and external conditions. Forty-two rules are used to determine the behavior of the robot according to the emotional intensity and his model of the world.

The emotional rules were very simple and were mostly formed from the descriptions in [12,4]. However, since emotions overlap, it is possible to end up with the three emotions (anger, pain and fear) at the same or different levels. The agent acts on the emotion with the highest intensity. If they are all on the same level, then the priority goes first to fear, then anger, and finally pain.

The behavioral rules are not as simple, because they involve more control from the robot. Thus we have rules like,

IF ANGER = LOW AND COMPANY=TRUE THEN ACTION=SUPRESS

That is, if anger is at a high level and there are people present, then anger will be suppressed. However, a mixture of anger and fear will move the agent to an aggressive state:

IF ANGER=HIGH AND FEAR=HIGH AND COMPANY=TRUE THEN ACTION=FIGHT

Thus, the number of rules can escalate dramatically, just because the environment is taken into consideration.

This distinguishes our model from previous models which are simple reflex agents. The robot actually has a choice between a set of different actions. Behavior is more complex than a simple reflex action according to the emotions' intensity. Although we embedded actions in the rules, this is only an example of some of the possible situations. We cannot enumerate all of the possible situations and actions, but we can build a model with a sufficient number of actions and situations that would make our agent act realistically.

As was discussed earlier, the agent will react according to a degree of an emotion that was chosen by the priority system. Actions are mapped according to the emotion and the intensity level. For example, when angry the robot will go in circles producing some noise. The pitch of the noise produced and the speed by which the robot moves will be a function of the intensity of the generated emotion. When afraid, the robot will shake, producing a shattering voice. The time that the robot will take to shake will be determined by the intensity of the fear. When in pain, it will cry while moving in a kind of jerky motion. As in anger, the intensity of pain will determine the speed and the pitch of the sound produced.

5 Conclusion

Researchers have been exploring ways to model human perception, intelligence and thinking. Until recently, emotions were considered to be obstacles to the human thinking process. However, Demasio showed that emotions can act as a reinforcer that guides us to the right action. His work provides our motivation for including an emotional agent as part of the decision-making process of a mobile robot.

In this paper, we presented a new framework for modeling emotions. We extended the framework of the Intelligent Agent to include internal representation of expectations and emotions, and we used fuzzy logic to capture the inherent complexity and uncertainty of the human emotional system. We then applied our new framework to the modeling of three innate emotions, fear, anger, and pain, and showed how it can be used to determine the resulting behavior. Finally, we created a prototype implementation on a mobile robot which used sensory inputs to determine an appropriate emotional response. Our experience has shown that fuzzy logic provides a useful strategy for modeling the inherently complex human emotional system.

The system discussed here is a simple prototype of an emotional system incorporating only innate negative emotions. It is merely a step towards building an *emotional agent*. One obvious direction for future work is to incorporate learning. Experience can change the way we perceive the environment. Also, experience can change our expectations, thereby triggering different emotions and changing the resulting behavior. If we can learn from a specific instance, then when a similar situation is encountered, we can act in a refined manner. In addition, we are currently working on incorporating more emotions than the basic three that have been discussed here. We hope to show that fuzzy logic will be appropriate for modeling other emotions as well.

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References

[1] J. Bates. The Role of Emotion in Believable Agents, *Communications of the ACM*, vol. 37, no.7, pp. 122-125, 1992.

[2] J. Bates, A. Bryan Loyall and W. Scott Reilly. *An Architecture for Action, Emotion, and Social Behavior*, Technical Report CMU-CS-92-144, School of Computer Science, Carnegie Mellon University, Pittsburgh, PA, May 1992.

[3] J. Bates, A. Bryan Loyall and W. Scott Reilly. *Integrating Reactivity, Goals and Emotion in a Broad Agent*, Technical Report CMU-CS-92-142, School of Computer Science, Carnegie Mellon University, Pittsburgh, PA, May 1992.

[4] R. C. Bolles and Fanselow M. S. A perceptual defensive recuperative model of fear and pain, *Behavioral and Brain Sciences*, vol. 3, pp.291-301, 1980.

[5] Antonio R. Damasio. *Descartes' error: emotion, reason, and the human brain,* New York: G.P. Putnam, 1994.

[6] Michael Dyre. Emotions and their computations: three computer models, *Cognition and Emotion*, vol.1, no.3, pp.323-347, 1987.

[7] N. Frijda. *The Emotions,* Cambridge University Press: Cambridge, 1986.

[8] N. Frijda and J. Swagerman. Can Computers Feel? Theory and Design of an emotional System, *Cognition and Emotion,* vol. 1, pp. 235-57, 1987.

[9] Daniel Goleman. *Emotional Intelligence,* Bantam Books: New York, 1995.

[10] Tim La Haye and Bob Philips. *Anger is a choice,* USA: Zondervan Publishing House, 1982.

[11] K. Inoue, K. Kawabata and H. Kobayashi. On a decision making system with emotion, *IEEE Int. Workshop on Robot and Human Communication*, pp. 461-465, 1996.

[12] Carroll E. Izard. *Human Emotions,* Plenum Press: New York & London, 1977.

[13] Joseph LeDoux. *The Emotional Brain,* Simon & Schuster:USA,1996.

[14] P. Maes. Artificial Life meets Entertainment: Lifelike Autonomous Agents, *Communications of the ACM. Special Issue on Novel Applications of AI*, 1995.

[15] E. Masuyama. A Number of Fundamental Emotions and Their Definitions, *IEEE International Workshop on Robot and Human Communication,* pp. 156-161, 1994.

[16] Michael Mauldin. ChaterBots, TinyMuds, and the Turing Test Entering The Loebner Prize Competition, *Proceedings of the AAAI Conference,* 1994.

[17] M. Minsky. *The Society of the Mind,* Simon and Schuster:New York, 1986.

[18] A. Ortony, G. Clore and A. Collins. *The Cognitive Structure of Emotions,* Cambridge University Press: Cambridge, 1988.

[19] R. Pfeifer. Artificial Intelligence Models of Emotions, *Cognitive Perspectives on Emotion and Motivation*, pp. 287-320, 1988.

[20] Donald D. Price, James E. Barrell, and James J. Barrell. A Quantitative-Experiential Analysis of Human Emotions, *Motivation and Emotion*, vol.9, no.1, 1985.

[21] W. Reilly and Joseph Bates. *Building Emotional Agents*, Technical Report CMU-CS-92-143, Carnegie Mellon University, Pittsburgh, PA, 1992.

[22] Stuart Russel and Peter Norvig. *Artificial Intelligence A modern Approach*, USA: Prentice-Hall Inc., 1995.

[23] K. R. Scherer. Studying the emotion antecedent appraisal process: An expert system approach, *Cognition and Emotion*, vol. 7, pp. 325-55, 1993.

[24] R. Schumacher and M. Velden. Anxiety, pain experience and pain report: A signal-detection study, *Perceptual and motor skills*, vol. 58, pp. 339-349, 1984.

[25] T. Shiida. An attempt to model emotions on a machine, *Emotion and behavior: A system approach*, vol. 2, pp. 275-287, 1989.

[26] R. L. Solomon and J. D. Corbit. An opponent-process theory of motivation: I. Temporal dynamics of affect, *Psychological Review*, vol. 81, pp. 119-145, 1974.

[27] Shigeki Sugano and Tesuya Ogata. Emergence of mind in robots for Human Interface - research methodology and robot model, *Proc. IEEE International Conference on Robotics and Automation*, April 1996.

[28] Stephen Tayrer (ed). *Psychology, Psychiatry and Chronic Pain*, Britain: Butterworth Heinemann, 1992.

[29] J. Velasquez. Modeling Emotions and Other Motivations in Synthetic Agents, *Proceedings of the AAAI Conference 1997*, pp. 10-15, 1997.