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Author
Ganjoo, Afshin

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Designing Emotion-Capable Robots, One Emotion at a Time

Afshin Ganjoo (afshin.ganjoo@intel.com)
Intel Corporation, 1900 Prairie City Road
Folsom, CA 95630, USA

Abstract

Recent advances in emotion modeling and continuous progress in robot design pose an intriguing question: can emotion-capable robots be constructed? This paper aims to compose an emotion model as a first step in this endeavor. Concrete concepts from existing advanced emotion models have been built upon to develop a new comprehensive computational model of emotions. This model bridges the gap between physical sensations and emotions to allow robots to develop a dynamic emotion system. It organizes emotions not just as opposites, but also as reverses of each other, critical for managing resources. The model further categorizes complex emotions based on evolutionary pressures into energy-based, object-based, social-based, and confrontation-based emotions. Categorization of emotions gives an additional flexibility in designing robots.

Keywords: Emotion Model; Emotion-Capable Robots

Introduction

Long gone are the days when emotions were considered illogical. Today, engineers design and develop emotion-capable systems with new found fervor (Arbib & Fellous, 2004; Breazeal, 2003). Computer games, software agents, pet toys, and simple robots now exhibit emotions. But there is a big difference between exhibiting emotions and feeling them. This gap is no where more apparent than in robots.

A robot which exhibits human emotions, yet understands nothing else about the human experience, does not convince even the most wishful of observers. Much like a bad actor, the observer is left to wonder if there is anything real about the emotion exhibited by the robot. The problem is not that robots can't be designed to feel emotions; the problem is that we don't have a model that allows for emotions to be felt. This paper hopes to bridge that gap.

Why Emotion-Capable Robots

The fact that millions of years of evolution have produced life forms with complex emotion systems should be enough to convince anyone that such systems provide irreplaceable benefits to the survival of these life forms. In fact, increase in the cognitive powers of the higher order life forms has not diluted their emotional complexity. We are the perfect example of this phenomenon.

Behavioral responses to environmental stimuli can be categorized as reflexive, emotional or cognitive. Reflexive responses do not require much analysis or brain power, but are made quickly. Cognitive responses require the most amount of brain power, but are made relatively slowly. Emotional responses fall somewhere between these two in response time and the required brain power. But what makes them stand out is their ability to manipulate the physiological and mental state of the life form to increase its chances of survival. And that is what differentiates emotional processing from reflexive and cognitive processing – that it is purely designed to increase the entity's chances of survival.

An emotion system will be activated when a stimulus negatively or positively affects the survival of the entity. Currently, robots do not enjoy the independence that other life forms enjoy. But the time will come when robots will need to be free from human control. At such a time, it will be crucial that they make decisions to increase their chances of survival. Those decisions can not be made for them in advance, as their environment can not be easily predicted nor can all robots respond the same way. We must do for robots what nature has done for us, and that is to equip them with an adaptable system for survival. An emotion system is just such a system.

The Model

Tremendous amount of analysis has gone into developing sophisticated models of emotions. Every aspect of emotions have been used to uncover clues to the structure of emotions, including functional, behavioral, cognitive, physiological, neural, facial expressive, linguistic, and evolutionary aspects of emotions. The model presented here takes some of the most concrete concepts from these models and adds new concepts to lay the foundations for creating emotion-capable robots.

Pain and Pleasure, and the Basic Emotions

A well discussed concept in advanced emotion models is the concept of basic emotions. Plutchik (1980), based on evolutionary concepts, identified eight basic emotions and neatly paired them as four opposites. Ekman (1992) identified five basic emotions based on universal signals. Johnson-Laird and Oatley (1992) developed their basic emotions on the analysis of the ontology of simple social mammals. Other methods used to identify basic emotions include density of neural firing (Tomkins, 1984), forms of action readiness (Frijda, 1987), and hardwired response (Panksepp, 1982; Gray, 1982). But perhaps the most basic of basic emotions were offered by Mowrer (1960) and Weiner and Graham (1984). Mowrer identified pleasure and pain as basic emotions due to their unlearned nature. Weiner and Graham identify joy and sorrow as the basic emotions since they are attribution independent. And here lies the connection be-

tween feelings and emotions. In the model presented here, pain and pleasure are identified as feelings, for the same reason Mowrer identified them as basic emotions. These two feelings are directly tied to what this model considers basic emotions, sorrow and joy.

Pain and pleasure are considered to be our most basic guides to avoiding and seeking things for our survival. For that purpose, there is no learning involved. Pleasure guides us to seek things that improve our survival chances, from consuming food to reproduction. Pain, on the other hand, focuses our attention to events that are decreasing our chances of survival.

Pain and pleasure are directly responsible for instigating emotions. The most immediate emotions instigated by pain and pleasure are sorrow and joy respectively. Sorrow is the recognition that an event has occurred that has or will cause pain. Joy is the recognition that an event has occurred that has or will lead to pleasure. Winning and losing money is always a good example here since the value of money has to be learned. Winning the lottery may not be physically pleasurable, but it is joyful. That recognition is important since the brain has learned that possessing money will bring pleasure later on. Equally, losing money at the gambling table may not be physically painful, but it is saddening as the brain has learned that it will require much resources and hard work to replace the lost money. A simpler way of looking at it: joy is the felt when an event occurs that will bring us pleasure and sorrow is felt when an event occurs that will give us pain. The difference is that pleasure and pain are hardwired sensations with no room for cognitively manipulation, while joy and sorrow require learning and can be cognitively manipulated.

Sorrow and joy provide a layer of sophistication to the feelings of pain and pleasure. They allow the entity to associate events that may not immediately cause pain or pleasure, with those feelings. Considering the systematic evolution of the brain (MacLean, 1967) and the different pathways information can take through the brain to generate emotions (LeDoux, 1989), it is easy to see how and why sorrow and joy would evolve from pain and pleasure.

To define pain and pleasure for a robot, it must be equipped with the ability to recognize its state of survival. Recognition of depredation of equipment can be defined as pain, requiring the robot to focus attention on eliminating the source of pain. Replenishment of resources can be defined as pleasure, guiding the robot to seek replenishment of its resources.

The robot must be given the ability to recognize and associate events that indirectly or eventually lead to pain or pleasure. This learning is critical in creating a dynamic emotion-capable system. The occurrence of these events will trigger the emotions of sorrow and joy.

Appraisal

Among the fundamental concepts shaping most advanced models of emotions is the notion of appraisal (Arnold, 1960). Events are appraised, negatively or positively, based on their value to the survival of the entity. Relevance to preferences, goals, motives, coping potential, and immorality, are among the many factors that can contribute to this calculation (Scherer, 1997; Lazarus, 1991). The appraising of events will determine whether one likes something to happen or not. It also explains why the same event can generate different emotions in different people, or even different emotions in the same person at different times. The value of appraisal describes the intensity of the emotion (Sonnemans & Frijda, 1995), allowing different names to be given to different intensities of the same emotion. Appraisal can be unconscious, due to repeated exposure to the same event, or conscious, deliberately done to assess a situation (Lazarus, 1991). It can take place before or after the eliciting emotion (Frijda, 1993). The appraisal before the emotion, causes the emotion, and the appraisal after the emotion, helps in measuring the effectiveness of the emotion and modifying it, if need be.

Here too, appraisal plays a central role. Its value, whether negative or positive, is used in conjunction with other factors to define emotions. The value of appraisal assists in defining the intensity of the emotion felt. It is also used to give different names to the same emotion, distinguishing for example, annoyance, anger, and rage. Reevaluation of an event, leading to a new appraisal value, is identified as one of the processes that would trigger a reverse emotion. But perhaps the most important claim made in this model in regard to appraisal is that it assigns a survival value to events based on the amount of pain or pleasure they are expected to cause. As explained previously, that measure exactly describes the amount of sorrow or joy the event will generate.

The robot must be able to feel different intensities of pain and pleasure, based on how its survival is influenced. Using this measurement, the robot will be able to appraise events accurately. Complex appraisal factors, such as immorality and motives, are built over many years of analysis of what causes pain and pleasure. That is why it takes years for children to develop a sense of what is right and what is wrong. A robot can and must go through the same process to develop these values. And it need not come to the same conclusions we have come to.

Anticipation and Surprise: The Learning Emotions

The ability to anticipate events plays a critical role in this model. Anticipation and surprise have been identified as emotions in some models (Plutchik, 1980) while rejected in others (Ortony, Clore, & Collins, 1988). Although anticipation and surprise have all the characteristics of emotions, namely physiological modifications, behavioral reactions, and cognitive focus, here they are not considered emotions but are considered to be responsible in giving intensity to emotions. The higher the anticipation of an emotion inducing event, the more intense the emotion experienced. Equally, the higher the surprise from the occurrence of an emotion inducing event, the more intense the emotion experienced. The emotion experienced depends on other fac-

tors present. While some consider anticipation as one of the many factors in the appraisal of events (Ortony et al., 1988), here it is considered an evolutionary leap, far removed from other learned factors in the appraisal process and necessary for generating more complex emotions.

Emotions are separated into two groups: those due to the appraisal of an occurred event and those due to the appraisal of an anticipated event. Joy and sorrow occur due to the appraisal of an occurred event. Other more complex emotions are due to the anticipation of events that, if and when they occur, they would bring joy or sorrow.

The robot needs to continuously monitor the environment and predict occurrences of events as they relate to its survival. If it predicts an event that would affect its survival, it will trigger complex emotions. If the outcome is not what it expected based on previous learning, surprise is triggered which would adjust its knowledge base and the emotion triggered by the incorrect prediction.

Opposite and Reverse Emotions

Emotions have been characterized as opposites of each other for some time now - anger opposite of fear, pride opposite of shame, and love opposite of hate. But there has never been an organized way of describing emotions as reverses of each other – relief reverse of fear, disgust reverse of love, and remorse reverse of pride.

Opposite emotions are activated by opposite stimuli. Fear, for example, occurs when a more powerful opponent attacks. Anger occurs when a less powerful opponent attacks. These two are opposite stimuli as the opponent can not be judged both more powerful and less powerful at the time of the attack.

Reverse emotions are activated by reverse stimuli. To follow the example given above, relief occurs when the more powerful opponent stops the attack. The attack by the more powerful opponent and the stopping of the attack are reverse stimuli. The latter is simply the removal of the former. This makes relief the reverse of fear, and visa versa.

Considering the massive effects emotions have on the physiology and the cognition, it only makes sense that any emotion be coupled with a reverse emotion to counteract its effects in case the environmental conditions changed and the emotion eliciting stimuli are removed. An opposite emotion could reverse the physiological and cognitive effects of an emotion, but it would require opposite stimuli to be triggered. A reverse emotion, on the other hand, simply requires the elimination of the original stimulus.

Clearly there is a functional purpose and a cognitive basis for the existence of reverse emotions. But if emotions were ever to evolve as reverses of each other, hormonal effects of emotions would be the best indicators of such an evolution. This is because, of all the characteristics of emotions, hormonal changes are by far the slowest responses of emotions. If the environmental conditions reversed, a reverse emotion would need to counteract the hormones already released as soon as possible to maximize the utilization of available resources.

Henry (1986) describes five basic emotions due to hormonal activities. He claims these to be anger, fear, depression, elation, and serenity. Fear and anger require the body to prepare for confrontation while serenity prepares the body for recuperation. Elation prepares the body for activity and expenditure of energy, while depression prepares the body for inactivity and conservation of energy. The functional description of serenity suggests that it is the reverse of anger and fear. That is because the removal of stimuli that caused anger or fear will lead to serenity. The functional description of elation and depression on the other hand, seems to suggest that they are opposites of each other. They are not necessarily reverses of each other, since the removal of the stimuli that caused one of the two emotions will not necessarily activate the other. The hormonal description of these emotions confirms these finding, but further finds that elation and depression also act as reverses of each other.

Catecholamine hormones (epinephrine and norephinephrine) are released when in fear or anger. These hormones help in maintaining the ability of neurons to fire, in effect, prolonging the autonomic nervous system's (ANS) arousal. Epinephrine also causes the release of glycogen in the liver which produces energy. Serenity on the other hand, reduces the release of catecholamine and hence reversing the hormonal effects of fear and anger. Serenity is acting as a reverse emotion.

Depression causes hypothalamus to release corticotrophin-releasing hormones, which influence the pituitary gland to release adrenocorticotropin. In turn, adrenocorticotropin activates the outer adrenal gland which releases glucocorticoid hormones including cortisone, corticosterone, and hydrocorticosone. Elation, on the other hand, inhibits the release of adrenocorticotropin, glucocorticoids, and endorphin, acting as the reverse of depression. Elation, for its part, releases testosterone perhaps because the entity can afford to expend energy. Depression represses the release of testosterone, and therefore acts as a reverse of elation.

Behavioral responses can also point to the existence of reverse emotions. Rolls (1998) alludes to this notion of reverse emotions through the analysis of reinforcing stimuli. He postulates, for example, that the presentation and termination of negative reinforcer produce the emotions of fear and relief respectively.

The robot, once in an emotional state, needs to constantly reevaluate the emotion eliciting event to determine if it is still justified to be in that emotional state. An emotional response utilizes resources and therefore can tax the robot. If the emotion is no longer justified, a reverse emotion needs to be triggered to release the resources.

Categorization of Emotions

A newer concept utilized in emotion models is the categorization of emotions based on the varying mechanism which instigate them. This categorization uncovers the relationship between emotions. Roseman, Antoniou, and Jose (1996) categorize emotions based on whether they were caused by circumstance, by self, or by other. Ortony, et al. (1988)

categorizes emotions based on whether they involve objects, caused by actions of agent, or are simply consequences of the situation. In the model presented here, four major survival mechanisms that control human behavior are used to categorize emotions. The desires to replenish energy, possess objects, live successfully in social groups, and protect the survival of self, are the four environmental pressures that seem to have influenced the development of emotions.
This categorization works well for designing robots. Robots that are not going to be used in social settings need not be equipped with the social-based emotions. Robots that should not take confrontational stances need not be equipped with confrontation-based emotions. It is also easy to see that robots may be put in situations were none of these categories assist the robot in surviving. Adding another category that does not exist in nature is made easy with this model.
It must be noted here that the names assigned to complex emotions below, represent a group of emotions. The members of each group differ only in intensity. For example, anger, rage, and annoyance, are all represented by anger. Rage is a more intense version of anger and annoyance is a less intense version of anger. It should also be noted that the names given to these emotions is not as important as how they are triggered and what function they serve.

Energy-Based Emotions The function of energy-based emotions is simple; expend energy when necessary to gain needed resources, and reserve energy when needed resources were out of reach. Consumption of food, absorption of heat to help in digestion of food, and other specie specific events related to replenishing needed resources trigger energy-based emotions. Energy-based emotions include the opposite emotions of excitement and depression, and their respective reverses, disappointment and rejuvenation (Table 1).

Table 1: Energy-Based Emotions.

	Anticipating a Positively Appraised Event	Anticipating a Negatively Appraised Event
Increase	Excitement	Depression
Decrease	Disappointment	Rejuvenation

Excitement is defined as the anticipation of a positively appraised energy-based event. In other words, excitement is the anticipation of joy in the context of energy. Excitement prepares the body for action and expenditure of energy in the hope of replenishing needed resources. These resources in turn allow the body to produce more energy and other byproducts it needs to continue functioning.
Disappointment is defined as the reduction in anticipation and/or positive appraisal of an anticipated, positively appraised, energy-based event. In other words, disappointment is the reverse of excitement. It occurs when the entity realizes that either the anticipated energy-based joyful event is not as likely to occur as previously calculated, or the event is not going to be as joyful as previously thought. Either way, the entity needs to reverse the physiological, behavioral, and cognitive movements which occurred as a result of the emotion of excitement. Basically, the event was not worth the level of excitement, and hence the level of energy expenditure, it originally initiated. Disappointment adjusts that to its proper level.
Depression is defined as anticipating a negatively appraised energy-based event, in other words, anticipating sorrow in the context of energy. Depression is the opposite of excitement because an event can not be appraised both positively and negatively in the context of energy. Depression prepares the body for inactivity and conservation of energy. Events that cause depression include the coming of winter which alludes to the reduction in energy sources and sustaining an injury which requires conserving energy, by shutting down non-essential activities, to heal.
Rejuvenation is defined as the reduction in anticipation and/or negative appraisal of an anticipated, negatively appraised, energy-based event. In other words, rejuvenation is the reverse of depression. It occurs when the entity realizes that either the anticipated energy-based sad event is not as likely to occur as previously calculated, or the event is not going to be as saddening as previously thought. Either way, the entity needs to reverse the physiological, behavioral, and cognitive movements which occurred as the result of experiencing depression. The event, simply put, did not justify the level of depression, and hence energy conservation, it caused. Rejuvenation adjusts that to its proper level.

Object-Based Emotions Possessing objects have proven to be an evolutionary successful exercise. Land for grazing, fruit trees for picking, supplies of water for drinking, and caves for hiding, are among few objects creatures have sought to possess. Strong houses, better farmland, fancy cars, nice clothes, and expensive jewelry, are among objects we seek to possess, as they are believed to increase our chances of survival. Object-based emotions include the opposite emotions of love and hate, and their respective reverses, disgust and acceptance (Table 2).

Table 2: Object-Based Emotions.

	Anticipating a Positively Appraised Event	Anticipating a Negatively Appraised Event
Increase	Love	Hate
Decrease	Disgust	Acceptance

Love is defined as the anticipation of a positively appraised object-based event. Love encourages the entity to possess the loved object in anticipation that such a possession will bring it joy at some point in the future. Like is the less intense version of love.
Disgust is defined as the reduction in anticipation and/or positive appraisal of an anticipated, positively appraised, object-based event, and hence, it is the reverse of love. The

entity, either miscalculated the appraised value of possessing the object, or the conditions have changed since the last calculation was made. It needs to reduce the amount of effort it expends on maintaining the possession of the object. Boredom is the less intense version of disgust.
Hate is defined as the anticipation of a negatively appraised object-based event. In other words, hate is the anticipation of sorrow in the context of possessing objects. Hate encourages the entity to expend energy in trying to dispossess the object in anticipation that continued possession will bring it sorrow at some point in the future. Dislike is the less intense version of hate.
Acceptance is defined as the reduction in anticipation and/or negative appraisal of an anticipated, negatively appraised, object-based event, and therefore, it is the reverse of hate. The entity reduces the effort expended in trying to dispossess the object as it realizes that either it miscalculated the appraised value, or the conditions have changed since its last calculation.

Social-Based Emotions Environmental pressures have forces many species to join in groups to increase their survival chances. It is only natural to expect that social-based emotions would evolve in these species. The wolf pack has a strict hierarchy of dominance where the higher members eat and mate first. If resources are scarce, the lower ranking members are deprived of food and eventually ejected from the group. Higher ranks will get the best of everything, from mating rights to grooming rights, all of which will increase their chances of passing on their genes to the next generation. Social-based emotions include the opposite emotions of pride and shame, and their respective reverses, remorse and vindication (Table 3).

Table 3: Social-Based Emotions.

	Anticipating a Positively Appraised Event	Anticipating a Negatively Appraised Event
Increase	Pride	Shame
Decrease	Remorse	Vindication

Pride is defined as the anticipation of a positively appraised social-based event. In other words, pride is the anticipation of joy in the context of social standing. Pride encourages the entity to exhibit its achievements and associations in the anticipation that such an exhibition will bring it joy at some point in the future.
Remorse is defined as the reduction in anticipation and/or positive appraisal of an anticipated, positively appraised, social-based event. In other words, it is the reverse of pride. The entity realizes that the event was not worth the level of pride, and hence the level of energy expenditure it was devoting to exhibit its achievements and associations. Remorse adjusts that to its proper level.
Shame is defined as the anticipation of a negatively appraised social-based event. In other words, shame is the anticipation of sorrow in the context of social standing. Shame encourages the entity to hide its achievements and social associations in the anticipation that such an exhibition will bring it sorrow at some point in the future.
Vindication is defined as the reduction in anticipation and/or negative appraisal of an anticipated, negatively appraised, social-based event, and based on that, it is the reverse of shame. The event, simply put, did not justify the level of shame, and hence hiding the achievements and associations, it caused. Vindication reduces the effort afforded in that regard.

Confrontation-Based Emotions Confrontation over food, objects and social standing are inevitable. Confrontation-based emotions evolved to help species survive such encounters. Confrontation-based emotions include the opposite emotions of anger and fear, and their respective reverses, relaxation and relief (Table 4).

Table 4: Confrontation-Based Emotions.

	Anticipating a Positively Appraised Event	Anticipating a Negatively Appraised Event
Increase	Anger	Fear
Decrease	Relaxation	Relief

Anger is defined as the anticipation of a positively appraised confrontation-based event. In other words, anger is the anticipation of joy due to a confrontation. Anger encourages the entity to fight in the anticipation that such a battle will bring it joy at some point in the future. The benefit can be keeping or gaining control over a needed resource, such as food or territory. It could also be in regard to possessing or maintaining possession of a valued object or in relation to maintaining or increasing social standings. Commonly however, anger results from simply defending against an unprovoked attack by a weaker attacker.
Relaxation is defined as the reduction in anticipation and/or positive appraisal of an anticipated, positively appraised, confrontation-based event, and hence, it is the reverse of anger. When the entity realizes that it has miscalculated the level of anger, relaxation will set in and reverses the effects of anger. Relaxation reduces the energy expenditure in response to confrontation.
Fear is defined as the anticipation of a negatively appraised confrontation-based event. In other words, fear is the anticipation of sorrow due to a confrontation. Fear encourages the entity to avoid confrontation in anticipation that such a confrontation will bring it sorrow at some point in the future.
Relief is defined as the reduction in anticipation and/or negative appraisal of an anticipated, negatively appraised, confrontation-based event, and therefore, it is the reverse of fear. The reduction in appraisal of the fear inducing event will trigger the emotion of relief. As a result, resources allocated to respond to the fear inducing event are released.

Conclusion

Designing emotion-capable robots presents challenges that designing emotion-capable software agents does not. The most considerable challenge is their physical connection with the real world. The emotion model presented here connects the physical sensations with emotional feelings specifically to address this need. The adaptability resulting from implementing this model allows robots to adjust their responses to survive their unpredictable environments.

Several significant elements distinguish this model from other existing models. The first distinguishing element is the pairing of emotions as reverses of each other. Other models, in the absence of reverse emotions, assume once the emotion instigating stimulus has been removed, the entity simply stops feeling the instigated emotion. It has been argued here that reverse emotions are triggered in such scenarios and that they are responsible for diluting or completely reversing the initial emotion triggered.

The second distinguishing element is the categorization of emotions based on evolutionary adaptations. Each of the four categories mentioned here include two opposite emotions and their respective reverse emotions. Each emotion within a category has equivalent emotions in other categories, all of which are defined similarly, differing only in the evolutionary adaptation that made them necessary.

The third distinguishing element of this model is the evolutionary path it suggests. All complex emotions are connected to the two basic emotions of joy and sorrow, which are in turn connected to the physical sensations of pleasure and pain. Such a path not only makes evolutionary sense; it also makes designing emotion-capable robots much easier.

To design emotion-capable robots using this model, the engineer needs to define pain and pleasure for the robot. Pain, as with any other entity, is defined as events that do physical damage to the robot. Engine overheat, electrical shock, and radiation exposure are examples of events that could be defined as pain causing events. Pleasure is defined as events that satisfy physical needs. Any type of resource replenishment, such as battery recharge and engine oil change, can be defined as pleasure causing events. From this basis, the robot can build a network of events that eventually lead to pain and pleasure. Those events trigger sorrow and joy. From anticipating sorrow and joy, the more complex emotions result, as described above.

This model, once utilized, will allow robots to build their emotion system based on their physical design, needs, and function. They will be able to adapt to their environment, in much the same way as we do. And most significantly, when they experience emotions, it will be as real as our own emotional experiences are.

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