Newtonian Emotion System

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Abstract. The main goal of our work is to provide virtual characters with the ability of emotion expression. Our approach is based on the idea that emotions serve a fundamental function in human behavior, and that in order to provide artificial agents with rich believable affective behavior, we need to develop an artificial system that serves the same purpose. We believe that emotions act as a subsystem that enhances human behavior, by stepping up brain activity in arousing circumstances, directing attention and behavior, establishing importance of events and act as motivation. This paper summarizes the psychological theories that our computational emotion model is based on, defines the key concepts of the Newtonian emotion model that we developed and describes how they work within an agent architecture. The Newtonian emotion model is a light-weight and scalable emotion representation and evaluation model to be used by virtual agents. We also designed a plug-and-play emotion subsystem to be integrated into any agent architecture.

1 Introduction

Emotions are a part of the human evolutionary legacy [2], serving adaptive ends, acting as a heuristic in time-critical decision-processes (such as fight-or-flight situations); however, emotions have also become an important part of the multi-modal process that is human communication, to the point that its absence is noted and bothersome.

Affective computing is the study and development of systems that can recognize, interpret, process and simulate human affects, in order to add this extra dimension into our interaction with machines. Our goal is to create believable intelligent artificial characters capable of displaying affective behavior. To achieve this, we attempt to provide artificial characters with an emotional layer similar to that of humans,

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serving adaptive ends. The emotion subsystem will influence agent behavior by establishing the importance of events and by influencing knowledge processing, as well as provide the agent with an emotional state that it will be able to express and that will further influence its behavior. We first describe our Newtonian emotion system, that explains the way we represent emotions and how external and internal forces act upon them, based on the work of psychologist R.E. Plutchik [5] and Newton's laws of motion. Based on the psychological theory of dr. R. Lazarus [4], we devised an emotional subsystem that interacts with and influences an agent architecture. The system also takes into account the effects that emotions on human perception and cognitive processes.

As an application domain, we chose virtual characters in computer role playing games (CRPGs) as they are a type of game meant to simulate all manner of human interactions (be they gentle or violent in nature). This type of game provides us with complex dynamic environments in which modern agents are expected to operate. It also focuses on individual characters and the way they respond to relevent changes in their environment (behavior). Last, but not least, the limited action set available to characters and current generation game engines significantly reduce the overhead of proof-of-concept apps.

Applications of the technology are not limited simply to CRPGs, as several types of endeavours find it useful, such as behavior simulation, interactive storytelling, and, indeed, any application involving human-computer interaction (for example, online social sites could recommend events and friends based on mood).

2 Psychological Basis

In order to endow virtual characters with an emotion system that provides agents with believable emotional reactions and influences their cognitive processes (perception, decision making) in the same way that emotions influence behavior in humans, we need a grasp of human cognitive emotion theory. In this chapter we summarize the psychological theories upon which we built our emotion simulation model.

Plutchik

One of the most influential classification approaches for general emotional responses was developed by Robert Plutchik in the 1980s. Plutchik developed a theory showing eight primary human emotions: joy, trust, fear, surprise, sadness, disgust, anger, and, interest, and argued that all human emotions can be derived from these [5]. Plutchik also stated that emotions serve an adaptive role in helping organisms deal with key survival issues posed by the environment, and that the eight basic emotions evolved in order to increase the reproductive fitness of the individual, each triggering a behavior or type of behavior with a high survival value (such as fear and anger triggering fight or flight behaviors). These eight basic emotions were grouped into four pairs of polar opposites with varying degrees of intensity (displayed as the wheel of emotions in Fig. 1), making it easy to represent emotional state in a four dimensional vectorial space.

Lazarus

In the 1960s, Singer-Schachter conducted a study showing that subjects can have different emotional reactions despite being in the same physiological state. During the study, experiments were performed where the subjects were placed in the same physiological state with an injection of adrenaline and observed to express either anger or amusement depending on whether a planted peer exhibited the same emotion. The study validated their hypothesis (known as the Singer-Schachter theory) that cognitive processes, not just physiological reactions, play an important role in determining emotions [6].

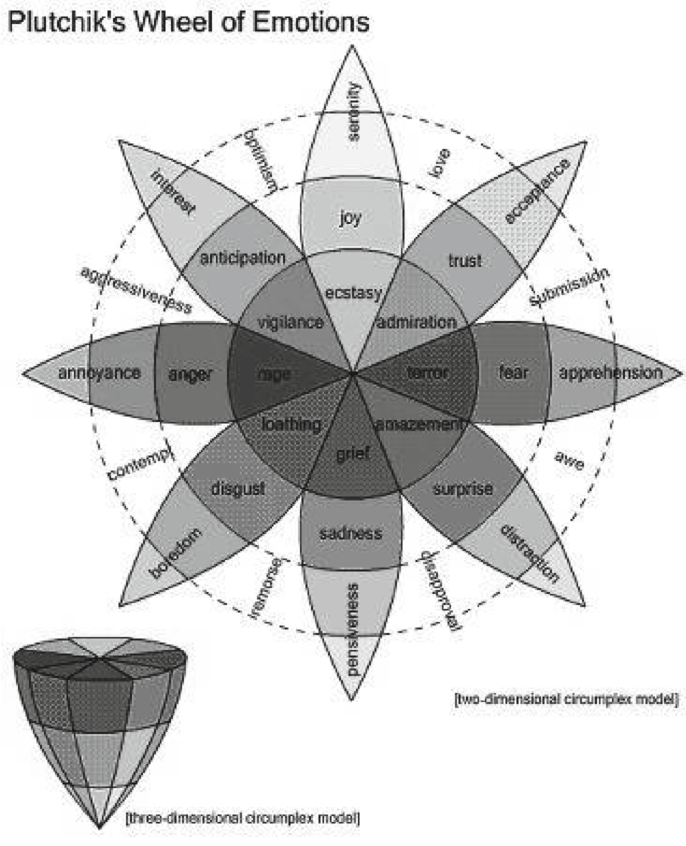

Fig. 1 Plutchik's wheel of emotions

A pioneer in the study of emotions and their relationship to cognition, Richard Lazarus, developed an influential theory in the field that explains the steps of emotion synthesis and how it affects cognition. As Singer-Schachter, Lazarus argued that cognitive activity (judgements, evaluations) is necessary for emotions to occur. He stressed that the quality (i.e. the combination of basic emotions according to Plutchik's theory) and intensity of emotions are controlled through cognitive processes, thus, the core of Lazarus' theory is the cognitive process of appraisal: before emotion occurs, people make an automatic, often unconscious assessment of the situation and its significance, and described the process as a three stage disturbance [4] (Fig. 2):

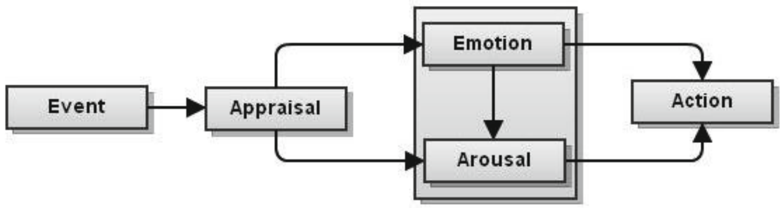

Fig. 2 Lazarus' emotion synthesis model

1. **appraisal** - the subject evaluates the event cognitively (consciously or not, symbolic or not)
2. a. **emotion** - cognitive appraisal triggers emotional changes (e.g. fear)
   b. **arousal** - the cognitive reaction coupled with the emotional response trigger physiological changes (e.g. increased heart rate and adrenal response)
3. **action** - the subject feels the emotion (which provides additional information) and chooses how to react

Perception

Emotions emerged in the process of evolution as the means by which living creatures determine the biological significance of the various states of the organism as well as of external influences; as a critical tool for adaptation and survival, emotions influence how we process and store information [7]. Through the attentional blink paradigm, it has been shown that events and objects that hold a high level of emotional arousal for the subject are more likely to be processed in conditions of limited attention [3], suggesting prioritized processing of such stimuli. What this means is that subjects will focus on the arousing details of the stimuli which will be processed, while peripheral details may not be (if attention is limited this leads to attention narrowing, where the subject's range of stimuli to which it is sensitive is decreased) [1].

3 Newtonian Emotion Space

In this chapter we will explain the basics of our Newtonian emotion representation system. We subscribe to Plutchik's theory (Sec. 2) in that only eight primary emotions are needed in order to derive the whole human emotional palette and that these eight primary emotions are grouped into four pairs of polar opposites, therefore, we chose to represent an emotional state as a vector in a four-dimensional space with the following four axes: joy-sadness, trust-disgust, anger-fear, and, anticipation-surprise.

Concepts

We will also introduce the following concepts in order to allow emotional states to interact with each other and external factors:

Definition 1. Position specifies the intersection of an emotional state with each of the four axes

Definition 2. Distance ($||\mathbf{p_2} - \mathbf{p_1}||$) measures the distance between two emotional *positions*

Definition 3. Velocity ($\mathbf{v} = \frac{\mathbf{p_2}-\mathbf{p_1}}{t}$) represents the magnitude and direction of an emotion's change of *position* within the emotion space over a unit of time

Definition 4. Acceleration ($\mathbf{a} = \frac{\mathbf{v_2}-\mathbf{v_1}}{t}$) represents the magnitude and direction of an emotion's change of *velocity* within the emotion space over a unit of time

Definition 5. Mass represents an emotional state's tendency to maintain a constant velocity unless acted upon by an external force; quantitative measure of an emotional object's resistance to the change of its velocity

Definition 6. Force ($\mathbf{F} = m \cdot \mathbf{a}$) is an external influence that causes an emotional state to undergo a change in direction and/or velocity

Laws of Emotion Dynamics

The following are two laws that form the basis of emotion dynamics, to be used in order to explain and investigate the variance of emotional states within the emotional space. They describe the relationship between the forces acting on an emotional state and its motion due to those forces. They are analogous to Newton's first two laws of motion. The emotional states upon which these laws are applied (as in Newton's theory) are idealized as particles (the size of the body is considered small in relation to the distance involved and the deformation and rotation of the body are of no importance in the analysis).

Theorem 1. *The velocity of an emotional state remains constant unless it is acted upon by an external force.*

Theorem 2. *The acceleration* $\mathbf{a}$ *of a body is parallel and directly proportional to the net force* $\mathbf{F}$ *and inversely proportional to the mass m:* $\mathbf{F} = m \cdot \mathbf{a}$

Emotion Center and Gravity

The emotion space has a center, the agent's neutral state, a point in space to which all of the agent's emotional states tend to gravitate (usually (0,0,0,0), however, different characters might be predisposed to certain kinds of emotions, thus, we should be able to specify a different emotional centre, and instill a certain disposition, for each character; we also use different emotion state mass to show how easy/hard it is to change an agent's mood). In order to represent this tendency we use gravitational force:

$$\mathbf{G} = m \cdot \frac{\mathbf{p} - \mathbf{c}}{||\mathbf{p} - \mathbf{c}||} \cdot k_g,$$

where p is the current position, c is the center and k_g is a gravitational constant. This force ensures that, unless acted upon by other external forces, the emotional state will decay towards the emotion space center.

4 Emotion System Architecture

We developed an emotion subsystem architecture that interposes itself between the agent's behavior module and the environment. The subsystem models the process described by Lazarus (Sec. 2).

Events perceived from the environment are first processed by the appraisal module, where an emotional force is associated with it. The resulting list of events is then sorted in descending order according to magnitude and fed into the agent's perception module. This is done in accordance with the psychological theory of attention narrowing presented in Sec. 2, so that in a limited attention span scenario, the agent will be aware of the more meaningful events.

We treat the agent behavior module as a black box that may house any behavior generation technique (rule based expert system, behavior trees, etc.). The interface receives as input events perceived from the environment and produces a set of possible actions. The conflict set module takes this set of rules and evaluates them in order to attach an emotional state to each. Out of these, the action whose emotion vector most closely matches the agent's current state is selected to be carried out.

$$\arg\min_{i \in \{conflictset\}} arccos \frac{e_{agent} \cdot e_i}{||e_{agent}|| \cdot ||e_i||}$$

Feedback from the environment has an associated emotion force vector that actually affects the agent's emotional state. Feedback is distributed to the appraisal and conflict set modules as well as the agent's behavior module. Actions undertaken are temporariliy stored in an action buffer for feedback purposes.

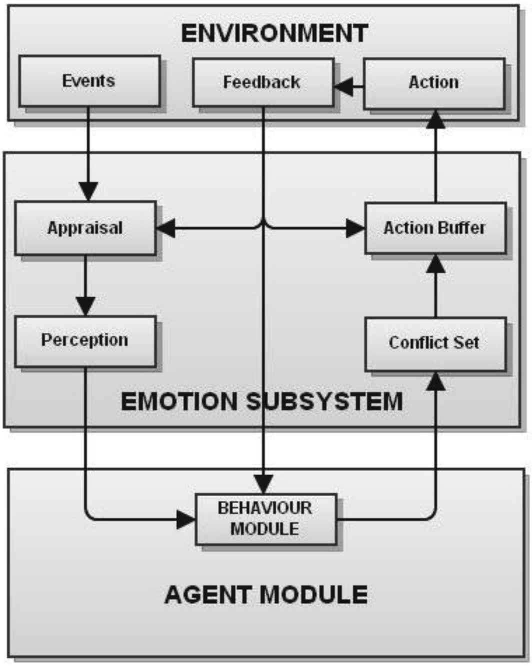

Fig. 3 Emotion system architecture

Learning

Both the appraisal and conflict set modules use machine learning techniques in order to learn to predict the outcome of events and actions, respectively. As there are many viable options for which learning technique to use (hidden markov models, neural nets, q-learning), we use a plug-and-play model where the technique can be replaced.

The appraisal module attempts to predict the emotional feedback received from the environment based on characteristics of the event to classify and previous feedback. The goal of the appraisal module is to better label (and thus establish priority of) events for the perception model. The conflict set module works in a similar way based on the characteristics of actions taken. The goal of the conflict set module is to settle conflicts between competing actions by selecting the most appropriate action to be performed. This is why an action is selected based on the lowest emotional distance to the agent's current state instead of magnitude.

Both modules treat the event, rule respectively, configuration as the observable state of the model, and attempt to predict the next hidden state (the emotional feedback force).

5 Conclusion and Future Work

We succeeded in developing a light-weight and scalable emotion representation and evaluation model to be used by virtual agents. The model is suitable for fast real-time evaluation and simulation such as that required in our chosen application type, computer role-playing games.

We also devised a plug and play emotion subsystem architecture that can be used with any agent behavior model and any machine learning technique. This allows us to provide artificial emotion simulation and modify agent behavior based on the given simulation. By using the model proposed in this paper, there is no need to adapt the game engine architecture to accomodate computationally expensive artificial intelligence techniques.

We chose computer role-playing games as an application domain due to personal preference, however, the system can be used in any type of application that requires emotion simulation. Moreover, other applications may not have the processing power restrictions that running along side CPU intensive special effects and physics simulations impose, and would leave more compuring power for the artificial intelligence module.

Collective Emotion

One interesting research direction is applying the model to multi-agent system techniques, such as swarm or ambient intelligence, in order to endow the entire system with collective emotions. Interacting agents would influence each other's moods based on the newtonian emotion model and have an emotion dissemination protocol over the multi agent system. The technology could further be integrated with ambient intelligence applications to either influence people's mood in order to make them more productive/happier or make them aware of the state of the ambient network around them in a non-invasive manner.

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