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A Formal Model of Emotional-Response, Inspired from Human Cognition and Emotion Systems

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In this paper, we used the formalisms of decision-making theory and theories in psychology, physiology and cognition to proposing a macro model of human emotional-response. We believe that using such formalism can fill the gap between psychology, cognitive science and AI, and can be useful in the design of human-like agents.
This model can be used in a wide variety of applications such as artificial agents, user interface, and intelligent tutoring systems. Using the proposed model, we can provide for human behaviors like mood, personality and biological response in machines. This capability will enable such systems, to adapt their responses and behaviors. In situations where there are multiple ways for performing an action, this model can help with the decision making process..

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1 Introduction

In recent years, there have been major advances in creating and improving more human-like applications and more effective interfaces for communication with users, such as Intelligent Agents and Intelligent Tutoring Systems. However, an AI based software system that can act like a human is still far from reality, because of the complexity of human capabilities and the uncertainty about it. Humans use their various capabilities to provide better predictions on results, have better judgment on situations and react better in unknown states. Human emotions and emotional responses are among these mysterious capabilities. Sometimes without having a strong logical path in our mind and with an incomplete set of reasons we make a correct decision,. In these cases, what we know is an appetence that forces us to do something. Something that drives us independently from our logical system: our emotional, or affective-response system. This is an advanced capability that we have, and makes us different from other species (Carlson, 1981).

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Within the Human-Computer Interface (HCI) community, there is growing agreement that traditional methods and approaches for user interface design need to become more human-like (Falangan, Huang, Jones, & Kasif, 1997). One aspect of developing such capability is to recognize the user's emotional or mental state and respond appropriately (Reeves & Nass, 1995). Adding such capability to machines can narrow the gap between human thinking and machine 'thinking', although, this gap is still very large.
In this paper, we discuss our formal model of emotional-response which was inspired from the facts and theories mentioned in section 2. Section 3 presents the proposed model for describing emotional-response, and section 4 presents our conclusions and discussions.

2 Research Background

There are two crucial issues on the path to what Picard (1997) has termed *"affective computing"*, which are: 1) Providing a system with a mechanism to infer the emotional state and personality of the user, 2) Providing a mechanism generating behaviour in an application, consistent with a desired personality and emotional state. There are several approaches for modelling or predicting emotional responses or emotional behaviour of humans. We categorize the research in two major branches presented in the following sections.

2.1 External Representation of Emotional Responses

This approach is based on observing a current state and predicting a future state based on a behavioural model. The behavioural model is an external representation of the person involved.
Bayesian networks are widely accepted as a tool for representing external representation of user's emotional responses based on internal emotional state or mood. Ball and Breese (1999) used this approach to show the emotional state of an animated agent. Historical record of external representation is a common feature of these approaches. Based on the best of our knowledge all of the analyses on external representation of emotions are: a) experimental (e.g., what a typical gesture or facial expression means) or b) assumption (e.g., a particular smile means happiness). A common foundation in these approaches, is considering emotion as a cause that has an external representation as an effect. These representations have a measurable or recognizable side-effect. Some of them are known and well studied (e.g. facial expression, body gesture and posture, heart rate, galvanic skin resistance, pupil size, body temperature, voice features), and there are some other effects that are not known or cannot easily be studied (e.g., side effects on digestion, or chain reactions in internal parts of brain, such as the limbic system).

2.2 Internal Representation of Emotional Responses

These approaches are based on predicting or measuring emotional-response, based on its internal representation. Although some of the internal mechanisms of human emotional-response are not well known, there are some theories and evidences asserting that the concept of emotions and mental-state can be formalized. Approaches to this idea are mostly based on psychological, physiological and neuropsychological findings

(Balkenuis, 1998; Canamero, 1997). Other approaches based on mathematical foundation also exist.

Few works have been done on the second issue, all of which were inspired from the human brain, although from different points of views. Canamero (1997) implemented a virtual world and a group of creatures with motivational states and a set of basic emotions. This model was inspired from hormonal stimulation in human brain. For instance, the presence of an enemy will cause hormones to be released (adrenaline and substance P). Each creature depending on the level of these hormones will perform an aggressive or evasive reaction. It is shown, that using emotions as amplifiers or modifiers of motives, allows for more flexible behaviours than those shown by a creature driven only by motivations.

Balkenius and Moren (1998) proposed a computational model of emotional learning and processing, inspired from neuropsychological findings. Key features of this model are the parts of the human brain that are involved in emotions, such as Amygdala and Orbitofrontal cortex. Ushiba, Hirayama and Nakajima (1998) proposed a mind model for life-like agents with emotions and motivations. They were inspired by an original idea from a psychological theory called the *cognitive appraisal theory*. Based on this theory, cognitive and emotional processes interact with one another. This model consists of reactive and deliberative mechanisms. The former generates low-level instantaneous responses to external stimuli that comes from the real world and virtual worlds. Gmytrasiewicz and Lisetti (2000) proposed a model for describing behaviour, based on a decision-making process, mood, and probability. In this model mood represents external state of an agent that can affect the probability of doing a specific action in response to an emotion.

2.3 Physiology of Emotion

The physical home of emotion is the limbic system, which is buried deep within the brain and which has links to systems in the frontal lobes. This setup permits emotion to be tempered by cognitive processes and vice versa. The limbic system in its entirety consists of the limbic cortex, hippocampus, amygdala, septum, anterior thalamus and mammillary bodies. In evolutionary terms it is a very old part of the brain that is also thought to be involved in memory functions in addition to motivation and emotion (Carlson, 1981). Our understanding of these systems is based on studies of neurological, neuropsychological and psychiatric populations in addition to animal studies (Borod, 1993). It is also believed that emotion is lateralised to the right hemisphere as speech is lateralised to the left hemisphere (Corballis, 1983). Borod (1993) notes that some research suggests that emotional perception is associated with frontal systems, while emotional expression is associated with posterior structures within the right hemisphere, probably the parietal lobe, and when emotional perception and emotional expression concern verbal material or verbal expression, there will be left hemisphere involvement. Recent brain-imaging techniques, such as PET, and MRI, add another dimension to physiological observation of emotions. Currently we know that, the amygdala has rich inputs from sensory systems (Killcross, 2000), and there is strong evidence that some feelings like joy or fear are controlled by this part of the brain (Best, 2003). In addition, it has been identified that the orbitofrontal cortex is involved in preparing behavioural and automatic responses.

2.4 Componential Model of Emotions

Borod (1993) provides what is termed a *'componential model'* of emotional processing that also demonstrates ways and levels of measuring emotion. It is a comprehensive model that includes processing modes, communication channels, emotional dimensions and discrete emotions. The model permits interactions between individual elements and components. His componential model is based on the brain damage cases in which disassociations have been found between expression and perception, experience and autonomic arousal (Borod, 1993).

Although research is equivocal as to association and disassociation between the communication channels, but in this model, the communication channel reflects the different ways in which emotion can be processed. For instance, prosodic communication refers to intonation and lexical content, which refers to speech. Discrete emotions are generally assumed to be biologically based and cross-culturally validated.

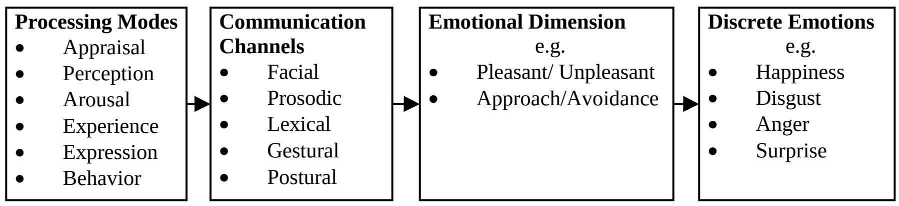

Figure 1. Componential Model of Emotional Processing (Borod, 1993)

3 Modeling Emotional Response

Although, there is no formal definition for term "emotion", in practice, the word "emotion" is assigned to a wide range of short-term to long-term feelings. In an artificial world and in relation to behaviour, we can define the word "emotion" as: 'The potential for doing a specific action as an affective response to internal or external stimuli'. For instance, when we feel "fear", we have the potential for taking defensive, or evasive, action. Although, emotional-responses in humans are neither unique nor certain.

Some emotional responses have physiological bases (Ekman, 1999), and these responses are directly linked to systems that evolved to deal with biologically significant situations, and they are therefore, universal. Some other emotional responses are based on our learning process (McNeill, 1992) adapted from our parents, teachers or our culture. Some responses are varying in different situations and change during our life, and finally some of them are dependent to personal parameters such as age, gender or mood.

Our conclusion from the physiological background as presented in the previous sections is that some emotions are fortified and some others are weakened by an independent source in the human brain. Stimulation of emotions will enable, or force us to do an action. However, because of uncertainty about the essence of emotions, describing emotions in a formalized scheme is another problem. Emotions are fuzzy and have relative meanings. In this paper we are basin our discussions on a multi-dimensional theory of emotions and affect grid (Ji, 2003; Russell, Weiss, & Mendelson, 1989). The reason for choosing this approach was: a) there were several successful experiments in

AI based on this theory (Picard, 1997), and b) measurability of emotions, which is an important issue in the digital world.
The affect grid is a two dimensional model for describing emotional state. Two basic dimensions are considered for describing emotions: valence and arousal. Valence represents overall happiness encoded as positive (means happy), neutral, or negative (means sad), and arousal represent the intensity level of emotions, encoded as excited, neutral or calm (Figure 2).

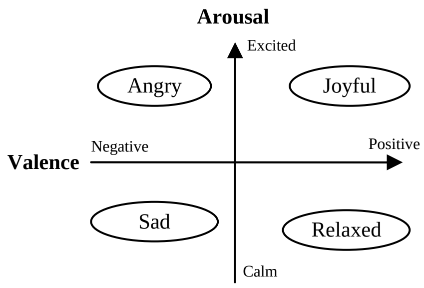

Figure 2: Describing emotions within the Valence-Arousal space (Russell et al., 1989)

Definition 1) Emotional State: Using the affect-grid, each emotional state described is represented by a pair (x, y), where *x* represents valence and *y* represents arousal. This representation means that a single point describes each emotional state. However, in the real world, emotions can occur simultaneously (e.g. having the feeling of happiness and fear together). We borrow the idea of measurability of emotions from the affect-grid and combined that with the fact of multiplicity of emotions. Therefore, each emotional state can be described by a set of (x, y) coordinates and defined as follows:

$$E = \{E_i \mid 1 \le i \le n, 0 \le E_i \le L\} \tag{1}$$

- ***n***, is the number of possible emotions, and ***L*** is maximum weight that emotions can have.

Definition 2) Action Space: We define an action-space as a set of all possible actions that can be performed by an actor. Action possibility space ***A*** is a set of weights for each action in action-space, and is defined as follows.

$$A = \{A_j \mid 1 \le j \le m, 0 \le A_j \le T\} \tag{2}$$

- ***m***, is the number of possible actions in an action space and T is maximum weight of an action.

Definition 3) Response: Response ***R*** is defined as a set of actions which their weights are maximal in an action possibility space. For the sake of simplicity, let’s assume each actor can have a single response at each time. Therefore, a “Response” is an action with maximum weight at that time defined as:

$$R = \{j \mid A_j \ge \max(A_k \mid 1 \le k \le m)\} \tag{3}$$

Definition 4) Emotional-Response: Based on the theories reviewed in the previous section, and the fact that each emotion can have 0 or more responses, we define the weight of a response or action $\boldsymbol{A_j}$ as:

$$A_j = \sum_{i=1}^{n} H(E_i) \tag{4}$$

Function $\boldsymbol{H}$ is the emotional-response function indicating the relationship of the emotion and response. However, the analytical description of this function needs more research and deeper understanding of the decision-making process.

Before introducing the model, we point to the long-term study on effects of emotions. We described that there are some fixed responses and some variable responses on emotions. Some physiological effects of emotions are under the control of the autonomic nervous systems (ANS), and therefore can not be pretended or inhibited (e.g. heart rate). Some effects are under the control of the peripheral nervous system (PNS), and these effects are under voluntary control and can be masked (e.g. facial expressions).
We categorize these factors in three major categories:

1) Genetic factors that are constant and independent to external state, like gender
2) Personal factors that are dependent to learning parameters, such as culture and knowledge
3) Finally environmental factors that describe the analysis of actor on side effects of this action, that naturally are considered by human.

We call these factors G, P, B respectively. Thus, function H is dependent to these factors. Therefore the weight of each action in a decision-making situation is dependent on the weight of all emotions in that situation Finally, we can demonstrate the idea, using a decision graph as follows:

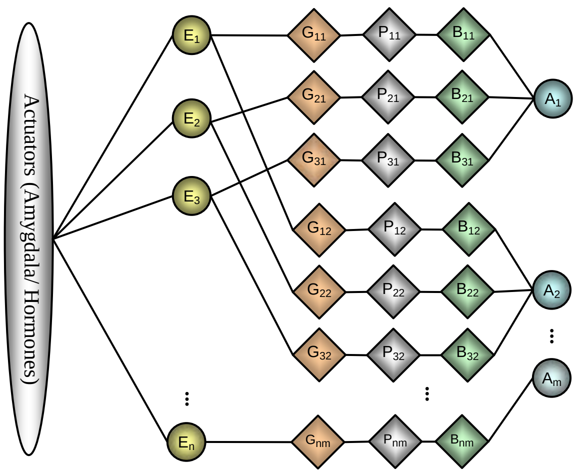

Figure 3. A Computational model of Emotional-Response

Where $E_1..E_n$ are weights of emotions *1..n*, and $\boldsymbol{G_{ij}}$, $\boldsymbol{P_{ij}}$, and $\boldsymbol{B_{ij}}$ are respectively: genetic, personality, and behavioural factors of the effects of emotion $\boldsymbol{E_i}$ to action $\boldsymbol{A_j}$. According to definition (1), the weight of action $\boldsymbol{A_j}$ is defined as:

$$A_j = \sum_{i=1}^{n} H\left(E_i, G_{ij}, P_{ij}, B_{ij}\right) \tag{5}$$

The value of parameters ***G***, ***P***, and ***B***, can be predicted from some natural behaviours and controllability of related actions. It is predictable that "happiness" has a high genetic effect on action "smile", or "sadness" has a moderate genetic effect on action "cry", although these emotional responses can be masked in changing personality or in different situations.
We will address the function ***H*** in further research. Here we mention that because all parameters can increase or decrease the weights of actions and peer emotions. Therefore one of the simplest methods for describing this function is a multiplication function, H(x,y,z,t)=xyzt. Therefore one approach to describing weights of action space will be:

$$A_j = \sum_{i=1}^{n} \left(E_i \times G_{ij} \times P_{ij} \times B_{ij}\right) \tag{6}$$

We can replace parameters $\boldsymbol{E_i}$, $\boldsymbol{G_{ij}}$, $\boldsymbol{P_{ij}}$, and $\boldsymbol{B_{ij}}$ by functions ***E(i)***, ***G(i,j)***, ***P(i, j)***, and ***B(i,j)***. If we assume that ***n*** is a big number, then the above equation is approximately equivalent to the following equation.

$$A\ (y) = \int_1^n \left(E\ \ (x) \times G(x,y) \times P(x,y) \times B(x,y)\right) dx \tag{7}$$

We must note that function ***E*** is not the same over time, and it is dependent on an actuator mechanism, therefore it is indicated as E_t. Therefore, function A can be described as:

$$A_t(y) = \int \left(E_t(x) \times G(x,y) \times P(x,y) \times B(x,y)\right) dx \tag{8}$$

Based on definition 3, the selected emotional-response is one of the results of the following differential equation:

$$d\left(A_t(y)/dy\right) = d\left(\int \left(E_t(x) \times G(x,y) \times P(x,y) \times B(x,y)\right) dx\right) \Big/ dy = 0$$

4 Discussion and Conclusion

In this paper, we outlined a formal definition of emotional-response as a decision making component for AI applications. Our model was inspired from theories and research in psychology, physiology and affective-computing.
Our proposed model has potential applications in intelligent agents. The model can help such agents look more human-like view . by enabling them to communicate more effectively with humans.

The approach we presented here is a proposal for combining existing micro models together and should be seen as a starting point. Indeed, additional work is needed in the future. For instance the actuator mechanism referred to in our approach requires a formal model of its own. Measuring and updating of genetic, personal, and behavioural parameters requires mathematical and psychological work. Finding the simplest descriptor functions for these parameters is another challenge. Providing learning and adaptation mechanisms are important tasks for enhancing this model, which should be addressed in the future research.

References

Balkenius, C., & Morén, J. (1998). *A Computational Model of Emotional Conditioning in the Brain.* Paper presented at the Proceedings of Workshop on Grounding Emotions in Adaptive Systems, Zurich.

Balkenuis, C. (1998). *A Computational Model of Emotional Conditioning in the Brain.* Paper presented at the Proceedings of Workshop on Grounding Emotions in Adaptive Systems, Zurich.

Ball, G., & Breese, J. (1999). *Modeling the Emotional State of Computer Users.* Paper presented at the Workshop in User-Adapted Interaction, UM.

Best, B. (2003). *The Anatomical Basis of Mind; Chapter 9: The Amygdala and the emotions*. Retrieved March 12, 2004, from the World Wide Web: http://www.benbest.com/science/anatmind/anatmind.html

Borod, J. (1993). Emotion and the Brain – Anatomy and Theory: An introduction to the special section. *Neurophysiology, 7*(4), 427.

Canamero, D. (1997). *A Hormonal Model of Emotions for Behavior Control.* Paper presented at the 4th European Conference on Artificial Life, ECLA.

Carlson, N. (1981). *Physiology of Behavior*: Allyn and Bacon: MA.

Corballis, M. (1983). *Human Laterality*. NY: Academic Press.

Ekman, P. (1999). Basic emotions. In Dalgelish (Ed.), *Handbook of cognition and emotion* (pp. 301-320). New York: John Wiley.

Falangan, J., Huang, T., Jones, P., & Kasif, S. (1997). *Final report of the NSF Workshop on Human-Centers Systems: Information, Interactivity, and Intelligence*. Washington D.C.: NSF.

Gmytrasiewicz, P. J., & Lisetti, C. L. (2000). *Using Decision Theory to Formalize Emotions for Multi-Agent System Applications.* Paper presented at the Workshop on Game Theoretic and Decision Theoretic Agents, Boston, USA.

Ji, Q. (2003). *Affective State Assessment, Affect-Sensitive, and Cognition-faithful. In: Human Computer Interaction*. Retrieved, March 2004, from the World Wide Web: http://www.ecse.rpi.edu/homepages/qji/HCI

Killcross, S. (2000). The Amygdale, Emotion and Learning. *The psychologist*, *13*(10), 502.

McNeill, D. (1992). *Hand and Mind*: The University of Chicago Press.

Picard, R. W. (1997). *Affective computing*: MIT Press.

Reeves, B., & Nass, C. (1995). *The Median Equation*. New York: CSLI Publication and Cambridge University Press.

Russell, J. S., Weiss, A., & Mendelson, G. A. (1989). Affect grid: A single-item scale for pleasure and arousal. *Journal of Personality and Social psychology, 57*(3), 493-502.

Ushiba, H., Hirayama, Y., & Nakajima, H. (1998). *Emotion Model for Life-Like Agent and Its Evaluation,*. Paper presented at the Proceedings of the Fifth Conference of Artificial Intelligence, California, USA.