Emotion and Embodiment in Cognitive Agents: from Instincts to Music

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***Abstract** - This paper suggests the use of modeling techniques to tack into the emotion/cognition paradigm. We presented two possible frameworks focusing on the embodiment basis of emotions. The first one explores the emergence of emotion mechanisms, by establishing the primary conditions of survival and exploring the basic roots of emotional systems. These simulations show the emergence of a stable motivational system with emotional contexts resulting from dynamical categorization of objects in the environment, in answer to survival pressures and homeostatic processes. The second framework uses music as a source of information about the mechanism of emotion and we propose a model based on recurrent connectionist architectures for the prediction of emotional states in response to music experience. Results demonstrate that there are strong relationships between arousal reports and music psychoacoustics, such as tempo and dynamics. Finally we discuss future directions of research on emotions based on cognitive agents and mathematical models.*

1. INTRODUCTION

Recent findings in neurosciences, psychology and cognitive sciences indicate the surprising role of Emotions in intelligent behavior. Particularly interesting for us are the studies looking at physiological interferences, and the relation between body and affective states, as well to the evolutionary mechanisms. Emotions have an important role in behavior and adaptation in biological systems.

This idea has recently gained special attention in computational models of cognition and behavior (e.g. [1,2]), following new theoretical approaches to cognition based on embodiment theories [3]. Whilst some of these models focus on different properties of an emotional system for task solving issues (e.g. using facial expressions for social engagement), we are interested in using computational models to understand the basic mechanisms of the emotional systems.

We are developing computational models of simulated autonomous agents that use emotion as a mechanism for organization of behavior. This way we intend to create an integrated model of instincts, perception, motivation and action, based on artificial environments and embodiments. In our modeling approach we share the neurobiological and evolutionary perspectives to Emotions, as discussed in the following sections.

We suggest that the agent should be embodied so as to allow its behavior to be affected by motivational processes, focusing on the internal demands and activity. By artificial embodiment we mean that the agent has a virtual physical body whose states can be sensed by the agent itself. We will discuss a theoretical framework and specific scenarios to test our hypothesis. We present results for one test framework on the emergence of motivational processes in embodied agents. The preliminary framework seems to be effective and versatile enough to allow the agent to adapt itself to unknown world configurations, maintaining controlled healthy states. We demonstrate that body/world categorizations and body maps can evolve from the simple self-survival rule. The results are coherent with Antonio Damasio's definition of background emotional system [4].

We are also studying the extension of this model to musical emotions [5]. In this paper we will also present experimental results derived from the application of recurrent connectionist architectures for the prediction of emotional states in response to music experience. Results demonstrate that there are strong relationships between arousal reports and music psychoacoustics. We believe that this approach can also contribute for different cognitive studies, and its large spectrum of applications may be specially interesting in computational approaches for intelligent systems. A potential field of application of these models arises from recent theoretical proposal in robotics, more specifically that of Internal Robotics [6].

2. EMBODIED EMOTIONS

The study of Emotion is increasingly considered of paramount importance for modern sciences. Throughout the last century emotion has appeared as a main research topic in several areas of knowledge, specially after the emergence of post-Cartesian theories exposing the relevance of emotional systems at all levels of behavior. Charles Darwin, William James, Walter Cannon, Wilhelm Wundt, Susanne Langer, among others, introduced great developments in the study of emotions, and their ideas are still largely considered as references for many emotions theorists. Several are the definitions for the process of Emotion, and consequent research focus, although current research generally accepts that it can be described as a multi-modal mechanism, with several processes involved including appraisal, basic emotions, physiological responses, and subjective feeling states [4,7,8].

It is important to stress that the process of emotion differs in important aspects from other psychological processes. For instance, emotion is an embodied experience with specific behavioral patterns (facial expressions, autonomic arousal, etc.); it is less susceptible to our control and also expressed at the unconscious level; has the capacity to affect other cognitive processes (e.g. decision making), though not only confined to the old sub-cortical structures in our brains [4]. Damasio suggests that the processes of emotion and feeling are part of the neural machinery for biological regulation, whose core is formed by homeostatic controls, drives and instincts.

Emotions are complicated collections of chemical and neural responses, organized in various patterns; all emotions have some regulatory role to play, leading in one way or another to the creation of circumstances advantageous to the organism exhibiting the phenomenon. The biological function of emotions can be divided in two: the production of a specific reaction to the inducing situation (e.g. run away in the presence of danger), and the regulation of the internal state of the organism such that it can be prepared for the specific reaction (e.g. increased blood flow to the arteries in the legs so that muscles receive extra oxygen and glucose, in order to escape faster). Emotions are also inseparable from the idea of reward or punishment, of pleasure or pain, of approach or withdrawal, of personal advantage or disadvantage.

Obviously this process is dependent on the mechanisms of integration that relates the inducer with the organisms internal state. It is on this border that the outer world of objects is separated from the inner world of emotions and concepts. Instincts continuously drive behavior towards the self protection and homeostatic balance. By evaluating concepts derived from internal and/or external stimuli (the internal model of the outer world), the process of emotion arises, integrating both dimensions and modulating ongoing processes in the brain. Survival mechanisms are related this way to emotions and feelings (the synthesis of emotion), in the sense that the they are regulated by the same mechanisms. In this line the internal representations of the outer world can induce emotional states, by interacting with both body and psyche.

Emotion as Arousal

The autonomic nervous system (ANS) regulates the body and its readiness for action. The correspondent physiological variations are referred as changes in arousal. Changes in arousal are related to emotional states or experiences, having both brain and physiological inducers. Regarding specifically the role of physiological responses on the emotional experience and elicitation (and the interaction with the brain), there have been several models proposed. As discussed in [9] regarding the role of the body in the emotional experience, three main models of emotion can be distinguished: (i) the undifferentiated arousal model, (ii) the cognitive appraisal model, and (iii) the central network model. The main idea behind the first model (see [10]) is that body responses increase with emotional intensity, but their pattern is not differentiated across the different emotional states. In this line cognitive information and/or the specific context differentiate the type of emotion, while bodily activation (arousal) determines the intensity of that emotion. One practical prediction of this model is that the perception of the emotional intensity can be influenced by the arousal intensity. The main finding of this research has been the fact that after the exposure to an arousing stimulus, the following emotional feeling state is intensified. This phenomenon is called activation transfer [11]. The second model focuses on the body changes as a function of cognitive appraisal processes [8], or action readiness. In this line of research, the patterns of body changes are the combined result of the several cognitive appraisal components, although the fact that the body itself might generate emotional states is quite marginalized in this model. Finally, from the third model perspective, emotions share different neural and cognitive mechanisms and pathways, and their pattern of interaction defines the emotional nature. In short, the patterns of body changes are differentiable across emotions. The activation of the body with a pattern related to a specific emotion will, in certain conditions, elicit that emotion (the peripheral feedback). This last process is automatic at an implicit level [4].

In summary, the underlying idea common to all these mechanisms is that a specific emotion can be elicited by creating specific body state patterns (by manipulating the body), even outside the awareness of the individual. An event (appraised via cortical or subcortical routes) elicits physiological changes that facilitate action and expressive behavior. These changes are accompanied by, and contribute to, an affective feeling state. Motoric and visceral feedback can contribute to the intensity and hedonic value of an emotional experience: consciously or subconsciously, individuals use their body state as a clue to the valence and intensity of the emotion they feel.

These ideas give rise to an interesting discussion about interaction between affect and logic, emotions and cognition. Sustained for an evolutionary perspective certain organizational principles in the brain might reflect emotional states (for further details and references on emotions, cognition and behavior, please refer to [4,9]). Levine [14] as suggested that the ancient emotional centers are also involved in the mediation of the mind-body connection of aesthetic emotions. Furthermore, Perlovsky [15] suggested that aesthetic emotions are related to cognition, to improvement of knowledge and are not directly related to specific bodily needs and experiences. Aesthetic emotions mediate value-relationships among cognitive concepts. A large number of these emotions is needed to unify knowledge in its relationship to our cognition as a whole. Music creates this diversity of emotions.

In the following section we will present two possible frameworks for the study of these issues. One focus on the biological subtract of artificial embodied agents, endowing them with basic instincts and exploring the role of emotional mechanisms in an adaptive task; the other investigates the nature of Music stimuli as a source of affect, in order to understand the nature of the signals that might interfere with arousal mechanisms, which have impact at all levels of behavior.

3. FRAMEWORKS

Experiment I: Instincts and Action

We created a conceptual A-Life model to implement artificial worlds inhabited by autonomous emotional agents, modelling the agent based on biologically plausible principles. We focused on the idea of having an embodiment (in the sense that the agent has a virtual physical body whose states can be sensed by the agent itself) so that low level tasks (e.g. satiate body needs) influence its overall performance, by affecting its behavior. A neural network endows the agent with cognitive capabilities, processing information related to its body, and to its environment. The agent's emotional state is mirrored into a set Background Emotions. This term is used by Damasio [4] for the responses caused by "...certain conditions of internal state engendered by ongoing physiological processes or by the organism's interactions with the environment or both" [1]. Note that in this paper we consider these emotions to be derived from Instincts.

The simulation environment (programmed in C++) is represented as a two-dimensional world populated by several objects. An autonomous agent inhabits this artificial world and is able to move within the borders that define its limits. Each object has different representations corresponding to a physiological interference. For instance a red object correponds to a source of food, though, simplisticly, a resource of blood sugar for the agent. When exhibiting the will to eat, by interacting with this object, the agents blood sugar level is increased. Similar objects were created (using different colors) related to physiologic demands related to energy, endorphine, and vascular volume. We also created obstacles in the world that, in the simplest case, are only the topological limits (or borders) of the world; these borders are considered as sources of pain.

Currently, the agent comprises three main formalized systems: Perceptual, Nervous and Motor.

In order to perceive the world, an agent contains a retina (represented as a color array) that resembles a biological retina on a functional level. It senses a bitmap world (environment) through a ray tracing algorithm, and it incorporates the attenuation of visual cues in function of the distance of the objects in relation to the agent. This information is feeded to the nervous system.

The nervous system includes a feed-forward neural network (NN) with a genetically encoded structure (fixed during lifetime). The neural network is organized in layers: an input layer (two groups: retina and body sensors), an output layer (two groups: instincts and motor control) and a hidden layer (with excitatory-only and inhibitory-only neurons). The instincts drive the agent attention towards specific needs. They are only controlled by the agent embodiment, which reacts to its environment, with no other interference, and they translate physiological changes into specific alarms or urges to action (e.g hunger if blood sugar is low). In any moment the agent can be hungry or satiated, tired or energetic, etc. To express its desire to act in the environment, the agent possesses a set of Motivations, which correspond to the level of will to adopt a certain behavior (eat, drink, etc.). The Motivational System is controlled by the neural process.

The agent also controls a motor system through linear and angular speed signals, allowing it to travel around the world (including obstacle avoidance and object interaction). These signals are provided by the neural network, which means that motor skills also have to be learned. With this capabilities the agent will be able to navigate in its environment, approaching or avoiding certain states.

The agent learns through a reward and punishment algorithm, in order to adapt itself to the environment by interacting with it. Our algorithm is inspired in Rolls' "Stimulus-Reinforcement Association Learning" [13].

The aim of this exercise is to design an embodied agent-based cognitive model and establish how an emotional system can emerge from self-regulatory Homeostatic Processes. The objective is to understand the role and the importance of Emotions in self-survival tasks; hence one of the reasons to implement a single-agent system at this stage. We are also interested in studying how the regulation of the Homeostatic Processes can influence world categorization and decision making (currently at a low level and for single tasks). We also analyze how emotions act as a system of internal rewards, that preserve the system, and permit a continuous adaptation process in self-survival tasks, by signalling and scaling pleasant or unpleasant interactions. Detailed simulations and results were reported in [12]. Here we give an overview of the main achievements.

With this framework we aim, at this point, to test three main hypothesis: (i) an emotional system can emerge from the interaction of self-regulatory Homeostatic Processes and the Environment; (ii) the regulation of the

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Homeostatic Processes influences world categorization and decision making by attributing hedonic values (or relations with Insticts) to objects, and by affecting cognitive processes (e.g. driving attention); (iii) emotions act as a system of internal rewards, that preserve the system, and permit continuous adaptation in self-survival tasks, by signalling and scaling pleasant or unpleasant interactions/stimuli.

Results overview - The evolution of the Fitness value in time showed an overall increase of the agent's ability to regulate its body state. The agent is not only capable of increasing its Fitness, but it does so by maintaining a "healthy behavior". Extreme body states were avoided, showing the ability of the agent to regulate its own body status, by coping with its metabolism and managing competitive internal stimuli.

We analysed the system further in order to better understand the dynamics of the NN and the learning process. Particularly, we wanted to understand how the agent categorizes the stimuli and how this information is integrated giving rise to behavioral changes. The first 2 Principle Components of a PCA analysis of the hidden units activations (when presenting to the agent all the objects isolatedelly and one at the time) showed that the agent was able to categorize the world. In fact, identical external stimuli (objects) are represented internally in a specific and dedicated way. In another test scenario we varied the physiological state of the agent, and we found that there is also a clear definition of the different body states.

Summarizing we hypothised that an emotional system, as a process of integration, would emerge from the interaction of self-regulatory Homeostatic Processes and the Environment. Moreover it would affect other cognitive processes namely related with internal concepts of the world. In our experiment we found that the agent is able to identify its own body needs and attribute dynamical meanings to the objects. This was specially evident by the complete separation of the different states of well-being (over-stimulated, homeostatic regime or under-stimulated) when stimulated by the world objects. These results confirm our hypothesis.

Experiment II: Differentiation and Synthesis

As emphasized by Perlovsky [15], Music might well be the main mechanism of differentiation of emotions. For that it is also considered as a mechanism of synthesis, since it can interact with the entire wealth of human experience. Music is able to speak to both conscious and subconscious states of mind, sometimes in unique ways, which have special impact on our lives for its ability to create a connection between the outer world of objects and stimulus, and the inner world of emotions.

While in the previous approach we hypothesized a scenario to observe the influence of instincts and emotion on behavior and adaptation, we now suggest to analyze the mathematics of musical stimulus as a source of information about systems of differentiation and synthesis. We will develop now our ideas about a possible line of investigation, which seaks for mathematical relantionships between acoustic properties of sound and psycho-physiological reports of emotion.

Music and Emotions - Music offers an extraordinary platform for the study of Emotion. People often report that their primary engagement with music is emotional, and there is a wide acceptance that musical stimuli are among the most powerful triggers of strong emotions [16]. But are these musical emotions similar to the emotions referred previously? Do they contribute for an individual's well being? Do they have any psychological consequences? To a certain extent recent research suggests a positive answer to these questions, particularly when looking at the interaction of the temporal patterns of music with body and brain.

Current research supports the hypothesis that music perception is a distributed process within the brain and is involved in an interactive spatiotemporal system of different neural networks [17,18], including even neural networks specialized for other cognitive processes (e.g. emotion, memory, language). Experimental evidence suggests the participation of both hemispheres in music perception, although it is possible to differentiate some interesting specializations [19]. For instance the left hemisphere seems to be related to perception of timing and rhythm, while the right hemisphere specializes in pitch and timbre perception. Along with the spatiotemporal patterns of neural activity presented to the primary auditory system, the brain engages in other processes, for instance in the motor system, language, emotion and reward related areas. Focusing on the emotion dimension, some researchers [7,20,21] suggest that music derives its affective power from dynamic aspects of the brain systems, which control emotional processes but are distinct, although interactive, with other cognitive processes. This hypothesis follows Susanne Langers ideas about the existence of shared properties in patterns of physical and mental states, emotion, and music.

Support for these ideas comes, for instance, from research with brain damage patients. It has been shown that the emotional appreciation of music can be maintained even in the presence of severe perceptual and memorization deficits, though reinforcing the idea that sub-cortical mediation is involved in emotional judgments [22]. Due to these interactions certain basic mechanisms related to motivation/emotion in the brain can be elicited by music. This gives rise to changes in the body and brain dynamics, and to interferences with ongoing mental and bodily processes. This multi-modal integration of musical and non-musical information might take place in the brain, opening a window for associations between music, emotion, and physiological states. Past research also indicates the existence of a possible relationship in the dynamics of musical emotion and the cognition of musical structure.

We suggest that the study of the music dimensions can unveil important information about the configuration of the stimuli that create specific, unique, and relevant patterns of mental and bodily activity. We are looking at the spatiotemporal relationships between music psychoacoustics and levels of psychological and physiological arousal. In [5] we focused on the contribution of mathematical and computational modelling techniques for understanding the relationship between music elements and evoked emotions. In particular, we support the use of spatiotemporal models. We applied the use of the connectionist paradigm to investigate the relationship between music (psychoacoustic features) and emotional responses (quantified as the arousal level).

Experiment overview - We focus the present analysis to psychoacoustic data and psychological arousal, aiming to test our hypothesis on emotional engagement during music listening. To do so we used Korhonen's experimental data, made available online in the researchers website [23]. Korhonen used 6 pieces of classical music for his experiments. Volunteers used a continuous arousal and valence scales (with a sample rate of 1s), to rate the emotion thought to be expressed by the music. The musics used were: Music 1 - Concierto de Aranjuez Adagio (Rodrigo); Music 2 - Fanfare for the Common Man (Copland); Music 3 – Moonlight Sonata Adagio Sostenuto (Beethoven); Music 4 - Peer Gynt Morning (Grieg); Music 5 - Pizzicato Polka (Strauss); Music 6 - Piano Concerto No. 1 Allegro Maestoso (Liszt). For our experiments we use all the 18 psychoacoustic variables chosen by Korhonen to encode the musical input to the system, since we want to include a wide spectrum of information about the musics. Arousal corresponds to the single output of the network. Music 1 to Music 5 were used to train the system, while Music 6 was used to test the generalization response to novel stimuli. All simulations are divided into two phases: the first corresponds to the training phase, and the second to the tests phase. During the former inputs are presented sequentially to the network input layer, where the training algorithm combines the current input with the previous activation of the hidden layer (through the previous states history stored in the context units) and activates the hidden units with the combined input. The output derived from propagating the inputs to the output is then compared with the reference values correspondent to the desired output (in this case the values of arousal obtained from the experiments correspondent to the current musical input). The MSE error calculated from this comparison is then used to adjust the values of the weights of all the trainable connections (which are all except the links between hidden and context layers, which are maintained constant to 1.0), in order to move the network outputs closer to the desired targets (again the values for arousal or valence were obtained experimentally).

Results overview - Results show that there are strong mathematical relationships between music psychoacoustics and arousal reports, having the model explained 85.0 % of the output variation , using the music inputs as predictors. We identify that there are not only spatial relationships between music variables, but also temporal. Arousal predictions derive from information related with different musical dimensions at different stages in the piece of music. Tempo, Dynamics, Mean Pitch and Texture were the variables which contributed with more information to the system. The resultant model is now being analyzed in order to establish the mathematical relationships that underly the interaction between music and psychological arousal. These results agree with research in music and emotion, as extensively reviewed by [24]. In this work strong relationship between arousal and dynamics are reported, as well as between arousal and tempo. Schubert also observes that his results fail to confirm his thesis in what regards to other psychoacoustic variables. In [5] we report that, apart from tempo and loudness, also mean pitch and texture, can explain great part of the variations in arousal ratings. These results improve significantly previous models.

We are able to demonstrate that a spatiotemporal connectionist model trained on music and arousal self-report data is capable of representing the process and generalizing the level of arousal in response to novel music input. The model is also capable of identifying the main variables responsible for such an emotional rating. Ongoing work aims to provide a framework for the understanding of the relationship between musical features and perceived emotions, based on the ideas we presented in [5]. Implications from this research might allow for the mathematical modeling of arousal variations during music listening, opening a way for their incorporation in artificial agents, allowing for its use in scenarios like the one we presented in the previous section.

3. CONCLUSIONS

We suggested the use of modeling techniques to tack into the emotion/cognition paradigm. For that we presented two possible frameworks that can account for such investigation. One explores the emergence of emotion mechanisms, by establishing the primary conditions of survival and exploring the basic roots of emotional systems; the other uses music as a source of information about the mechanism of emotion. We propose to use these frameworks as a basis to develop a simulation scenario to study the dynamics of emotion and its relation with cognition. Recent advances in neuroscience and other studies of emotion, endow us with new information that can be successfully applied in modeling frameworks.

We addressed the notion of the emergence of a stable emotional system by means of self-regulatory Homeostatic Processes, and we demonstrated that it is possible to model such phenomenon. As suggested by Damasio [4], environmental events of value should be susceptible to preferential perceptual processing regarding their pleasant or unpleasant meaning. We believe that the architecture and particularly the reward system (the agent's appetite for well-being) were responsible for the emergence of stable emotional systems in our simulations. Furthermore, the results are coherent with Damasio's convincing theories about the existence of a background emotional system [4]. We demonstrated that phenomena such as body/world categorization and existence of a body map can evolve from a simple rule: self-survival. As a starting point to develop further Experiment 1, we suggest that the agent architecture should be updated. For instance we combined perception and action systems, allowing for affective responses to drive behavior, although we didn't incorporate at any level the fact that an affective response also has an internal feedback within the organism. A suggestion consists on creating a proprioceptive feedback system that can account for such interactions. At a different level we suggest the extension of the simulations scenario to a multi-agent system, allowing, for instance, for studies of emotion at different levels such as communicative or social. We also intend to apply our model to decision making tasks (e.g. music composition), as it allows to reduce the space state of choices, through an emotional categorization. Another interesting perspective comes from recent claims, specially Internal Robotics [6].

From a different perspective we are trying to understand how the different perceptual dimensions associated with music are perceived, integrated and organized, in such a way that they convey meanings as a whole. This task implies processes of segmentation and differentiation, as well as categorization. Moreover, in music, the temporal combination of the stimuli has a strong emotional effect. These aspects suggest that music can be a relevant source of information about the brain organization, accounting with new information for cognitive studies. If we can mathematically represent the basic aspects of musical emotions, we might also be able to bring that knowledge into computer models, using it also as a platform for emotion/cognition studies. Current work shows that musically induced arousal can be predicted by looking at the psychoacoustic properties of the stimuli. Future directions focus on formalizing the spatiotemporal dynamics of the stimuli, from their effect on arousal. We might be able to understand how these signals are organized and though obtain information of the nature of the stimuli that can trigger emotional responses.

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