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RESEARCH ARTICLE

A cognitive architecture for the implementation of emotions in computing systems

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Abstract
In this paper we present a new neurobiologically-inspired affective cognitive architecture: NEUCOGAR (NEUromodulating COGnitive ARchitecture). The objective of NEUCOGAR is the identification of a mapping from the influence of serotonin, dopamine and noradrenaline to the computing processes based on Von Neumann's architecture, in order to implement affective phenomena which can operate on the Turing's machine model. As basis of the modeling we use and extend the Lövheims Cube of Emotion with parameters of the Von Neumann architecture. Validation is conducted via simulation on a computing system of dopamine neuromodulation and its effects on the cortex. In the experimental phase of the project, the increase of computing power and storage redistribution due to emotion stimulus modulated by the dopamine system, confirmed the soundness of the model.

Introduction

In recent years, the complexity and power of the human brain/mind system have been further revealed by several studies, still an uncountable number of questions regarding mechanisms and functions has not been answered. An

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increasing number of biologically-inspired studies and publications has appeared in the scientific community spanning from approaches to Artificial Intelligence (AI) to results of more general interest in Information Technology (IT). It has been widely recognized that emotions play an important role in human life Picard (1997), Arbib and Fellous (2004), Marsella and Gratch (2003). However, traditional AI approaches do not take into account all the dynamics and creative aspects of the mind, therefore demanding for new attacks to the problem of mind modeling.

There are several projects which are worth mentioning in the context of emotions and affect simulation in cognitive architectures: Kansei implemented an emotional-oriented approach Nagamachi (2010), emotions are widely taken into account in CogAff by Sloman and Chrisley (2003), and work of Ortony, Clore, and Collins (1990) ''OCC'' is based on the appraisal theory and the emotion generation. The seminal book for whole domain of the ''Affective computing'' was created by Picard (1997), and also located in the MIT we can find one of the first and brightest examples of the social robotics: ''Kismet'' by Breazeal (2002).

One of the groundbreaking books on emotions and their implementation in a computing system was written by Minsky (2007), where among huge number of ideas he provided the description of the role of the emotions and identified possible computing implementation approaches.

On the other hand, the neuropsychological picture of emotions in form of base affects was provided by Lovheim (2012), where emotions are expressed in a three-dimensional model of monoamine neurotransmitters: serotonin, dopamine, noradrenaline.

Still a comprehensive framework bridging the biological affects and computing processes is lacking in the scientific literature. In this paper we attempt to fill the gap providing the bio-inspired approach for the mapping of the biological affects on modern computers with common Von Neumann architecture.

The main contribution of this paper is twofold: (i) extending the neuro-psychological three dimensional model of affects, the Cube of Emotion, with mapping to parameters of Von Neumann machine and computing systems; (ii) implementing neuromodulation mechanisms of dopamine in spiking neural network NEST[1] Gewaltig and Diesmann (2007) framework, thus one axis of three dimensional model and indicated the connection of one affect (fear) with computing power load and storage parameters.

The remainder of the paper is organized as follows: problem description is provided in Section ''The problem'', while our emotion-based approach, NEUCOGAR, is presented in Section ''Our cognitive affective architecture: NEUCOGAR'', and detailed analysis is provided in Section ''Validation'' with experiment description and results discussion. Sectio n ''Conclusions and future work'' closes the paper with some remarks and conclusions.

The problem

It has been historically believed that AI systems could have been built upon traditional computing architectures, and that with enough computing power and memory resources, plus some good algorithms, a human-like symbolic intelligence was feasible. It was just a matter of time, money and technology after all. After the initial excitement to this regard (mainly in the 1950s of last century) and numerous failures in reaching the desired results, it has been lately hypothesized that this may not be the case. Technically, the neuroendocrine system that provides the mechanisms for brain activity may not be a Turing Machine, though the functioning is not fully understood at the moment. In particular, it is not clear whether higher functions performed by humans, as for example consciousness, are epiphenomena of the brain itself or not.

Despite of this, and accepting the fact that we may not be able to model the full neuroendocrine system into the Von Neumann architecture, parallels can still be built, and relationships between the two can help in developing new systems for specific purposes. This is the case of Lövheim Cube of Emotion where analogies are only built on top of it in relation to *dopamine, serotonin and noradrenaline* brain levels. Simulation of emotions plays a major role in several IT and AI field, not last in the robotics. The ability of a system to feel emotions, for example, *fear, interest or joy* can trigger behaviors that were not possible in the era of *unemotional machines*. Our interest on emotional AI is not the result of basic curiosity, but is grounded on most of evidences that show emotions as main regulators of cognitive processes.

The study of brain disorders, related to emotional management, can also provide ways to understand some complex actions such as creativity, concentration or interest. Recently, a new generation of cognitive scientists and roboticists proposed a turnover: on one hand, emotions are a fundamental part of the cognitive processes (attention, motivation, strategy selection, mood disposal, reaction, invention, among a long list); on the other hand, the intrinsic relationship between mind and body led to the birth of embodied cognition or grounded cognition Barsalou (2008). This allowed the emergence of a second and powerful wave of cognitive and robotics experts lead by people like Brooks (1991), Brooks and Stein (1995), DeLancey (2001) (Robotics), Clark (2003) (Philosophy), Damasio (1999), Ramachandran (2004), and Rizzolatti and Craighero (2004) (Neuroscience).

In the middle of this cognitive revolution that led to embodied robotics, enactive cognition or morphological computation ideas, an important discipline emerged as a main reference: neuroscience. Neuroscientists revolutionized the discipline with data coming from *in vivo* scanned brains (by EEG, fMRI) and brought relevance to the emotional processes into the whole system. As a consequence, some authors, such as Llinás (2001), attempted explanations on the emergence of consciousness. Therefore, researchers in AI or cognitive sciences started to introduce ideas about emotional processing.

Once explained the crucial role of grounded and emotional aspects in cognitive architectures, we assume the Lövheim model as a reference for our own architecture. Lovheim (2012) based his theory on a three-dimensional model of emotions and monoamine neurotransmitters (*serotonin, dopamine, noradrenaline*). The vertexes of the model are affects, as defined by the Tomkins theory, which

[1] http://www.nest-initiative.org/.