Modulation of Multi-level Evolutionary Strategies for Artificial Cognition

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ABSTRACT
Integrating different kinds of micro-theories of cognition in intelligent systems when a huge amount of variables are changing continuously, with increasing complexity, is a very exhaustive and complicated task. Our approach proposes a hybrid cognitive architecture that relies on the integration of emergent and cognitivist approaches using evolutionary strategies, in order to combine implicit and explicit knowledge representations necessary to develop cognitive skills. The proposed architecture includes a cognitive level controlled by autopoietic machines and artificial immune systems based on genetic algorithms, giving it a significant degree of plasticity. Furthermore, we propose an attention module which includes an evolutionary programming mechanism in charge of orchestrating the hierarchical relations among specialized behaviors, taking into consideration the global workspace theory for consciousness. Additionally, a co-evolutionary mechanism is proposed to propagate knowledge among cognitive agents on the basis of memetic engineering. As a result, several properties of self-organization and adaptability emerged when the proposed architecture was tested in an animat environment, using a multi-agent platform.

Categories and Subject Descriptors
I.2.6 [Artificial Intelligence]: Learning – connectionism and neural nets, knowledge acquisition. I.2.11 [Artificial Intelligence]: Distributed Artificial Intelligence – Intelligent agents, multiagent systems.

General Terms

Keywords
Cognitive architectures, gene expression programming, artificial immune systems, neural nets, memetics.

1. INTRODUCTION
There are several theories of cognition, each taking a different position on the nature of cognition, what a cognitive system should do, and how a cognitive system should be analyzed and synthesized. From these, it is possible to discern three broad classes: the cognitivist approach based on symbolic information processing representational systems; the emergent systems approach embracing connectionist systems, dynamical systems, and enactive systems, all based on a lesser or greater extent of principles of self-organization [1], and the hybrid approach which combine the best of the emergent systems and cognitivist systems.

Our research focuses on implementing a hybrid architecture for cognitive agents supported by both cognitivist and emergent approaches. On the one hand, the cognitivist approach provides an explicit knowledge representation through the use of symbolic AI techniques. On the other hand, the emergent approach defines three evolutionary strategies as observed in nature [11]: Epigenesis, Ontogenesis, and Phylogenesis, endowing the architecture with implicit knowledge learning, sub-symbolic representations, and emergent behavior guided by bio-inspired computational intelligence techniques.

2. PROPOSED HYBRID COGNITIVE ARCHITECTURE
Architecture is distributed in two dimensions: horizontal and vertical dimensions (see Figure 1). At horizontal dimension, modules belong to either emergent or cognitivist level, whereas modules at vertical dimension are distributed according to their functionality (attention, procedural reasoning, intentions, motor processing, and so on).

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GECCO ’09, July 8–12, 2009, Montréal Québec, Canada.

Figure 1. Hybrid Cognitive Architecture.

In our work, the epigenetic approach references to the mechanisms that allow agent modifying some aspects of its both internal and external structure as a result of interacting with its...
environment, in other words, “learning”. This approach is driven in our architecture by task-oriented Specialist Behaviors (SB). Therefore, we propose the development of two main approaches which intend to simulate the most evident epigenetic systems observed in nature: the central nervous system and the immune system. These systems are simulated inside the architecture by the connectionist and autopoietic modules.

The SBs are proposed as hybrid units of procedural processing which are in charge of specializing the cognitive skills of the architecture. These specialists are hybrid because of incorporation of both symbolic and sub-symbolic components at the procedural module (production rules, neural networks, and autopoietic machines).

The purpose of including multiple components in an SB is that each one compensates the weaknesses of the rest. For example, neural networks are often better at making forward inferences about object categories than production rules, whereas production rules are often better at making forward inferences involving causal change than neural networks. Autopoietic machines are able to make both kinds of inferences from implicit representations but it involves less processing time discovering new rules than the other two components. Hence, we stated that the main architectonic features of procedural module are parallelism, behavior specialization, and autonomy:

The Connectionist module (found at the emergent level of the diagram) models innate skills, which require less processing time in comparison with other deliberation processes. It therefore uses the Backpropagation Neural Networks (BNN) which is more appropriate for enacting reactive reasoning.

The Autopoietic Machines module is formed by multiple self-organized and self-regulated systems, where each one models a set of sub-symbolic rules on the basis of autopoietic principles [3]. We propose an Artificial Immune System (AIS) [5] as an autopoietic machine which starts with an sensory input data set (antigens) that stimulate an immune network, and then goes through a dynamic process until it reaches some type of stability.

The Ontogenetic approach defines the history of structural change in a unity without the loss of organization that allows that unity to exist. Some outcomes of these principles as self-replication and self-regulation properties in biological systems can be valued.

In our work, the ontogenetic approach is simulated through the interaction among different modules: the Attention module (based on Global Workspace Theory [2]), the Goal module, the Anticipatory Module, and the SBs in Procedural module.

The attention module defines a set of attention machines (AM), which are systems implemented as attention fixations that execute algorithms by sequences of SBs. Each AM has a set of premises that describe the pre-conditions of AM activation, the stream of SBs, and the post-conditions that will have to guarantee after the execution of the stream. Te pre-conditions indicate the goals, expectations, emotions, and stimuli (provided by the working memory) which the agent will have to process and satisfy at any given time. The stream of SBs is a sequence of SBs and relations among them which describes how the agent must behave in a particular situation. Finally, post-conditions are a set of states and new goals generated after the execution of the stream.

We propose an evolutionary model based on Gene Expression programming (GEP) [4] that is used to evolve the AMs in order to generate an appropriated behavior orchestration without defining a priori the conditions of activation about each SB. Each agent has a multigenic chromosome, that means, each chromosome has a gene set where each gene is an eligibility rule like in the example, so the agent has several rules (genes) as part of its genotype and each one is applied according to the situation that matches the rule antecedent. Each gene becomes to a tree representation and afterwards some genetic operators are applied among genes of the same agent and genes of other agents, as in [4]. These genetic operators are: selection, mutation, root transposition, gene transposition, two-point recombination and gene recombination, in order to evolve chromosomal information.

After certain number of evolutionary generations, valid and better adapted AMs are generated. A roulette-wheel method is used to select individuals with most selection probability derived from its own fitness. Fitness represents how good interaction with environment during agent’s lifetime was.

On the basis of phylogenetic theory [3], a co-evolutionary mechanism is proposed to evolve fine-grained units of knowledge through the multi-agent system, taking the foundation of meme and memetic algorithms [6]. In our work, each meme contains a symbolic and sub-symbolic representation of knowledge, and also a set of indicators such as demotion, reliability, rule support and fitness.

3. REFERENCES