

A Framework for the Implementation of Artificial Robotic Emotional Brain Based on Embryonic and Evolutionary Hardware

Fernando Cortez Sica
 Department of Computer Science
 Federal University of Ouro Preto
 Ouro Preto, Brazil
 Graduate Program in Electrical Engineering
 Federal University of Minas Gerais
 Av. Antnio Carlos 6627, 31270-901
 Belo Horizonte, MG, Brazil
 sica@iceb.ufop.br

Ricardo de Oliveira Duarte
 Department of Electronics
 Federal University of Minas Gerais
 Av. Antnio Carlos 6627, 31270-901
 Belo Horizonte, MG, Brazil
 ricardoduarte@ufmg.br

Frederico Gadelha Guimarães
 Department of Electrical Engineering
 Federal University of Minas Gerais
 Av. Antnio Carlos 6627, 31270-901
 Belo Horizonte, MG, Brazil
 fredericoguimaraes@ufmg.br

Abstract—This paper proposes a framework architecture to export services and facilities for the implementation of artificial robotic emotional brain. The framework utilizes concepts from embryonic and evolutionary hardware. Additionally, we map correlations between computational systems with natural cognition, knowledge formation and representation. The main contribution of the paper relies in the utilization of symbolic and connexionist approaches to cover all the knowledge representation aspects. This way, this framework facilitates the implementation of generic intelligent systems.

Keywords—*embryonics; evolutionary systems; evolvable hardware; artificial brain; artificial life.*

I. INTRODUCTION

Many current systems that require action-behavior predictions, e.g., control systems, data mining, biomedical analysis and telemetry systems, are focused on the knowledge manipulation, whether deterministic or not. Real systems can be highly susceptible to environmental interferences, often not evaluated and not covered during the intelligent system modeling and simulation.

Considering these challenges and demands, this paper aims to develop a framework for developing artificial robotic emotional brains endowed with embryonic and evolutionary mechanisms. The model presented is general and can be used in many applications that require knowledge manipulation for decision making. A possible application of this framework is the implementation of decision support and diagnostic systems. In both cases, the artificial brain has the ability to learn, in a continuous way, new rules and structures on the manipulated knowledge.

In the intelligent systems area, we can find implementations using three different approaches: symbolic (which simulates the reasoning mechanism without considering the biological factor), connexionist (which simulates the biological brain structure to process knowledge) or hybrid approaches [4]. As examples of these approaches, we can cite the projects described in [1], [2] and [3], respectively. In our case, we adopt the hybrid approach to make the system flexible in relation to knowledge representation (as mentioned in Subsection III-B).

This framework implements embryonic and evolutionary mechanisms on a software and hardware integration solution. The solution adopted by this framework is used to map artificial robotic brain

cognitive models and also to provide a direct mapping between cognitive science concepts and computer science.

In addition of being able to contribute to achieve the fusion between embryonic and evolutionary mechanisms, this project is also intended to make adaptation and modeling using autonomous intelligent agents in the computational design. The use of intelligent agents will facilitate the abstraction of the mental structures and their relations, allowing for a better representation of the artificial mental scheme. In this context, by artificial mental scheme we mean the way knowledge is represented and abstracted.

The manipulation of emotional factors will act as excitatory or inhibitory signals to the process of knowledge manipulation, learning and decision making.

In order to validate the proposed model, this project will be applied in an example of application that require knowledge manipulation for decision making: aircraft system health monitoring [5]. The artificial robotic emotional brain, substantiating the knowledge stored in his hybrid structure (connexionist and symbolic), will be able to assist the aircraft failure prevention systems. In this case, the stimuli and input information will be collected from the electronic components and, from these, the system will be able to generate, autonomously, the knowledge needed to be converted into preventive actions.

This paper is structured as follows. In Section II, the basic concepts in cognitive systems and evolutionary robotics are presented. In Section III, the proposed framework architecture is described and our basic mechanism is shown in Section IV. In Section V, the preliminary results are provided. Finally, we present our conclusions in Section VI.

II. BACKGROUND

A. Cognitive Systems

Initially, it is interesting to mention that the cognitive process presents a dynamic behavior. This dynamic behavior is related to the environment interaction: collecting information, encoding it, storing it and processing it such that then there may be some action performed in the environment.

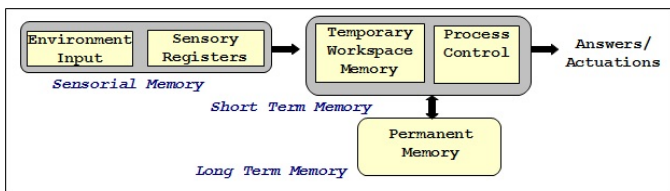


Fig. 1: Cognitive model proposed by Atkinson and Shiffrin in 1971 [6]

The work described by Atkinson and Shiffrin [6] portrays one of the first relevant cognitive computational systems. In that work, a cognitive system is described as a hierarchical memory system: sensory memory, short term memory and long term memory (Figure 1).

Other models, such as in [7] – [11], have been proposed with opposite ideas or complementary ideas to the model of hierarchical memory. Some of these proposals have incorporated the filter attention idea. Filters are capable of acting in the attenuation or amplification of signals to be inferred and manipulated by the cognitive system. Filters react due to the emotional aspects, stored knowledge and importance of the stimuli.

To better illustrate the cognitive systems idea, Figure 2 presents the model proposed in [12].

In the architecture shown in Figure 2, the perception and action events produce signs that can be evaluated for the formation of beliefs. Beliefs are states and interactions expected to be assumed by the agent. During the action event, there is a feedback for possible restructuring of signs, adapting them to the new situation imposed by the environment. Every action is the result of the Action Selection process computed by the deliberative module.

Another important issue in cognitive systems is the knowledge representation. The information to be stored for later processing represents information about the environment and about the system itself, rules, goals, heuristics, relationships, actions, events and other information used to represent the real world and its interaction with the computational system. The most well-known techniques for knowledge representation are based on logics (predicate calculus), production rules, frames, conceptual graphs and ontologies, and combinations of these techniques. [13]

B. Evolutionary Robotics

One of the first projects in evolutionary robotics is presented in [14]. In that work, a navigation system to enable a robot to move in an area with obstacles was designed.

Another application in evolutionary computation and electronics that deserves to be mentioned for its pioneering in the scope of artificial brains can be found in [15] and [16]. In these references, a brain structure is mapped through a three-dimensional arrangement using FPGA (Field-Programmable Gate Array) [17].

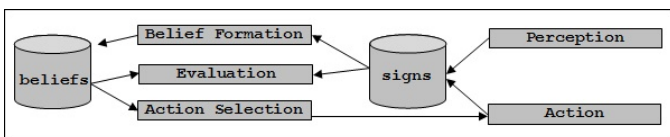


Fig. 2: IVA (Intelligent Virtual Agent) Architecture proposed by A. Arnellos et al. [12]

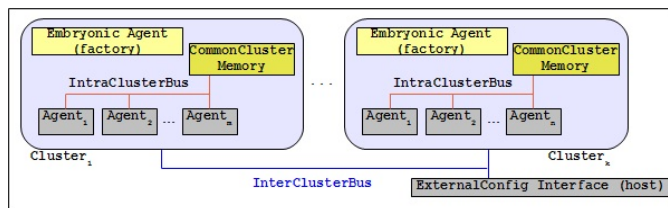


Fig. 3: Proposed architecture for the artificial robotic emotional brain

Others applications can be cited, as control engineering based on artificial brains endowed with emotions [18] – [20].

III. PROPOSED ARCHITECTURE

In general terms, the proposed architecture (Figure 3) for the development of robotic artificial emotional brain based on embryonic and evolutionary hardware uses the idea of autonomous intelligent agents for clustering information and, consequently, to better express the knowledge incorporated by the agents. Another reason for clustering is to resemble the brain anatomy, where the cortex is divided into functional areas, allowing for a better computational performance and a higher system granularity.

Figure 3 shows a macroscopic view of the system with multiple clusters instantiated. Each cluster has three basic and fixed elements (*Embryonic Agent*, *CommonCluster Memory* and *IntraClusterBus*) and their respective agent instances.

The *Embryonic Agent* manages the creation or removal of agents instances. This mechanism allows for the self-adaptation of the multi-agent systems, given the environment dynamics. The *CommonCluster Memory* is a common area for information storage (long term memory). The *IntraClusterBus* and the *InterClusterBus* are communication elements based on the *Wishbone* standard [21].

Referring to Figure 3, notice the presence of instances of agents in the clusters. Each agent, operating autonomously and cooperatively, is responsible for: Sensory information acquisition (sensory system); Encoding, storage and data processing; Actuation on the environment.

To accomplish such functions, each agent has a functional structure illustrated in Figure 4.

Figure 4 presents the basic elements that comprise the cognitive agent: *sensory system*; *storage, coding and processing system (SCP System)*; *Agent Core* and *Agent Memory*, which will be described below.

A. Sensory System

The *sensory system* must be able to pick up stimuli from the environment to provide knowledge modifications and to make the

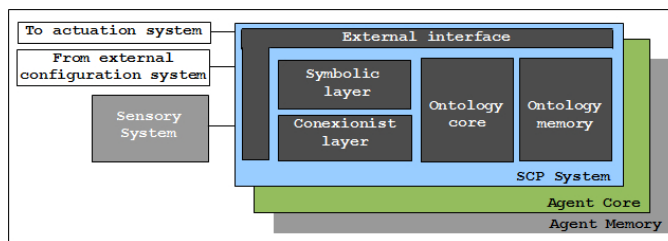


Fig. 4: Functional structure of each agent.

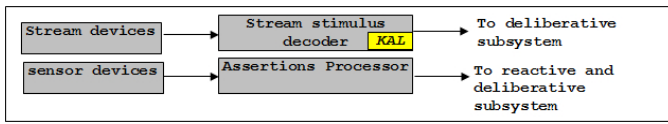


Fig. 5: Structure of the sensory system.

actuation on the external environment promptly. These two processing types represent the deliberative and reactive behavior, respectively [12].

The *sensory deliberative system* is responsible for interfacing the system with the environment to capture, for example, image, sound or other waveforms (stream devices). Regardless of the device type used to capture data, the goal of the sensory deliberative system consists in encoding external stimuli in connexionist mappings. The connexionist maps will be the cognitive system basis - in this case, the information will form, according to Peirce [22], the informational *Firstness*, i.e., isolated information that does not represent knowledge yet (*qualisigns*).

The Peirce categorizations (*Firstness*, *Secondness* and *Thirdness*) for the organization of symbols in the knowledge generation will be contextualized, in system level modeling, during the explanation inherent to the *SCP System*.

The reactive sensory system should observe environmental values, which represent exceptions to normal conditions. Therefore, in order to get a prompt response, this project utilizes a library for hardware failures verification: the *Open Verification Lib (OVL)* [23].

Since *OVL* is a library for fault verification and its utilization is motivated by:

- Continuous checking of critical elements (values);
- Product evaluation during all life cycle;
- Possibility of incorporating fault tolerance mechanisms. It is understood as those originating failures due to errors in design or transient errors;
- Possibility of activating reconfiguration mechanisms when hardware and software flaws are observed.

The use of *OVL* purely as a flaw verification and correction element can be found in [24], where chained assertions are used to send signals to a functional element (e.g., a processor) to perform specific events. However, in this project, *OVL* will be used as an inspection element of values that might result in events of the reactive system. This idea of using the library to launch various events can be found in [25], where assertions (monitoring points within the hardware) are used in order to extend the exception handling in the computing environment.

In conclusion, in order for the deliberative and reactive systems to receive information from the environment, the sensory system consists of two functional modules, as explained in Figure 5.

Also, in relation to Figure 5 and to the sensory system, the stimulus stream decoder aims to capture and process information streams (stimuli), e.g., video and sound, dividing them into frames such that they can be evaluated and handled by the deliberative system. The coding models used by the decoder are stored in a repository called *Knowledge Abstraction Layer* (denoted by *KAL*).

The assertions processor is a hardware that aims to collect information from sensors and to signal the reactive and deliberative systems when previously determined values (or range of values) occur. This information will shape or will interfere with the emotions or the artificial robotic brain learning rates.

B. Storage, coding and processing system (*SCP System*)

In order to allow greater modularity and reuse of the mental structures that represent knowledge, the *SCP System* is based on a hybrid topology, adopting, in this case, the connexionist and symbolic models. A hybrid modeling was adopted to best abstract Peirce's categorizations for knowledge representation and composition. In this case, one has:

- *Firstness*: connexionist model where each nerve cells cluster denotes a real-world object - the *qualisigns*;
- *Secondness*: mapping between the connexionist model and the stored knowledge by means of ontologies to denote the signs composition and structuring;
- *Thirdness*: application of high-level ontological rules to thought and logical reasoning formation, relating *Firstness* and *Secondness* instances.

The *SCP* internal elements form the robotic artificial emotional brain basis and can be replicated in clusters for better information representation (knowledge classes) and to provide greater dynamism to processing. Each cluster can evoke cluster creation or destruction functions exported by the *embryonic agent layer (factory)*, shown in Figure 3.

For a better detailing of the model, the components belonging to the *SCP* will be presented in the following sections.

1) connexionist Layer: Briefly, under the biological viewpoint, a neuron can have as basic functionalities: to receive external stimuli (afferent neurons), to provide the interneurons association (associative neurons) and to provide the output stimulus (motor neurons). Regarding its functionality in associative aspect, a neuron can be pyramidal (derived association between layers) and non-pyramidal (provides connection between neurons in the same layer).

For modeling purposes, this project will model only two neurotransmitters to incorporate the emotions idea: acetylcholine (acting in attention, learning and memory) and glutamate (associated with long-term memory and learning) [26]. The neurotransmitters act only in the symbolic processing layer because they are cognitive processes and long-term memory regulatory elements. The change in levels of neurotransmitters is due to the information values provided by the sensory acquisition.

Finally, completing the basic biological characterization and to give the clustering abstraction, the cortex is divided into association regions (where the motor and sensory areas are located) and projection regions (where the processing itself is performed). Initially, we mapped only two cell types: pyramidal and non pyramidal. This criterion was adopted to provide communication optimization and to better manipulate the attribute types associated with each cell. Pyramidal cells are modeled only as connection cells between layers. Non pyramidal cells can be classified as afferent, associative and motor.

The mechanisms for the creation of neuronal structures are contained in the acquisition layer, represented by the *KAL*.

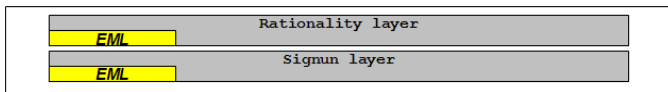


Fig. 6: Structure of the Symbolic Layer.

In this project, only projection cortex areas are mapped, since the mechanisms associated with the association areas are handled by the symbolic processing layer. The number of instantiated regions is related to the external stimuli types to be captured by the system. To facilitate the processing, the cortical regions may be further divided, making the system scalable according to the actual needs.

2) *Symbolic Layer*: The function of the Symbolic Layer is the formation of signs and reasoning in the artificial robotic emotional brain. It should act in accordance with the ontologies stored in its bases. Moreover, it is responsible for the implementation of the evolutionary mechanisms that allow a cognitive dynamics.

In order to abstract Peirce's categorizations as mentioned earlier, the symbolic layer is divided into two sublayers (Figure 6).

In Figure 6, note the presence of the evolutionary mechanisms layer (*EML - Evolutionary Mechanisms Layer*), which, as already mentioned, will provide system reconfiguration mechanisms to signs generation and logical reasoning improvement.

3) *Ontology Core*: The *Ontology Core* is based on a general purpose microprocessor optimized to memory access. The basic function of the Ontology Core is to execute the XML parser, which performs search and manipulation operators over the XML structures (*XML* denoting ontologies). It was decided, initially, to use a general-purpose microprocessor because of the ease to implement *XML* parser via software. The ontologies, in our project, provide the knowledge representation under manipulation, e.g., grammatical rules, a circuit specification or an initial Bayesian network [27].

4) *Ontology Memory*: The *Ontology Memory* module has the function of storing ontologies manipulated by each agent cluster.

5) *Agent Core*: The *Agent Core* is a general purpose processor to perform the agent functions. To ensure efficiency, flexibility and software availability, the *OpenRisc 1200* [28] has been chosen to equip the framework.

6) *Agent Memory*: Unlike *Ontology Memory*, the *Agent Memory* aims to store agents code and attributes (e.g., their states).

C. Actuation System

For initial and prototyping purposes, the *Actuation System* is modeled as simply a set of input and output pins in order to provide basic functionality, for example, digital output, strobe and *ACK* pins.

D. Communication System

Besides the need to represent the cognition environment, it is also necessary to have infrastructure for communication between agents and between agent clusters. Joining the cognitive functionalities, where each cluster stores part of the knowledge, intra and inter communication mechanisms are also required. Returning to Figure 1, these two communication levels are represented by *IntraClusterBus* and *InterClusterBus* respectively. To facilitate the initial prototype, it was decided to use an open model bus: the *Wishbone*.

TABLE I: Hardware Values

FPGA model	Xilinx Spartan 3
Number of LUTs	1% (9 of 15360)
Number of IO Ports	12% (27 of 221)
Number of Slice Flip-Flop	1% (15 of 15360)
Minimum period	4.238ns (Max. Freq.: 235.960MHz)
Minimum input arrival time before clock	7.032ns
Maximum output required time after clock	8.962n
Maximum combinational path delay	8.618ns

IV. PROPOSED BASIC MECHANISM

As mentioned earlier, our project uses a hybrid architecture to acquire, map and process information. More specifically, we used:

- SOFM (Self Organizing Feature Maps) and direct load values to discover new basic information types (Firstness);
- Bayesian Networks to map the relationship between the primary information;
- Extraction of production rules from the Bayesian Network;
- Conversion of production rules to electronic digital logic.

In brief, Figure 7 illustrates the information composition scenario.

Faced with this scenario, we adopted the following algorithm:

Algorithm 1 Basic Update Values Algorithm

```

if new external stimulus then
  if mapped knowledge then
    update the hardware registers values
    hardware inference start
  end if
  modify the Bayesian Network
  run learning evolutionary mechanisms (into Bayesian Network)
  run the mechanism to extract production rules from Bayesian Network
  transfer, on-the-fly, the new production rules structure to the
  programmable device (FPGA)
end if
    
```

V. PRELIMINARY RESULTS

A hardware prototype was designed to support production rules with up to 256 nodes (Figure 8 shows the hardware interface).

The modification of the production rules will change, only, the internal routing, without the insertion of new hardware structures. Table I shows relevant information about the hardware designed.

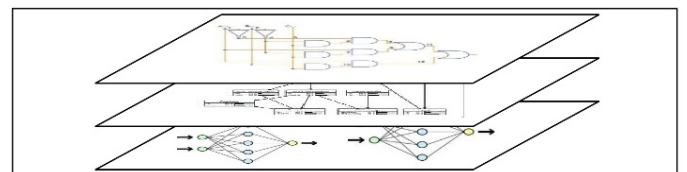


Fig. 7: Composition of information: the lower layer corresponds to the isolated values of information obtained from SOFM or general data input (e.g., sensors); the intermediate layer denotes the Bayesian Network and, finally, the upper layer represents the mapping in electronic digital logic.

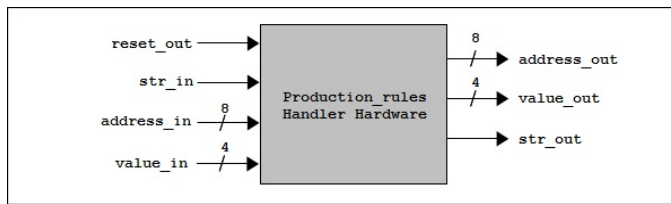


Fig. 8: Hardware interface of the production rules handler (reset_out: reset the strobe out pin; str_in: strobe input; address_in: input node identification; value_in: input node value; address_out: identification of activated output node; value_out: value of activated output node; str_out: strobe out).

VI. CONCLUSION AND FUTURE WORK

This paper presented the framework architecture for the development of artificial robotic emotional brains based on embryonics and evolutionary hardware.

Our framework has been tested in small production rules. The result was satisfactory with respect to the response time of the external stimulus (in about 8ns). The FPGA reconfiguration time was not taken into account at this stage in the project.

As future plans, and for testing and validation purposes, this framework will be used in the implementation of a commercial aircraft proactive maintenance system. The signals from the aircraft systems and components will act in reactive and deliberative knowledge processing. The signs will also be modeled as emotional elements that interfere in the sensitivity level to be passed to the cognitive process and to the reactive actuation system.

ACKNOWLEDGMENT

This work has been supported by the Brazilian agency CAPES [29].

REFERENCES

- [1] J. R. Anderson, J. M. Fincham, Y. Qin, and A. Stocco, "A central circuit of the mind," *Trends in Cognitive Science* 12 (4), 2008, pp.136143.
- [2] J. Mugan and B. Kuipers, "Autonomously learning an action hierarchy using a learned qualitative state representation," *Proc. 21st International Joint Conference on Artificial intelligence (IJCAI'09)*, 2009, pp. 1175-1180.
- [3] N. Cassimatis, "Adaptive algorithmic hybrids for human-level artificial intelligence," *Advances in Artificial General Intelligence*, IOS Press, 2007, pp.151163.
- [4] B. Goertzel, R. Lian, I. Arel, H. de Garis, and S. Chen, "A world survey of artificial brain projects, part II: biologically inspired cognitive architectures," *Neurocomputing* 74 (2010), 2010, pp. 3049.
- [5] R. Kothamasu, S. H. Huang, and W. H. VerDuin, "System health monitoring and prognostics - a review of current paradigms and practices," *Handbook of Maintenance Management and Engineering*, 2009, pp. 337-362.
- [6] R. C. Atkinson and R. M. Shiffrin, "The control of short term memory," *Scientific American*, August 1971, 225(2), 1971, pp. 82-90.
- [7] A. D. Baddeley and G. J. Hitch, "Working memory. The psychology of learning and motivation," *Academic Press*, 1974, pp. 47-89.
- [8] S. Franklin, "Autonomous agents as embodied AI," *Cybernetics and Systems*, 28:6, 1997, pp. 499-520.
- [9] D. Isla, R. Burke, M. Downie, and B. M. Blumberg, "A layered brain architecture for synthetic creatures," *Proc. 17th International Joint Conference on Artificial Intelligence (IJCAI'01)*, Volume 2, 2001, pp. 1051-1058.
- [10] R. Imbert and A. de Antonio, "An Emotional Architecture for Virtual Characters," *Proc. Third international conference on Virtual Storytelling: using virtual reality technologies for storytelling (ICVS'05)*, 2005, pp. 63-72.
- [11] J. E. Kogler Junior, R. I da Silva Filho, et al., "First steps toward a cognitive architecture based on adaptive automata," *Proc. Workshop on Modelling Adaptive and Cognitive Systems (ADAPCOG)*, 2008, pp. 1-11.
- [12] A. Arnellos, S. Voinakis, G. Anastasakis, and J. Darzentas, "Autonomy in virtual agents: integrating perception and action on functionally grounded representations," *Proc. 5th Hellenic conference on Artificial Intelligence: Theories, Models and Applications (SETN '08)*, 2008, pp. 51-63.
- [13] E. Motta, "Reusable components for knowledge modelling: case studies in parametric design problem solving," *IOS Press Amsterdam, The Netherlands*. 1999.
- [14] A. Thompson, "Evolving electronic robot controllers that exploit hardware resources," *Proc. III European Conference on Artificial Life (ECAL95), Advances in Artificial Life*, Springer-Verlag, 1995, pp. 640-656.
- [15] H. de Garis, "CAM-Brain: A new model for ATR's cellular automata based artificial brain project," *Proc. International Conference on Evolvable Systems (ICES'96)*, 1996, pp. 437-452.
- [16] H. de Garis and M. Korkin, "The CAM-Brain machine (CBM): real time evolution and update of a 75 million neuron FPGA-based artificial brain," *Journal of VLSI Signal Process. Syst.* 24, 2/3, March 2000, pp. 241-262.
- [17] I. Kuon, T. Russell Tessier, and Jonathan Rose, "FPGA architecture: survey and challenges," *Foundations and Trends in Electronic Design Automation*, Vol. 2(2), 2007, pp. 135253.
- [18] B. M. Dehkordi, A. Parsapoor, M. Moallem, and C. Lucas, "Sensorless speed control of switched reluctance motor using brain emotional learning based intelligent controller," *Energy Conversion and Management* 52, 2011, pp. 8596.
- [19] M. R. Jamali, A. Arami, M. Dehyadegari, C. Lucas, and Z. Navabi, "Emotion on FPGA: model driven approach," *Expert Systems with Applications* 36, 2009, pp. 73697378.
- [20] A. Sadeghieh, H. Sazgar, K. Goodarzi, and C. Lucas, "Identification and real-time position control of a servo-hydraulic rotary actuator by means of a neurobiologically motivated algorithm," *ISA Transactions* 51, 2012, pp. 208219.
- [21] M. Sharma and D. Kumar, "Wishbone bus architecture - a survey and comparison," *International Journal of VLSI design & Communication Systems (VLSICS)* Vol.3, No.2, April 2012, pp. 107-124.
- [22] C. S. Peirce, "Collected Papers," *Harvard University Press*, 1958.
- [23] <http://www.accelera.org/activities/committees/ovl> (Retrieved: Jan 2013).
- [24] J. A. Nacif, F. M. De Paula, H. Foster, C. Coelho, F. C. Sica, and A. O. Fernandes, "The chip is ready. Am I done? on-chip verification using assertion processor," *Proc. VLSI-SOC2003*, 2003, pp. 111-116.
- [25] F. C. Sica, J. A. M. Nacif, C. N. Coelho Jr, F. M. de Paula, H. Foster, J. M. Mata, D. C. Silva Jr, and A. O. Fernandes, "Exception Handling in Microprocessors Using Assertion Libraries," *Proc. 17th Symposium on Integrated Circuits and Systems Design (SBCCI 2004)*, 2004, pp. 55-59.
- [26] L. M. Giocomo and M. E. Hasselmo, "Neuromodulation by glutamate and acetylcholine can change circuit dynamics by regulating the relative influence of afferent input and excitatory feedback," *Mol Neurobiol* 36, 2007, pp.184200.
- [27] M. J. Druzdzel and L. C. van der Gaag, "Building Probabilistic Networks: Where Do the Numbers Come From?," *IEEE Trans. on Knowledge and Data Engineering*, 12(4), 2000, pp. 481-486.
- [28] D. Lampret, "OpenRisc 1200 IP Core Specification," http://www.da.isy.liu.se/courses/tsea44/OpenRISC/or1200_spec.pdf (Retrieved: Jan 2013).
- [29] <http://www.capes.gov.br/>