



Reinforcement Learning based on Computational Cognitive Neuroscience in Neuromorphic VLSI Chips

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Abstract— Recent advances in study of Information Processing systems have developed in a number of interrelated, yet distinct disciplines which are developing overlapping domains of inquiry. Most of the attention, however is given to the Cognitive Sciences, which is the empirical study of intelligent systems, including humankind. Neuromorphic systems are inspired by the structure, function and plasticity of biological nervous systems. This field is evolving a new era in computing with a great promise for future medicine, healthcare delivery and industry. This paper focuses on the emerging trends in computational cognitive sciences by surveying on a new interdisciplinary field called neuromorphic engineering. A complete overview starting from its origin to its applications is described. The overall process of developing neural networks and simulation of them in a form of neuromorphic chip is explained. Modeling of Attention and Perception is done. Trivial Perception is modeled based on BDI models. In this paper, Cognitive models are used to implement the Reinforcement Learning in Neuromorphic VLSI Chips, to exhibit intelligence when the machines are exposed to an undefined Situation

Keywords— Computational Science, Cognitive Science, Neuroscience, Reinforcement Learning, Neuromorphic Engineering.

I. INTRODUCTION

Cognitive Science combines various disciplines of sciences to study different processes and activities of mind, with application for Information Technology and the study of AI. Study of Cognitive Computing involves both aspects of science and engineering. First we have to understand working of brain- how it processes information, create emotions and achieves cognition. By this it would be possible to create computer which can think and feel, like us. We propose to implement Cognitive architectures in Neuromorphic VLSI Chips for scientific study of human mind. The field is highly interdisciplinary, combining ideas and methods from psychology, computer science, linguistics, philosophy and neuroscience. Broadly speaking, the goal is to characterize the nature of human knowledge— its forms and content and how the knowledge is used, processed and acquired. Active areas of cognitive research include language, memory, visual perception and cognition, thinking and reasoning, social cognition, decision making and cognitive development.

Brain networks have dense clustered local connectivity between any pair of neurons or regions in networks. Neurons and synapses are well accepted as the basic functional components of a brain, just as the switches are the basic components of digital computer. In our effort to develop cognitive systems over a Neuromorphic computing architecture we try to design the hardware for cognitive information processing applications and thereby giving rise to emerging Neuromorphic computing architectures. The principles and methodologies of Cognitive sciences are being implemented to robots, so as to create humanoid robots. These robots are not just software agents but are mobile robots and autonomous vehicles. In Neurolinguistics, Cognitive Computing is used to solve neurocognitive disorders and help in computational modeling. There are many projects using Cognitive computing for investigation of different languages like Spanish, Russian, Japanese, Portuguese, and Dutch etc. Cognitive computing is also used in investigation of hearing and speech. Brain imaging technique also uses Cognitive computing to see how a man speaks in pathological conditions as compared to healthy conditions

Cognitive computing promises safer more enjoyable future. This has been the most awaiting technology of the era for humans. Present day machines are recognizing images, voice, detect face as we do. The day is not far when these machines start recognizing our languages, emotions and respond accordingly.

IBM and Swiss government collaboration is aiming to build replica of neocortical column followed by whole brain that too in a decade. This research will help repair damaged brains today and allow robots to mimic humans tomorrow. “Smart” cars: Many automotive industries are highly investing on automation and computerized safety features. This may lead to driverless vehicles in future. Automating war: Intelligent robots can be used as spy and pilots to enter into the enemy territory thereby saving many lives of soldiers. Humans loose neurons because of old age, these aged neurons can be replaced and in future according to John Bruce “We could be replacing our brain cells with non-biological nanotech materials which processes faster than our brain. Cybernetics expert Christ of Koch predicts cognitive computing will grow in such a way that by mid-2020, human machine interface will become routine. Soon we are going

to see robots which will read our mails and messages and reply according to our expressions, responses and non-verbal behavior.

II. BACKGROUND

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The semiconductor/VLSI (electronics) industry has been following Moore's Law since several decades, and has reaped tremendous benefits in terms of transistor speed and density. Transistor density on current state-of-the-art Intel microprocessors has reached billion/die, and transistor speeds are in pico-seconds. However, the semiconductor industry is now facing several challenges as the transistor scaling (according to Moore's Law) approaches the lower nano-scale regime. In addition, so far, the computer industry has focused on only general-purpose processors/architectures. Some ultimate questions for the future of the computer engineering field are: How do we advance the field of computer engineering over the next few decades? And how do we efficiently utilize the currently available high density and speed advantages of semiconductor technology? Other than general-purpose computing, where else can we use computer technology?

Human Brain is different from Computers. Major difference is in Information Processing. Computers follow instructions of programmed algorithms and user inputs, the information in memory are accessed by byte-addressing. In contrast human brain processes information in non-linear way, the brain access memory by content-addressing i.e. by "spreading activation" from closely related concepts. Brain is like a "built-in Google" where few keywords are enough to cause a full memory to be retrieved as in [24]. Early computers had fixed programs, later came the stored program concept. The stored-program design allows the programs modify themselves while running. Stored program computer also called as Von Neumann architecture. But the architecture has two fundamental drawbacks: 1. the connection between the memory and processor can get overloaded, there by sacrificing the speed of computer and 2. Specific programs should be written to perform specific tasks.

In contrast, "human brain works by activating thought modules" (Cognitive Modules). The brain distributes memory and processing functions throughout the system, undergo learning by situations and uses a complex combination of reasoning, synthesis and creativity to solve the problems it has never encountered before. Cognitive Science and human mind are interconnected. Cognitive researches study nature of intelligence from a psychological point of view, mostly building compute models which help in analyzing what happens in our brains during problem solving, remembering, perceiving and other psychological process .

III. THE SURVEY

A survey that too in such a topic can never be exhaustive, firstly because of less space and secondly because there have been so many attempts. Here we briefly review some recent and important work. Most, if not all, of this work involves implementation of cognition and not just theory, and was carried out in last two decades.

1. Sony Computer Laboratory Paris: "Generating Plausible models for processes underlying children's development," [9], Children acquire new things in a continuous and open-ended manner in their initial years of childhood. It needs an integrative approach to capture the part of open-ended nature that characterizes children's development. New biologically-inspired architectures are designed to control autonomous. This work helps to understand the mechanisms involved in human development and provide new perspective to the building of intelligent robots.

2. The Genesis Group [MIT]: The group believes that we have to understand the contributions of our vision, language, motor and faculty-connection mechanisms to understand the nature of human intelligence [10]. The members also believe that those faculties make it possible to understand physical world which will provide a foundation for abstract thinking and learning.

3. MIT Computational Cognitive Science group: Through a series of mathematical modeling, computer simulation and behavioral experiments [11], the members of this group are trying to study the computational basis of human learning and interference.

4. University of California-Merced: Kello and his team are creating a virtual environment that could train the simulated brain to experience and learn. The training is provided by an unreal tournament video game engine [12]. Once it is ready, it will teach the neural networks how to make decisions and learn by the time.

5. Department of Brain and Cognitive Sciences (BCS): "Maggie is a smart monkey". It plays video games to generate abstract representations and then use those abstractions as tools. Maggie's gaming [13] lies at the intersection of Artificial Intelligence and Neuroscience.

6. SuperMemo: SuperMemo is a software program which will turn people into geniuses. SuperMemo is based on finding the right moment to practice what you have learned. Practice too soon and you waste your time practice too late and you have forgotten, hence the right time to practice is just a moment you are about to forget. It was invented by Piotr Wozniak and was based on spacing effect by Hermann Ebbinghaus.

7. IBM Almaden Research Centre: "The plan is to engineer the mind by reverse-engineering brain," says Dharmendra Modha, manager of Cognitive computing project. The Cognitive computing team [14] is achieving progress in creating a large scale cortical simulation and new algorithm which synthesis neurological data-2 major milestones on the path to Cognitive computing chip. IBM says computers that mimic the human brain are just 10 years away.

8. IBM Cat-like Cognitive Computing: As in [15], IBM researchers have developed a Cognitive computer simulation that mimics the way a cat brain processes thought, and they expect to mimic human thought processes within a decade.

9. IBM Blue matter Algorithm: To measure and map the human brain, IBM scientists have developed a Blue matter algorithm which exploits the blue gene supercomputing architecture. As in [16], they use magnetic resonance diffusion weighted imaging to map the brain's communication network which will help the scientist to know how human brain represents and processes information in a tiny space and little energy.

10. Carnegie Mellon University: "There is an identifiable neural pattern associated with perception and contemplation of individual objects, and that part of the pattern is shared by people" [17]. Based on how a person thinks about a hammer a computer can identify when another person is also thinking about a hammer. It also can differentiate between different items.

11. University of California, San Diego, USA: Here they build robots with more simple purpose: to be touched and smiled by small children as often as possible. Actually they aim the robots to learn how to teach and how to interact with humans in general, which they found possible by constant human robot interaction. The theme of the project is to create a robot which not only teaches apple and oranges to children but should also learn by experience that if it repeats same stuff then it will lose its audience.

12. CCRG (Cognitive Computer Research Group): This group is working on a cognitive link between perception of the environment and the expression of emotions (or movements) in short model of human cognition. They have been working on an architecture called Learning Intelligent Distribution Agent (LIDA) [18]. LIDA is an artificial mind based on a series of digital sense-cognize-act atoms that build onto one another.

13. Federal DARPA's [19] Cognitive Computing programs (strong AI by 2010-2012): Some of the important milestones of DARPA are listed below:

- Application Communities
- Architecture for Cognitive Informative Processing (ACIP)
- Bio-Computation (Bio-Comp)
- Biologically-Inspired Cognitive Architectures (BICA)
- Combat zones That See (CTS)
- Data Intensive Computing
- High Productivity Computing Systems (HPCS)
- Integrated Learning
- NASA's Intelligent Archive
- Personalized Assistant that Learns (PAL)
- Quantum Informative Science and Technology (QuIST)
- Real-World Reasoning (REAL)
- Self-Regenerative Systems (SRS)
- Transfer Learning (TL)

IV. COGNITIVE MODELLING

Cognitive architectures are also called as artificial mind models. They are defined as the design and organization of mind with ability to integrate all cognitive processes. A number of cognitive architectures have been designed which are common in concepts but are different in methodologies. These architectures commonly have short term and long term memory. The representation of information may be different with different architectures. The perception is an important aspect of cognition [14]. The entire perceived information is not essential for cognition, it would be sufficient to store only effective perception in the working memory and get the trivial perception in long term memory. This results in less working memory requirement and enhances cognition process because no irrelevant information will be part of it. But there is a dichotomy that whenever trivial information is required the cognition process degrades. The core issue is how to classify perception, so that there can be clear distinction and what the approaches are.

Perception in Psychology

In psychology perception is broadly viewed as conscious and unconscious perception. The awareness of stimulus is known as conscious perception with working memory and attention as essential ingredients of it [10]. The unconscious perception refers to the stimuli that are below the threshold for conscious perception [11]. There is no clear distinction between conscious and unconscious perception and many a times the lines are crossed. A long standing controversies still lies in the conceptual distinction between conscious and unconscious perception. Initially there was controversy regarding existence of unconscious perception. The gravity of controversy is to find the necessary behavioral measures that constitute conscious experience [12]. There are many experimental reports and conceptual models put forth by many suggesting that behavior is influenced by unconscious perception, but these finds also remain controversial. Most of the experiments are based on dissociation paradigm to ascertain that unconscious perception is significant in cognitive process. The line that separates conscious and unconscious perception is the awareness or attention.

According to Ian Heath with the inspiration of Franz Brentano conceptualizes perception as being active or passive. He views perception as an act starting from passive observation. If the image interests then there will be a keen or close observation. This stage results in what he considers as foreground image or content.

Passive observation interest → attention → foreground content

The foreground image or content is the perceived information that is going to be part of cognition process.

Based on the foreground content judgment is taken. The judgment can be correct or wrong like when you are seeing somebody feeding stray dog you might think that what he /she is doing is a novel job (correct) . Thoughts might say that

he/she is polluting the area by doing so (wrong). This judgment will acquire the feeling (pleasure or displeasures). This feeling enhances the perception process and will be significant in storage of perceived information.

Foreground content → judgment → feeling

Quantity	Attention Modelling		
	Belief	Desire	Intention
High	High	X	X
High	X	High	X
High	X	X	High
Medium	Medium	Medium	X
Medium	Medium	X	Medium
Medium	X	Medium	Medium
Low	Low	Low	low

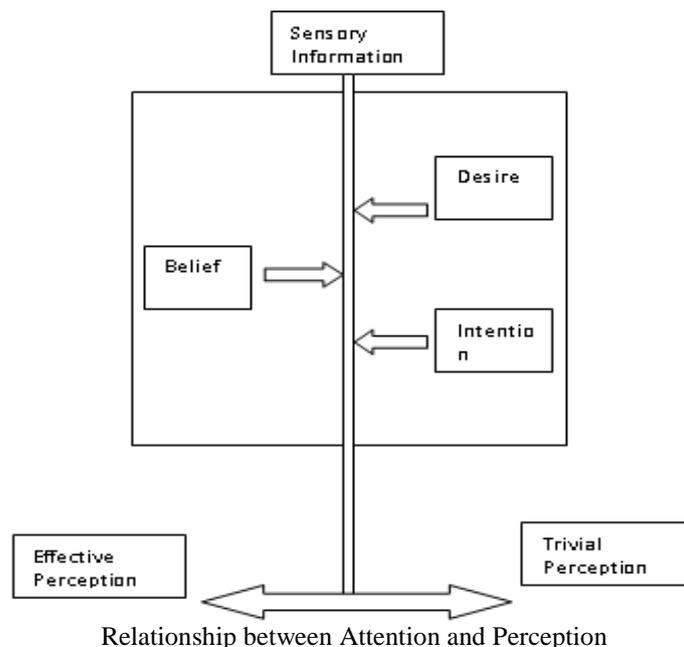
Where X signifies don't care condition

Classification Approach

We find a number of factors that can be part of cognition and which influences the perception process. We can also find that perceived information can be effective or ineffective information. At this point we propose that Perception is of two types 1) Effective 2) Trivial

- ✓ Perception = effective perception + trivial perception.
- ✓ Effective perception can be represented as = perception + Attention
- ✓ Trivial Perception = perception + no attention

The classification can be enhanced by using deliberative (bdi) model. BDI i.e belief, desire and intention are the mental components present in rational agent architectures [15]. Belief, desire and intention reflects motivation and learning. The BDI model intentions are adopted plans or strategies for achieving desires. Belief is the judgment along with desire and intention to reason. The perception process in our proposal is shown in figure 1. The perceived sensory information is received and based on the factors belief, desire and intention the perceived information can be classified as effective and trivial perception. The trivial perception will not remain trivial permanently at some point of time it may be required by cognition then it gets transformed to effective.



A. Intelligence

The definition of intelligence has many open questions. A general summary of intelligent agents is listed below.
 Responds to changes in the environment
 Control over its own actions

- Does not simply act in response to the environment
- Is a continuously running process
- Communicates with other agents, perhaps including people
- Changes its behaviour based on its previous experience
- Able to transport itself from one machine to another
- Actions are not scripted
- Believable personality and emotional state

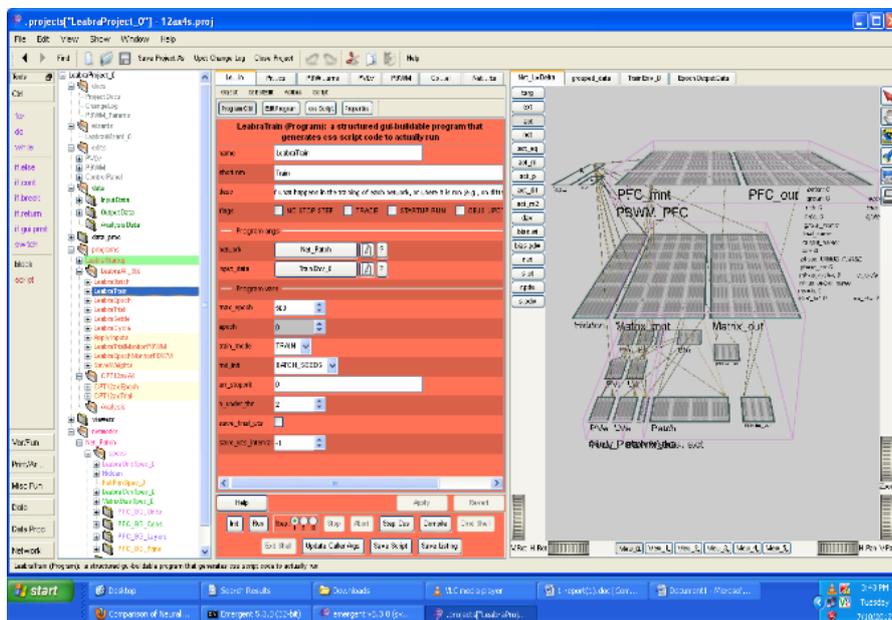
V. NEUROMORPHIC ENGINEERING

The neuromorphic engineering could be divided into neuromorphic modelling, reproducing neurophysiological phenomena to increase the understanding of the nervous systems and neuromorphic computation which uses the neuronal properties to build neuron like computing hardware. Basically, the former provides the knowledge of the biological algorithm while the latter translates the algorithm into electrical circuits. This is an iterative process, since the understanding of the biological algorithm is a very complex process. As more knowledge evolves yielding improved algorithm, the electrical circuits are revised and improved.

These circuits then pass through all the stages of developing integrated circuit (or chip), which involves the circuit layout, verification, fabrication in foundry and testing and subsequent deployment. A brief explanation of each of these steps is provided below:

Layout design: This stage involves the translation of the circuit realized in the previous stage into silicon description through geometrical patterns aided by computer aided design (CAD) tools. This translation process follows a process rule that specifies the spacing between transistors, wire, and wire contacts and so on. The layout is designed to represent the electrical circuit schematics obtained from the algorithm. Fabrication: Upon satisfactory verification of the design, the layout is sent to the foundry where it is fabricated. The process of chip fabrication is very complex. It involves many stages of oxidation, etching, photolithography, etc. Typically, the fabrication process translates the layout into silicon or any other semiconductor material that is used.

Testing: The final stage of the chip development is called testing. Electronic equipment like oscilloscopes, probes, and electrical meters are used to measure some parameters of the chip, to verify its functionalities based on the chip specifications [2]. Emergent tool is used to implement reinforcement learning in Neuromorphic Engineering. Emergent is neural simulation software that is used for creating complex, sophisticated models of the brain and cognitive processes. It can also be used for any task to which neural networks are suited.



Emergent Software for Neural Simulation

VI. CONCLUSIONS

In this paper we have given a critical review of different streams arising because of Cognitive sciences, computational Intelligence, Neuroscience and Neuromorphic Engineering. There is a new field of science which combines psychology, computer science, mathematics and neuroscience and Electronic Hardware Design. The cognitive neuroscience computing is at a verge to give rise for many potential mainstream applications. Neuromorphic is one such example.

In cognitive sciences we have modeled Attention and Perception based on BDI modeling. Intelligence for ICs has been defined in a generalized way. Emergent is identified as the best option for implementation of Reinforcement Learning. Finally, an exciting, but very difficult, prospect is that of an integrated cognitive system which evolves; a system which absorbs new knowledge, learn through experience and respond like one of us. (Being able to combine different behaviors of humans, showing creativity).

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