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A Review of Reinforcement Learning in Neuromorphic VLSI Chips using Computational Cognitive Neuroscience

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Abstract: In this review 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 or field so as to achieve maximum rewards for taking right decision or very feasible solution or optimal path. This is done by modelling the attention and perception of machine just as a human being. Because the thought process is the unique nature of humans' intelligence can be implemented by modelling the Cognition. Comparison with other methods of attaining Artificial Intelligence shows that Computational Cognitive Neuroscience is the best and most evolved system for exhibiting intelligence to learn in real time scenarios. It is concluded that all the sensory input is not necessarily being calculated, instead attention is given to effective perception and trivial perception is ignored. This differentiation of perception is done based on BDI Model. Intelligence is broadly defined and requirements of an intelligent agent is summarized. The emerging field of electronics for implementation of reinforcement learning by imitating human brain i.e. Neuromorphic Engineering is discussed. The significance of the accurate knowledge of intelligence in machines based on learning and decision making is discussed.

Keywords: cognitive sciences, computational intelligence, Reinforcement Learning, Intelligent systems, Neuromorphic Engineering.

I. INTRODUCTION

The purpose of this paper is to review the progress being done in the field of machines that learn new tasks and behavior from common man in everyday life. We assume that machines which can learn from everyday interaction can better take advantage of the teaching and training as in [1] & [2]. We understand the cognition behind learning and in this paper we have computationally modeled specific mechanisms of human social behavior in general and learning in particular. This paper shows that how reinforcement learning is improved by providing proper attention to the human interactions. This work spans the fields of Cognitive Sciences, Psychology, and Machine Learning in particular Reinforcement Learning, Human Computer interactions and VLSI design.

A social learner [2] has to learn in real time situations on its own, but taking aid of human partner whenever necessary thereby exploring the environment and learning from it. This exploration can be influenced by attention direction, action suggestions, providing positive and negative feedback. This Guided Reinforcement learning has to frame its own learning problems, define goals and plan to achieve it.

We have many algorithms from various domains that explain to achieve some intelligence in machines, such as Neural Networks, Fuzzy Logic, Cognitive Architectures, Computational Sciences, Bio-inspired computing, so on and so forth. But still human behavior cannot be imitated. Section II makes a comparative study and identifies the missing ingredient for the dish of Intelligence.

Human working memory is limited [3], machine memory is still more limited when compared with humans. Human memory addresses this by storing the information into long term memory, short term memory and working memory. Every kind of memory has some time duration and after which the information decays there by efficiently utilizing the memory space. But in machines no such differentiation and decaying is observed. This serious limitation poses us a challenge of intelligently accumulation of information and efficiently building the Knowledge. This is where machine performance and learning ability comes into picture. The best way to overcome this limitation is schema acquisition, which means chunks of information are extracted and can be processed as meaningful units. For our simulation the language which helps us to have abstracts or chunks of information is Prolog [4].When we are able to model the memory we have to model the attention and perception viz. Accumulation of only necessary information else the machine will be flooded with chunks of irrelevant

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information. This modelling is done based on the BDI (belief, Desire and Intention) Model. Section III describes modelling of memory and attention.

Now when we are able to model the attention and differentiate memory, does that mean a machine is intelligent? What it takes for a machine to be intelligent? And what an intelligent agent should exhibit? What is the relation between date, information, knowledge, intelligence and wisdom? Section IV has a detailed analysis of all questions pertaining to intelligence.

A new field of Electronics is introduced i.e. Neuromorphic Engineering where the computational cognitive neuroscience based reinforcement learning can be implemented on hardware VLSI Chips. Section V identifies Neuromorphic Engineering as a tool for Implementation. Neuromorphic engineering builds artificial systems utilizing both electronics and computation biological nervous systems knowledge [5]. Before going into implementation we need a tool for modelling and simulation of these intelligent ICs. Emergent [6] is identified as a simulation tool for guided reinforcement learning [7 o riely]. To articulate significant conclusions to a wider audience, paper concludes with open research issues and future scope.

I. COMPUTATIONAL COGNITIVE NEUROSCIENCE

A. Computational Sciences

Artificial Intelligence began with the imagination of philosophers, where the characters of their fictions had supernatural powers and nearly imitate the humans-physically and emotionally.

The field of Artificial Intelligence research was founded at a conference on campus of Dartmouth College in 1956. Since then AI has grown exponentially. Things that seem impossible 2 decades back have been realized and are used in successful commercial products. Now the humankind is headed towards building a human level of intelligence, (which may be possible any time now).

The field of AI originated with game-playing and theorem-proving programs and gradually evolved with lot of research in various interdisciplinary streams. "Today, AI spans a wide horizon", [25]. It deals with various kinds of knowledge representation schemes, different techniques of intelligent search, various methods for resolving uncertainty of data and knowledge, different schemes for automated machine learning and many others.

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 [5].

In contrast, "human brain works by activating thought modules" (Cognitive Modules), [27]. 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.

The brain solve the problems, using complex combination of reasoning, synthesis and creativity, according to 'Modha' brain is hardware of which different processes such as sensation, perception, action, cognition emotion and interaction arises. For us cognition is of most importance.

As motors augment human or horse power AI can use the computers to augment human thinking, [6]. Robotics and expert systems are major branches of that. On the other hand computers artificial intelligence can be used to understand the process of thought, nothing but Cognition.

If we approach the programs not merely by what they can accomplish but how they accomplish it, "then you are really doing Cognitive Science; you are using AI to understand the human mind" [6].

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 analysing what happens in our brains during problem solving, remembering, perceiving and other psychological process .

B. Cognitive Sciences

The term Cognitive Science gained currency in last half of the 20th century, is used to refer to the study of Cognition---Cognitive structures and processes in mind or brain, [1].

Cognitive Science is an interdisciplinary field that has emerged by the intersection of existing branches of science such as Psychology, Linguistics, Computer Science, Philosophy and Physiology. "The shared interest that has produced this coalition understands the nature of the mind", [26].

Origin of Cognitive Science began in mid-1950 when the researches began to treat mind not as a machine but as a biological system which has several non-linear responses and can be analyzed based on complex representations and computational procedures.

"The notion that mental states and processes intervene between stimuli and responses sometimes take the form of a computation", [2]. As software is to hardware, the mind is to the brain; mental states and processes are like computer programs implemented in brain.

The moral in so far discussion is the human mind can be investigated based on computations. Hence Computer Science in general and Artificial Intelligence in particular have come to play a central role in Cognitive Science.

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C. Computational Cognitive Neuroscience

Cognitive Computing goes well beyond Artificial Intelligence and human-computer interaction by exploring the concepts of perception, memory, attention, language intelligence and consciousness, [7].

"Cognitive Computing is when computer science meets neuroscience to explain and implement Psychology, [8]". Both AI and *Neural networks* (NN) fail to replicate the phenomenon of thinking, though they have considered brain as the starting point to explain Cognitive phenomena. In contrast Cognitive Computing is about learning how brain operates, designing algorithms, reverse engineering and testing plausible models. "Cognitive Computing is about engineering the mind by reverse engineering the brain, [8]". 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 Neuroscience 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, Dutch etc, [28].

Computational Cognitive Neuroscience 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.

II. Attention and Memory Modelling

A. Attention

Selective Attention provides an effective mechanism to conceptualize the perceived data both in biological systems and machines. The perceived data consists of important, not so important and irrelevant information. If we process all the data what we receive, then the overhead will be more and the machines will be busy in accumulating and processing, in this rush hour machine cannot dedicate time for learning and imitating human behaviour.

This can be overcome by classifying Perceived data as Effective and Trivial. Effective perception becomes part of cognition process and on processing goes to long term memory, whereas trivial perception data will be in the working memory. It is just like viewing a Photograph, we observe and give great attention to the photo but not to the background. We remember the photos and people in them but doesn't remember the background colour combination.

Therefore data obtained by effective perception is going for long term memory. It doesn't mean that background information is not at all necessary. If the background is disturbing or if there is no usual colour then we don't focus on foreground i.e. the person in the image. Hence the background is very much necessary only for that instance hence background data or trivial data is limited only for the working memory. At any instance Effective perception can become Trivial and vice-versa.

B. Psychological Background

In psychology perception is classified as conscious and unconscious perception. The awareness of stimulus with working memory and attention is known as conscious perception [10]. The unconscious perception refers to stimuli that are below the threshold for becoming conscious [11]. There is no clear distinction between conscious and unconscious perception and many a times the lines are crossed.

According to philosophical view: passive observation is because of less interest and we don't pay much attention, so the data would be in working memory and decay after some time. If the interest is very high then attention is more and we perceive the data with utmost care and remember those things for a long time i.e. stored in long term memory. As interest increases more the chances of being important and less the importance less the storage duration.

At this juncture we classify Perception to be of two types. Active perception where sensors are waiting for the data i.e. Effective Perception and Passive perception where the data is not so relevant or totally irrelevant. Table below summarizes the types of perception base on attention and duration for which the perceived data is stored in memory.

TABLE I. PERCEPTION TYPE

Type of Perception	**Parameters Deciding Perception**	
	Level of Attention/ level of Threshold	***Duration of storage in memory***
Effective	High	Long term memory
Trivial	Low	Short term/ working memory

C. Modelling using BDI Model

The classification can be enhanced by using deliberative model. BDI (Belief, Desire and Intention) Model. These are the basic mental components present in rational agent architecture [15]. Belief Desire and Intention reflects motivation and learning. The BDI Model INTENSIONS are adopted plans and strategies for achieving DESIRES. BELIEF is the judgment along with desire and intention to reason.

We model the perception as effective and trivial based on the threshold set by Belief, Desire and Intention. Perceived information is the input, based on the classification the trivial data will be present only for working memory and the effective perception data will be sent for long term memory.

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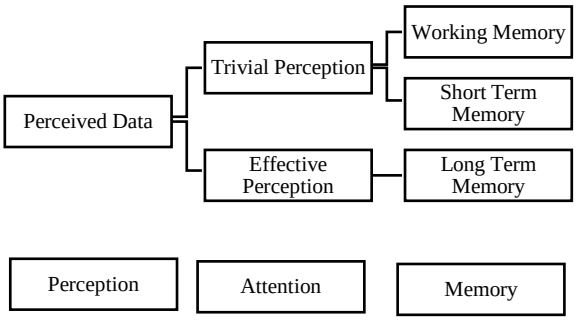

Figure 1. Attention and Memory classification

D. Mathematical Modelling

The Naïve Bayes classifier is simple probabilistic classifier technique based on Bayesian Theorem. It is best suited when dimensionality of inputs is high. Naïve Bayes is better than sophisticated classification methods.

Consider a mixture of triangles and circles. Let triangle be our interested shape i.e. Triangle will be our effective Perception and circle would be our Trivial Perception. Our task is to identify new cases as they arrive. We have to decide the new arriving shape is of interest or not based on current available data.

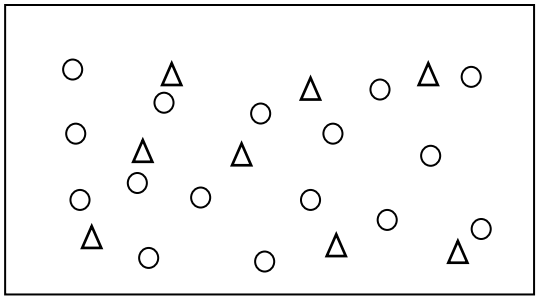

Figure 2. Combination of Circles and Triangles

Since there are twice number of circles, probability of new arrival being circle is more.

$$Probability\ of\ arrival\ of\ Circle = (Number\ of\ circle) /(Total\ number\ of\ objects) \quad (1)$$

$$Probability\ of\ arrival\ of\ Triangle = (Number\ of\ Triangle) /(Total\ number\ of\ objects) \quad (2)$$

The Threshold is set between the probability of circle and that of Triangle. Circle probability is 16/24, whereas triangle probability is 8/24. If we set the Threshold as 12/24, then whenever the threshold is less than 12/24, that means the new arrival is Triangle and perception has to be effective, now we will increase our attention.

Setting the Threshold using a BDI table is as shown below in Table II.

If the machine is unable to make out whether the perceived information then Threshold is given much Importance. For just above threshold condition the information is stored in Short term Memory.

III. INTELLIGENCE

To tell a machine is Intelligent, we don't have any touchstone experiment. From the beginning of computing every new feature which demonstrated Autonomy was said

TABLE II. BDI MODELLING OF ATTENTION AND MEMORY

Type of Perception	**Parameters Deciding Perception**				
	Belief	***Desire***	***Intention***	***Level of Attention/ level of Threshold***	***Duration of storage in memory***
Effective	Yes	Yes	Yes	High	Long term memory
Trivial	No	No	No	Low	Short term/ working memory
Effective	High	X	X	High	Long term memory
Effective	X	High	X	High	Long term memory
Effective	X	X	High	High	Long term memory
Less Effective	Medium	Medium	X	Medium	Short term
	Medium	X	Medium	Medium	Short term

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Type of Perception	**Parameters Deciding Perception**				
	Belief	***Desire***	***Intention***	***Level of Attention/ level of Threshold***	***Duration of storage in memory***
Less Effective					
Less Effective	X	Medium	Medium	Medium	Short term
Trivial	Low	Low	low	Low	working memory

to be intelligent. Later when machines were able to have computational excellence, controlling its environment, have communication between different or other computing devices were called as intelligent machines. When there features became compulsory and every machine started to have these options, those systems are known as smart devices. We can conclude that if any device 'A' which exhibits autonomy, senses its environment, reacts to the changes, and take best decisions is called an Intelligent machine, whenever a new device 'B' with some more new intelligent feature is available then it is called as Intelligent machine and the device A is a smart device now. Hence evolution of devices bring new intelligent machines whereas previous machines are called as smarter. We can also define intelligent machine as one which exhibits Cognition, just like humans viz. extracting chunks of data, schema acquisition, building knowledge base and taking appropriate and best possible decisions in real time scenarios.

Below is an algorithm which shows the modelling of Attention and Memory for Prolog.

Algorithm for the abstract language PROLOG for the modelling of Attention and Perception. Prolog is a language which helps us to make sense from chunks of information, and exhibit self-learning.

Gathering the Data from environment
Start (input perceived data)

Check for Belief
Compare with prior threshold and likelihood for belief.
If Belief >> prior Threshold
Attention → High,
Else
Compare with prior threshold and likelihood for desire.
If Desire >> prior Threshold
Attention → High,
Else
Compare prior threshold and likelihood for Intention.
If Intention >> prior Threshold
Attention → High,
Else
Compare with prior threshold and likelihood for belief and Desire and Intention.
If BDI > prior Threshold
Attention → Medium,
Else
Attention → Low

IV. 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 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

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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.

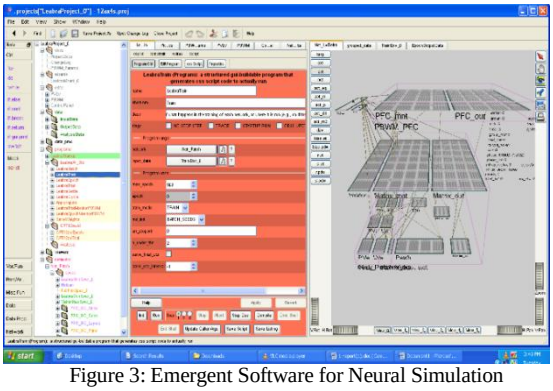

Figure 3: Emergent Software for Neural Simulation

II. CONCLUSION

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 modelled Attention and Perception based on BDI modelling. Intelligence for ICs has been defined in a generalized way. Emergent is identified is 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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