A Platform Technology For Brain Emulaton

Synthetic Neuroanatomy

Peter AJ van der Made M.Sc.
vWISP Pty Ltd.
Technology Park E3, suite 11, Bentley
pmade@vwisp.net.au

Abstract—**A computer is a great tool for statistical analysis, simulation and number crunching, but their usefulness is limited in Artificial Intelligence applications and in the simulation of biologically accurate neural networks. This is due to the sequential nature of these machines whereby all data has to pass through the central processor in chunks of 16, 32 or 64 bits, depending on the width of the device's data bus. In contrast, the brain's network is massively parallel and processes the equivalent of millions of data bits simultaneously. Sizable networks of biologically accurate artificial neurons require the resources of huge supercomputer systems consisting of tens of thousands of processors. Even so, attempts to emulate the entire human brain are far removed from their goal. They typically emulate several hundreds of thousands mammalian neurons of varying complexity, verses at least 100 billion in the brain.**

So called "Artificial Neural Networks (ANNs) have little to do with how the brain actually works. They are no more than data classifiers. The learning time of Multi-layer ANNs with back propagation networks increases exponentially due to the method of learning, even when simplified training sets are applied[i].

A new approach is proposed here, whereby the synthetic brain is constructed as an information carrier that inserts new information into its network through autonomous learning from sensory input through feedback and Synaptic Time Dependent Plasticity (STDP). The information that is learned in this way is applied to later recognize the recurrence of the same or similar events. It has been proved that synapses are memory[ii] that acquire information through learning. Synapses are everywhere in the brain, Therefore memory is everywhere. Every movement, vowel, and shape etcetera has been learned and is stored as a set of variables somewhere in synaptic memory. Learned motor functions are stored in the motor cortex, while learned speech patterns are stored in Broca's and Wernicke's areas. Each module of the brain has been trained early in life and has formed connections that are appropriate to its function. A new device has been created that mimics the learning, association and processing techniques of the brain. Learned 'training models' can be stored and later reused as innate knowledge in new devices and they can be combined to form a platform for further learning. This approach has required a new processing architecture that consists of a massive interconnected network of autonomous learning nodes, each containing memory, feedback and an integrator capable of learning and matching incoming temporal spatial waveform patterns. The platform technology can be applied in prostheses that communicate with the brain, in safety devices, in recognition engines of every biomorphic variety, in autonomous robots and in intelligent toys. It can also be used in conjunction with a PC to enable the emulation of brain phenomena that currently require a supercomputer.

Keywords-component; Artificial Intelligence, Neuromorphic systems, Neuromimic systems, Synthetic Neuroanatomy

I. Introduction

Artificial Intelligence is a division of computer science. Compared to the rest of the field, it has seen little success over its 65 year history. All attempts to emulate human level intelligence, or to recreate it in a digital computer, have failed. Even the question "what is intelligence" cannot be answered with absolute certainty. A bush man has skills that enable him to survive off the land in a harsh climate. A business man has skills that allow him to survive despite a downturn in the economy. Both are intelligent, and even stand out from their peers, but they will struggle to survive in each others' world. Intelligence is relative to the environment from which it has been formed.

The human brain is a three pound pinkish organ that is supported in the clear, salty Cerebral Spinal Fluid (CSF). Its wrinkly outer appearance does not convey its complexity. The brain consists of an estimated 100 to 200 billion neural cells, at least ten times as many glial cells and 100 to 200 trillion synapses. These are approximate figures based on the neuron count in small parts, and multiplied by the entire volume of the brain, compensating for 'white matter' that contains very few neurons. Its performance is poor to average in tasks that require the recording and recall of precise details. The density of active components per square millimeter is greater than that of a microprocessor chip. Neural cells can have up to 200,000 inputs, with an average of 7000 inputs. The interconnections between these cells, the 'connectome' forms a complex network that is unique to each human being. It is different between identical twins, which is an indication that it is not formed from DNA, but as a result of real-world learning and experiences. Inputs directly address local memory, but they do not simply recall values to be summed. Synaptic memory consists of a chemical junction that contains a neurotransmitter. At least fifty different neuro-tranmitters have been identified that have persistence values ranging from about a millisecond to several hundred milliseconds. Neurotransmitters can be either excitatory or inhibiting. In addition to these there are neuro-modulators that affect large groups of neurons across the entire brain. Neuro-modulators are released into the

Neuro-Spinal Fluid. Neurons match patterns of waveforms that have previously been learned. The learning process causes physiological changes in the connectome. Therefore the boundaries between structure acquired through learning and innate structure are not clearly defined. The brain is an entwined mesh of information carrier and stored knowledge. Mathematical ability is poor. Cognitive and recognition abilities are advanced and far exceed the capabilities of any supercomputer. Copying its processes is a challenge, but the realization of this goal appears to be well within our grasp. Neural cells have two prime functions; to learn from input and to match temporal and spatial waveform patterns. In computer simulations, much effort has been spent on matching of incoming data, to the detriment of learning abilities. Any brain emulation that is not capable of learning cannot be realistic. Due to the brain's structure and distribution of neural cells which is determined by DNA, conditions at birth and nurturing, there is a natural inclination to learn certain skills in preference to other skills. The brain is an information carrier which creates a mind through learning at many different levels. The brain consists of nothing but cells and synapses. Every action that takes place in the synthetic brain must therefore be explainable from neuron physiology. A realistic hardware emulation of the brain, the Synthetic Neuro-anatomy is capable of learning and matching learned waveform patterns in time (temporal) and in spatial distribution.

A. *Information carrier*

This new approach to Artificial Intelligence is to create an electronic information carrier that has structure allowing it to be trained, and is capable of acquiring complexity through learning rather than attempting to recreate the complexity of a fully developed brain and mind by programming. The principal unit of each node is the neuron, which has feedback, synaptic memory and a single output that branches out to connect to thousands of synapses on other neurons. The function of Glial cells is to synchronize the neural core, and to clear it when necessary. The synthetic digital node, consisting of the digital equivalent circuit of a neuron, glia and synapses, is structured to;

a. Learn from input pulse patterns
b. Match temporal / spatial input waveforms to previously learned parameters
c. Produce an output pulse when a waveform set has been recognized
d. Provide feedback to modify synaptic memory to strengthen the response to future occurrences of the same or similar temporal / spatial waveform sets. The learning algorithm is a modified Synaptic Time-Dependent Plasticity model, adapted to respond to the repetition and intensity of input waveforms.

Since neurotransmitters are synthesized in the presynaptic neuron, all connections inherit the same neurotransmitter. Neurotransmitters can be either inhibiting or excitatory, and their effects vary in persistence from a millisecond to several hundred milliseconds. Many different neurotransmitters exhibit similar characteristics. Neuromodulators affect large groups of neurons simultaneously and are secreted into the cerebrospinal fluid. The nodes are organized in minicolumns and hypercolumns. Vernon Mountcastle described the columnar organization [iii] of the somatosensory cortex in his 1957 paper. In his 1978 paper[iv] he elaborated that this columnar organization is found everywhere in the cortex. A hypercolumn consists of up to 100 minicolumns. Each minicolumn consists of around 80 neurons. A hypercolumn comprises a computational unit, able to learn and to match complex temporal patterns. At least 10,000 digital nodes can be mapped onto a full-custom ASIC, representing one complete hypercolumn. Larger systems will require multiple devices, which can be stacked. Brain size alone is no indication of intelligence. Parrot brains are approximately 40 grams, compared to a human brain of 1500 grams and a bull elephant brain of around 5000 grams. The abilities of Alex the parrot[v] were astonishing. Intelligence is related to brain structure and density of neurons.

B. *Modular Training*

An intelligent machine will consist of a network of many devices. Rather than programming the machine, the machine learns from sensory input. Training a machine that consists of 100-200 billion neurons would be an impossible task. Therefore it is possible to train individual hypercolumns for a specific task, such as the recognition of sounds, syllables and words, or visual image recognition consisting of the identification of line segments. This task is then copied into a function library, where it can be used to upload the function to larger networks consisting of many hypercolumns. This gives the machine sufficient innate knowledge to proceed to learn from subsequent sensory input streams. Increasingly complex learned functionality is copied into the function library over time.

II. THE PRESENT STATUS OF ARTIFICIAL INTELLIGENCE

Artificial Intelligence does not exist at this time. The term is used loosely to describe machines that respond to inputs by logic inference. These are cause and effect machines, which repeat the same algorithms for each set of input variables. They have a synthetic expression of knowledge, not knowledge itself, and are unaware of the tasks that they are performing. The algorithm fails when an unexpected event occurs. Strong AI, also called 'Artificial General Intelligence' or AGI has as an objective to produce a machine that equals or exceeds human intelligence. How this will be accomplished is not clear. The expectation is that this will be accomplished through the programming of a massively fast computer using a as-yet-to-be defined technology. No mention is made of sensory organs. Without an actual hardware platform, this goal remains as yet unreachable and the subject of intense academic debate. Consider that intelligence is defined[vi] as:

a. The capacity to autonomously acquire knowledge and skills
b. To be aware of the self and the environment, to learn from it and to be able to interact with it
c. The ability for autonomous adaptability to a new environment
d. The ability to think, reason and combine knowledge to form new solutions
e. The ability to comprehend relationships
f. A capacity for abstract thought
g. A capacity to create new ideas, philosophy and art

A Synthetic Intelligence must include at least some, if not all of these features. 'Smart' is term that is used loosely to describe products that contain a microprocessor and run programs, such as smart phones. Smart is defined as "having a quick mental ability" or as "a sharp pain". Today's 'smart phones' have no mental ability whatsoever. No machine is capable today of anything approaching intelligence.

Current 'State of the art' machines are generally implemented as software on a computer. These machines have no or a very limited learning ability. A computer does not have any awareness, much like a voice recorder has no awareness of a great speech it has recorded. Industrial robots are cause and effect machines that repeat the same actions to a number of limited stimuli within a simplified environment. Voice recognition is the most advanced form of direct human to machine interactions. Its abilities have increased in recent years with the introduction of multiple parallel matching, in which a probability factor is calculated for each phonetic match. The machine then programmatically picks the match that has the highest probability before mapping the phonetics to a word. In general, human recognition ability is simulated by the binary comparison of elements in an incoming data stream to known elements representative of an entity. A value is calculated from elements that match verses elements to do not match. If this value is higher than a threshold then the stream matches or almost matches the entity. This is a selection process and it will never lead to intelligent machines.

III. ARCHITECTURAL DIFFERENCES

There are a considerable number of differences between the digital architecture that is proposed here and a 'von Neumann' stored program computer. The first and most obvious difference is the lack of a stored program. The synthetic brain is trained, not programmed. Programming would severely limit the ability to evolve intelligence. Further, there is no Arithmetic Logic Unit (ALU). The ALU forms the heart of every microprocessor. It performs logic and arithmetic functions. Another major difference is the lack of a separate memory block. In a synthetic brain memory is scattered across the device and is accessible in parallel by each node. We will consider the implications of these technological differences one by one;

DRAWBACKS OF PROGRAMMING

Within a programmed system, the programmer needs to be aware of all possible conditions that the system will be exposed to. This has major disadvantages. Failing to recognize one or more situations is likely to lead to a system crash or unexpected behavior. Programmed systems that learn are severely limited in the scope of tasks that can be learned. By eliminating programming altogether, the machine is freed from these limitations. Learning within the Synthetic Neuro-anatomy occurs in small steps. The first level of learning indoctrinates the machine with basic objects, such as sounds or line fragments. The next level of learning combines these prime objects into phonetics or simple shapes. These 'simple shapes' would be similar to the stick people a child draws. At each level of training the objects become more complex. At a higher level associations are built between objects from different sensory devices, such as the association between a word and a picture. Learning proceeds beyond the training period. Learned objects can be copied into a library of training sets, available to be used in untrained devices. This enables the creation of innate knowledge upon which more intricate applications can be built.

Arithmetic Logic Unit (ALU)

The ALU forms the heart of every modern microprocessor. Together with its routing logic it executes a stored program by fetching instructions from memory, fetching data from registers or from memory, performing the function and then placing the result back into either memory or the Accumulator register. ALU's are generally from 8 bits to 128 bits wide, acting on data 8 to 128 bits at a time. The major disadvantage of this processing method is that all data has to pass through the ALU. Its operation is sequential, with one instruction executed after another. This limits the amount of data that can be processed at any moment in time. The ALU forms a bottleneck in the data stream. Direct Memory Access (DMA) techniques bypass the ALU, but it is limited to block moves from one part of memory to another. A synthetic brain does not require an ALU. The brain contains nothing like it. Its mechanisms require no arithmetic, but work through the association of incoming waveforms with the previously stored (learned) parameters of a previous event.

DRAWBACKS OF SEQUENTIAL MEMORY

In a computer all memory is sequential, connected to the ALU through a data and address bus. The address bus provides the offset in sequential memory that the ALU is acting upon. The data bus contains data to be read or written. Having one large memory block causes contention issues; e.g. no other process can access the memory block during the time that one word is read or written. In the Synthetic Neuro-Anatomy architecture memory is distributed. Each synapse contains its own memory, allowing massive parallel access of all stored data at the same time. All nodes can be accessed in parallel. For example, 70% of nodes can be active within the same millisecond in a cortical column consisting of 10,000 nodes. Each node has several thousand synapses. This represents an equivalent data throughput of

$$(N / t) * S$$

$$7000 / 0.001 * 7000$$

Whereby N is the number of active nodes, t is the time duration in seconds and S is the number of Synapses per node. At an average of 7000 synapses per node this represents a sustainable throughput of nearly 50 Gigabytes of data per second per device. A modest synthetic brain will consist of thousands of devices.

IV. REAL-WORLD APPLICATIONS OF INTELLIGENT MACHINES

The technology that is discussed here has been tested on a small scale component by using Field Programmable Gate Array (FPGA) devices from Xilinx and Actel. The design is highly repetitive, with each node an exact replica of every other node. It is therefore expected that the small scale design will scale quite well to a component containing at least 10,000 nodes. The connectome for the larger scale device will be the biological model of a cortical column. The circuit's learning ability has been verified in an experiment by using a signal generator and spectrum analyzer software as a sound source and artificial cochlea respectively, with the output connected to a synthetic neuro-anatomy consisting of ten nodes in FPGA. The FPGA that was used was a 1.5 million gate ACTEL device on an ACTEL development board. The signal generator frequency was varied to simulate the frequency of common vowels in human speech. The synthetic neuro-anatomy learned to recognize ten sounds that were later also identified in a speech pattern. Learning time was less than 2 minutes. An obvious application for this technology is in speech recognition, speaker recognition, and extraction of speech from a noisy background environment. Other experiments show that the devices can be successfully applied in applications such as visual image recognition, robotics, emulation of the brain on small desktop computers, autonomous learning machines used in exploration, unmanned vehicles, and robotics. The advantages of using a Synthetic Neuro-Anatomy device over a traditional programmed device are a shorter development track, better quality recognition, persistent learning after the initial commission of the system and the reusability of training models.

More examples and a more detailed explanation of this technology is available in a new book by Peter van der Made called "Higher Intelligence", available from the end of March 2013.

REFERENCES

[i] H Mühlenbein "Limitations of multi-layer perceptron networks - steps towards genetic neural networks" Parallel Computing Volume 14, Issue 3, August 1990, Pages 249–260

[ii] Mark Mayford, Steven A. Siegelbaum, and Eric R. Kandel "Synapses and Memory Storage", Cold Spring Harbor Perspectives in Biology, June 2012;4:a005751 First published April 10, 2012

[iii] Mountcastle, V.B. (July 1957). "Modality and topographic properties of single neurons of cat's somatic sensory cortex". *J. Neurophysiology* **20** (4): 408–34.

[iv] Mountcastle, V. B. (1978), "An Organizing Principle for Cerebral Function: The Unit Model and the Distributed System", in Gerald M. Edelman and Vernon B. Mountcastle, *The Mindful Brain*, MIT Press

[v] Pepperberg, Irene Maxine. The Alex Studies: Cognitive and Communicative Abilities of Grey Parrots. Harvard Universitiy Press, 2000

[vi] Higher Intelligence, by Peter AJ van der Made. Page 72