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A Study on Blue Brain Modeling, Applications and its Challenges

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***Abstract*: We all are fascinated about how human brain works and why it is so superior and extraordinary. As some of the brains (Einstein, Ford, Edison and so on) in world are too resourceful and astonishing were also had the similar human brain but functioning is differ. To understand those workings, we require Blue brain. This technology is somewhere more state-of-the-art and groundbreaking than others. Even after the death of an individual, his/her brain will be alive virtually. In this paper an overview, modeling and recommendations for Blue brain has been presented for conceptual information. Through study it is also found that there are some challenges faced by this revolutionary technology. The simulation of human or mammalian brain with Blue brain is to identify the fundamental principles of brain structure and function in health and disease.**

***Keywords*: Blue Brain, Human Brain, Artificial intelligence, Super computer, Artificial Brain, Nanobots, Neocortex**

1. Introduction

We have all heard about the very famous scientist Stephen Hawking who has a motor neuron disease and is entirely paralyzed. It is through a speech generating device that he communicated with the world. He would be able to contribute more to the world of science if he was physically sound. Through the blue brain technology we would be able to make use of the intelligence of such great men for the future developments. Virtual brain or blue brain is an artificial brain which act like as the brain to great extent. The name blue brain is coined because the primary machine used by the Blue brain project was a Blue Gene super computer built by IBM [1].

The objective of Blue Brain project is to build biologically detailed digital reconstructions and simulations of the rodent, and ultimately the human brain. The supercomputer based reconstructions and simulations built by the project offer a radically new approach for understanding the multilevel structure and function of the brain. Supercomputer based simulations of their behavior turns understanding the brain into a tractable problem, providing a new tool to study the complex interactions within different levels of brain organizations and to investigate the cross level links leading from genes to cognition

Human species always need such an intelligence that will grow and develop something and will be beneficial for all the living things, but we lose such intelligence after the death. The virtual brain is an elucidation to keep that great worth intelligence for future generations. Understanding the brain is spirited, not just to understand the biological mechanisms which give us our thoughts and emotions and which make us human, but not for practical reasons. More essential still, understanding the brain can be cooperative for diagnosing and treating brain illnesses.

2. Related work

The architect behind the Blue Brain project (BBP) was Henry Markram [2] scientist at EPFL (Ecole polytechnique federale, Switzerland). European brain researchers came into being in June 2005 when IBM and EPFL signed an agreement to launch the project and install a Blue Gene Supercomputer. By 2005 the first single cellular model was completed. The first artificial cellular neocortical column of 10,000 cells was built by 2008.

The Blue Brain group constructed a 10,000 neuron model of a neocortical column from that part of cortex which can sense anywhere from the body of a 2-week-old rat, and simulated it on the Blue Gene supercomputer in 2014 [1]. The simulation ran about ten times sluggish than biological neurons. The modeled cortical column is about 0.5mm in diameter and about 2.5mm in height. The model is not a map of real connections in any particular rat, the connections are arbitrarily derived based on the percentage connectivity of neurons of different types in different layers of rat cortical columns.

Though, the model does attempt to account for the 3D morphology of the neurons and cortical column, using about 1 billion triangular compartments for the mesh of 10,000 neurons. A multi-processor adaptation of the NEURON simulation software was run at this fine grain using Hodgkin-Huxley equations [3], occasioning in gigabytes of data for each compartment, and presumably a high level of bio-realism.

IBM, in partnership with scientists at Switzerland’s Ecole Polytechnique Federale de Lausanne’s (EPFL) Brain and Mind Institute will begin simulating the brain’s biological systems and output the data as a working 3-dimensional model that will recreate the high-speed electro-chemical interactions that take place within the brain’s interior [6]. These include cognitive functions such as language, learning, perception and memory in addition to brain malfunction such as psychiatric disorders like depression and autism. From there, the modeling will expand to other regions of the brain and, if successful, shed light on the relationships between genetic, molecular and cognitive functions of the brain.

Including Cajal blue brain (coordinated by the supercomputing and visualization center of Madrid) there are number of sub-projects based on Blue Brain which are run by universities and independent laboratories [3].

In 2015 scientists at EPFL developed the measurable model of the formerly unknown relationship between the gilal cell astrocytes and neurons. The model labels the energy management of the brain through the function of the neuro-gilal vascular unit [2].

On July 9 2018 HPE (Hewlett Packard enterprise) and EPFL declared collaboration regarding Blue brain project. Based on the HPE SGI 8000 system, HPE is providing tailored and scalable compute performance to enable the Blue brain project to pursue its scientific roadmap goal for 2020 [13]. Finally, a cellular human brain is predicted possible by 2023 equivalent to 1000 rat brains with a total of a hundred billion cells [1].

3. An overview

A. Uploading in blue brain

The uploading is possible by the use of small robots known as the Nanobots. These robots are small enough to travel throughout our circulatory system. Traveling into the spine and brain, they will be able to monitor the activity and structure of our central nervous system. They will be able to provide an interface with computers that is as close as our mind can be while we still reside in our biological form. Nanobots could also carefully scan the structure of our brain, providing a complete readout of the connections. This information, when entered into a computer, could then continue to function these robots will be small enough to travel throughout our circulatory systems [5]. They would also record the current state of the brain. This information, when entered into a computer, could then continue to function as us. All that is required is a computer with large enough storage space and processing power.

B. Human brain and simulated brain

One of the world's most complicatedly organized electron mechanisms is the nervous system. Not even engineers have come close to making circuit boards and computers as delicate and precise as the nervous system. To understand this system, one has to know the three simple functions that it puts into action: sensory input, integration, motor output.

C. Steps for building a blue brain

Conceptually there are three steps for Building a Blue Brain:

1. Data acquirement
2. Data simulation
3. Visualization

1) Data acquirement

It involves collecting brain portions, taking them under a microscope, and gauging the shape and electrical behavior of neurons individually. The electrophysiological behaviour of neurons is studied using a 12 patch clamp instrument (fig.1). This tool was developed for the Blue Brain Project [3] and it forms a foundation of the research. It enables twelve living neurons to be concurrently patched and their electrical activity recorded. The Nomarski microscope enhances the contrast of the unstained samples of living neural tissue [3]. Carbon nanotube-coated electrodes can be used to improve recording.

Table 1
Comparison of Human brain and simulated brain

Parameter	Natural brain	Simulated brain
Input	Through natural neurons.	Through the silicon chip of artificial neurons.
Integration	By different states of the neurons of the brain.	By a set of bits in the set of register.
Output	Through the natural neurons	Through the silicon chip
Memory	Through permanent states of neurons.	Through secondary meomory.
Processing	Through arithmetic and logical calculations	Through arithmetic and logic calculations and artificial intelligence.

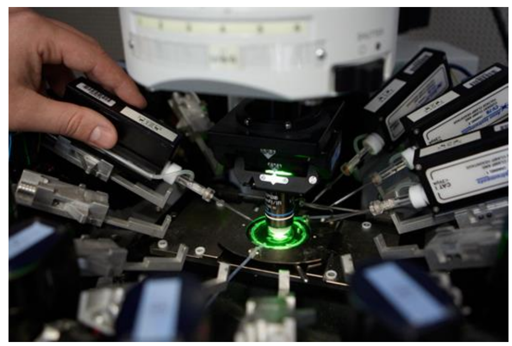

Fig. 1. 12 patch clamp instrument for neuron study

2) Data simulation

It concerns with two major aspects: Simulation workflow and Simulation speed. Simulation speed of one cortical column (more than 10,000 neurons) run about two hundred times slower than real time [3]. It takes about five minutes to complete one second of stimulated time. The simulations display unevenly line scaling. Presently the major seek is biological accuracy rather than presentation.

3) Visualization of results

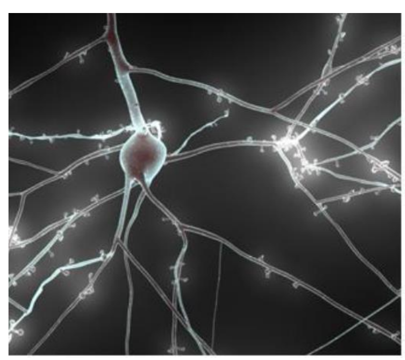

Fig. 2. RT Neuron visualization of neuron

RT Neuron (fig. 2) is the main application that Blue Brain Project uses for visualization of neural simulations. The BBP (Blue brain project) team developed this software internally. It was coded using C++ and OpenGL [3]. RT Neuron is an ad-hoc software written specifically for neural simulations, i.e. it can't generalize to other kinds of simulation. RT Neuron takes the output from Hodgkin-Huxley simulations as input in NEURON and delivers them in 3D [5]. This allows the programmers and researchers to view as activation potentials propagate through or between neurons. The animations can be paused, stopped, started and zoomed, hence allowing the researchers to interact with the model. The visualizations are multi-scale (they can render individual neurons or a whole cortical column).

D. Components used

Since 2005 there are number of hardware, software and supercomputers which are involved in this project, list of them are shown below:

(i) Blue Gene/p: The primary machine used by the Blue Brain Project is a Blue Gene supercomputer (fig. 3) built by IBM. This is where the name Blue Brain originates from. IBM agreed in June 2005 to supply EPFL with a Blue Gene/L as a technology demonstrator. The IBM press release did not disclose the terms of the deal. In June 2010 this machine was upgraded to a Blue Gene/P. The machine is installed on the EPFL campus in Lausanne and is managed by CADMOS (Center for Advanced Modeling Science). The computer is used by a number of different research groups, not exclusively by the Blue Brain Project. In mid-2012 the BBP was consuming about 20% of the compute time [6].

Fig. 3. Blue Gene/p supercomputer

(ii) JuQUEEN: JuQUEEN is an IBM Blue Gene/Q supercomputer that was installed at the Jülich Research Center in Germany in May 2012. It currently performs at 1.6 peta flops and was ranked the world's 8th fastest super computer in June 2012 [6]. Since 2013 this machine is used for BBP simulations, provided funding was granted via the Human Brain Project. The JuQUEEN machine is also to be used by the research initiative. This aims to develop a three-dimensional, realistic model of the human brain.

(iii) BLUE BRAIN 4: The Blue Brain 4 is an IBM Blue Gene/Q acquired from the Blue Brain Project (EPFL Lausanne) and installed at CSCS.

The Blue Brain 4 system is a key scientific tool for the neuroscientific research done at EPFL [8] within the Blue Brain project. This system makes possible the simulation of larger and larger neuron networks. A target for this system is to achieve the simulation of a brain at the rodent's scale (approximately 200 millions neurons).

The Blue Brain 4 system is a set of tightly integrated high-performance resources. It is comprised of a four-rack IBM BlueGene/Q system 65, 536 PowerPC A2, 1.6 GHz cores for computing, providing a peak performance of 839 TFlops 65 TB of RAM 128TB of BlueGene Active Storage (BGAS) to enable data-intensive supercomputing [8].

(iv) BLUE BRAIN 5: HPE and the Ecole Polytechnique Federale de Lausannne (EPFL) Blue Brain Project introduced Blue Brain 5, a new supercomputer built by HPE, which displaces a long line of IBM Blue Gene systems that previously supported the 13-year-old Blue Brain Project whose ambitious goal is to digitally reconstruct and simulate the human brain.

Blue Brain 5 is a set of tightly integrated high-performance resources. It is comprised of a HPE SGI 8600 cluster system with 327 nodes, 0.8TFlops, 64TB/s aggregated bandwidth, 100Gbps EDR Infiniband interconnect, 2.3TB High speed DRAM, 96TB DDR-4 DRAM and 160TB SSD. The GPFS storage connected to the SGI system is comprised of 72TB SSD with 80GB/s and 4PB HDD with 50GB/s bandwidth [7].

Broadly, HPE characterizes the subsystems as:

Subsystem 1: Intel KNL, 16GB of HBM, 96GB DRAM

Subsystem 2: Dual Intel Xeon, 768 GB memory + 4 Nvidia V100 GPUs

Subsystem 3: Dual Intel Xeon, 384 GB memory

Subsystem 4: Dual Intel Xeon, 384 GB memory + 2 NVME

(v) Blue brain software development kit: The Blue Brain Project Software Development Kit, a set of Application Programming Interfaces allows the researchers to use and audit prototypes and simulations. The Blue Brain Project-SDK is a C++ library wrapped in Java and Python. The primary software used by this for neural simulations is NEURON. Michael Hines of Yale University and John Moore at Duke University developed this in the starting of the 1990s.

4. Model of working

A. Architecture of bluegene/p supercomputer

The following diagram (fig. 4) represents the architecture of Blue Gene/p supercomputer.

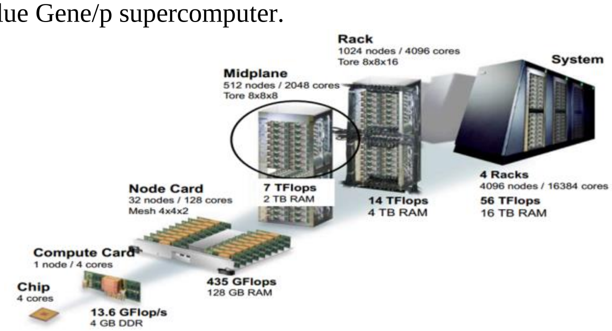

Fig. 4. Architecture of Blue Gene/p

B. Modeling the microcircuit

Microcircuits are composed of neurons and synaptic connections. To model neurons, the three dimensional morphology, ion channel composition, and distributions and electrical properties of the different types of neuron are required, as well as the total numbers of neurons in the microcircuit and the relative proportions of the different types of neuron. Modeling involves Neuroscience where a systematic collection of experimental data making it possible to describe all possible levels of structural and functional brain organization [6]. Modeling also involves neuro infomatics (automation curation and databasing of data) and mathematical abstractions (definition of parameters, variables, equations and algorithms) [6].

C. Simulating the microcircuit

Once the microcircuit is built, the exciting work of making the circuit function can begin. All the 8192 processors of the Blue Gene are pressed into service [11], in a massively parallel computation solving the complex mathematical equations that govern the electrical activity in each neuron when a stimulus is applied. As the electrical impulse travels from neuron to neuron, the results are communicated through inter-processor communication.

D. Interpreting of results

By means of enormously parallel computers the data can be analyzed where it is created (server-side analysis for experimental data, online analysis during simulation). Given the geometric complexity of the column, a visual exploration of the circuit is a significant part of the analysis. Plotting the simulation data onto the morphology is invaluable for an immediate verification of single cell activity as well as network phenomena. Architects at EPFL have worked with the Blue Brain developers to design a visualization interface [11] that translates the Blue Gene data into a 3D visual demonstration of the column.

5. Applications of blue brain

Following are some of the widely used applications:

(i) Gathering and Testing 100 Years of Data: The most immediate benefit is to provide a working model into which the 100 years (approximate) knowledge about the microstructure and mechanisms of the neocortical column can be gathered and experienced. The Blue Column will therefore also produce a virtual library to explore in 3D the microarchitecture of the neocortex and access all key research relating to its structure and function.

(ii) Cracking the Neural Code: The Neural Code refers to how the brain builds objects using electrical patterns. In the same way that the neuron is the elementary cell for computing in the brain, the NCC (Neocortical column) is the elementary network for computing in the neocortex. Creating an accurate replica of the NCC which faithfully reproduces the emergent electrical dynamics of the real microcircuit is an absolute requirement to revealing how the neocortex processes, stores and retrieves information

(iii) Understanding Neocortical Information Processing: The power of an accurate simulation lies in the predictions that can be generated about the neocortex. Indeed, iterations between simulations and experiments are essential to build an accurate copy of the NCC (Neocortical column). These iterations are therefore expected to reveal the function of individual elements (neurons, synapses, ion channels, receptors), pathways (monosynaptic, disynaptic, multisynaptic loops) and physiological processes (functional properties, learning, reward, goal-oriented behaviour).

(iv) A Novel Tool for Drug Discovery for Brain Disorders: Understanding the functions of different elements and pathways of the NCC will provide a concrete foundation to explore the cellular and synaptic bases of a wide spectrum of neurological and psychiatric diseases. The impact of receptor, ion channel, cellular and synaptic deficits could be tested in simulations and the optimal experimental tests can be determined

(v) A Global Facility: A software replica of a NCC will allow researchers to explore hypotheses of brain function and dysfunction accelerating research. Simulation runs could determine which parameters should be used and measured in the experiments. An advanced 2D, 3D and 3D immersive visualization system will allow “imaging” of many aspects of neural dynamics during processing, storage and retrieval of information. Such imaging experiments may be impossible in reality or may be prohibitively expensive to perform

(vi) A Foundation for Molecular Modeling of Brain Function: An accurate cellular replica of the neocortical column will provide the first and essential step to a gradual increase in model complexity moving towards a molecular level description of the neocortex with biochemical pathways being simulated. A molecular level model of the NCC will provide the substrate for interfacing gene expression with the network structure and function.

6. Advantages and disadvantages

A. Advantages of blue brain

Following are major benefits of Blue brain:

1) Blue brain is an approach to store and utilize human intelligence and information present in the mind even after human demise.
2) It is an important move towards self-decision.
3) It can be used as an interface between human and animal minds.
4) It a good remedy towards human disability like a deaf can get the information via direct nerve stimulation.
5) Without any effort we can remember things.
6) Intelligence of a man can be used even after the death.

B. Disadvantages of blue brain

Following are some of the disadvantages of Blue brain:

1) It increases the risk of human dependency on Blue Brain every time.
2) Once a Blue Brain related to a particular person’s

neural schema is hacked, the brain could be used against the very person.
3) Since it an approach to make machines intelligent and thoughtful it increases the risk of machines conducting war against human.
4) Computer viruses are risky of this that could corrupt the data.
5) This requires a large amount of memory and processing power to create a virtual brain that could act as a natural.

7. Challenges

(i) Neural complexity: In cortical neurons, synapses themselves vary broadly, with ligand-gated (a molecule that is selectively binds to another) and voltage-gated channels, receptive to a variety of transmitters [12].

(ii) Scale: A massive system is required to emulate the brain: none of the projects we discuss have come close to this scale at present. The largest supercomputers and computer clusters today have thousands of processors, while the human cortex has tens of billions of neurons and a quadrillion synapses.

(iii) Interconnectivity: Emulation of the cortex in hardware represents a massive "wiring" problem [12]. Each synapse represents a distinct input to a neuron, and each postsynaptic neuron shares synapses with an average of 10,000 (and as many as 100,000) other presynaptic neurons. Similarly, the axon emerging from each neuronal cell body fans out to an average of 10,000 destinations.

(iv) Plasticity: It is generally accepted that an emulated brain with static neural connections and neural behavior would not produce intelligence. Synapses must be "plastic": the strength of the excitatory or inhibitory connection must change with learning, and neurons must also be able to create new synapses and hence new connections during the learning process.

(v) Power consumption: A final, indirect problem is the power consumed by a brain emulation with 50 billion neurons and 500 trillion connections, and the dissipation of the associated heat generated. The human brain evolved to use very little power, an estimated 25 watts [12] whereas current supercomputer may use as much as 1MW.

8. Recommendations

- Nanotechnology and ultra–low power design could be helpful in developing computer technologies that can be more efficient in terms of power consumption as supercomputers consume too much power than a human brain so we need to develop such computer technology which is anywhere nearly efficient as that of human brain.
- Poligraphy testing can be done with the help of this technology. The criminals and terrorists can be made to undergo this test in order to know more about their mindset and activities which will help us to take necessary precautions to save our country from the black hands.
- At present, detailed, accurate brain simulations are the only approach that could allow us to explain why the brain needs to use many different ion channels, neurons and synapses, a spectrum of receptors, and complex dendritic and axonal arborizations, rather than the simplified, uniform types found in many models.
- Detailed models could reveal powerful circuit designs that could be implemented into silicone chips for use as intelligence devices in industry.

9. Conclusion

We will be able to transfer ourselves into computer using this technology. It is challenging to simulate a human brain because humans have two million columns in their cortices. The only serious threats raised are also overcome as the combination of biological and digital technologies. Blue brain technology is also useful in medical field to help the neurological disordered people and also help the people who are deaf by providing them all the information via direct nerve stimulation. This technology will stimulate the characteristic and the structure of the human brain in the super computer that will preserve the intelligence of the human even after the death.

10. Future scope

- In future this technology will be useful in diagnosis of malfunction of human brain as well as development of treatments for neurological treatments.
- Blue Brain technology can be used in fully paralyzed people to communicate with the world.
- Blue brain technology can be used in animal in order to find their mental state, and take precautions if any unfavorable or dangerous situation occurs.
- GPS enabled chip can be installed in human beings like animal to trace the location if any missing occurs.
- Using the Blue brain technology, we will be able to understand how this happens which will eventually help us to connect with the nature in a better way.

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