Journal of Informatics
Electrical and Electronics Engineering, 2020,
Vol. 01, Iss. 01, S. No. 003, pp. 1-11
ISSN (Online): 2582-7006

Review on the Artificial Brain Technology: BlueBrain

Madhulika Vinny[1], Pawan Singh[2]

[1,2]Department of Computer Science and Engineering, Amity School of Engineering and Technology, Amity University Uttar Pradesh, Lucknow, India
[1]md_vy@yahoo.com, [2]pawansingh51279@gmail.com

How to cite this paper: M. Vinny, P. Singh (2020) Review on the Artificial Brain Technology: BlueBrain. *Journal of Informatics Electrical and Elecrtonics Engineering*, Vol. 01, Iss. 01, S. No. 3, pp. 1-11, 2020.

http://doi.org/10.54060/JIEEE/001.01.003

Received: 17/01/2019
Accepted: 19/02/2019
Published: 25/04/2020

Abstract

Blue brain is a supercomputer programmed such that it can function as an artificial brain, which can also be called a virtual brain. IBM is developing this virtual brain which would be the world's first such created machine. Its main aim is to create a machine in which the information of the actual brain can be uploaded. This would ensure that a person's knowledge, personality, memories, and intelligence are preserved and safe. The Blue Brain project utilizes the technologies of reverse engineering and artificial intelligence at its core and is implemented through the use of supercomputers and nanobots. Special software like BBP-SDK are also specifically developed for the Blue Brain project. The Blue Brain project is centered towards finding viable solutions to brain-disorders, a working model close to the actual brain which would help in greater understanding of the human brain and the human mind and the state of consciousness, a step towards building an independently thinking machine, and finally collecting information of hundreds of years from the human brains and storing it in the form of a databases. The Blue Brain project mimics the human brain by acquiring the data from its surrounding through special software, interpreting through neural electrophysiology and morphology, and simulating them on computers. Thus, The Blue Brain project is a powerful tool for the study and analysis of the human brain and for the advancement of the human brain and society.

Keywords

Blue Brain, Virtual Brain, Intelligence, Reverse-Engineering, Artificial Intelligence, Supercomputers, Nanobots, Neural Electrophysiology, Morphology, Hodgkin-Huxley, BBP-SDK.

1. Introduction

The Blue Brain project is an artificial brain project which attempts to solve the mysteries of the human brain by employing the concept of reverse engineering so as to recreate the human brain at the cellular level in a computer simulation. It is implemented using supercomputers. The project is dependent on the technology of Artificial Intelligence as its backdrop.

Blue brain is a supercomputer programmed such that it can function as an artificial brain, which can also be called a virtual brain. IBM is developing this virtual brain which would be the world's first such created machine. In just a few years it would be possible to scan the core essence of ourselves, our persona, our attitude, and above all our intelligence into a computer device. The Blue Brain, once fully developed, would be able to not only think like a human brain, but also take decisions based on data and experiences of the past, and also respond like an actual brain does.

The project was started in May of 2005 by Henry Markram in the Brain and Mind Institute of the École Polytechnique Fédérale de Lausanne (EPFL) in Lausanne, Switzerland. [1] The objective of the project is to gain complete knowledge of the human brain and also to find better and faster ways to develop brain disease treatments. [1] The project employed the help of the Blue Gene supercomputer which is constructed by IBM.[2]

The technology of Blue Brain provides the people with a chance to preserve their memories in the form of digital data, and storing information even after the death of the person. It also opens a door to further explore, advance and increase the human brain capabilities and capacity, and also acting as a substitute for the natural brain for simulating the effect of a drug treatment or other such brain related problems.

And not only would it help in giving an in-depth knowledge about the brain's power of thinking and remembering, it would also help in obtaining invaluable knowledge about the working of brain which would lead to the generation of never-before thought devices and supercomputers.

This paper attempts to give an overall review of the technology of Blue Brain from a standard perspective, defining its need, exploring how it works and the technologies that it uses, its applications and its pros and cons. The paper also explores into contemporary topics that are similar to the Blue Brain project, explaining their distinguishing features as well as their relationship to each other and how they might improve further with the help of each other.

Figure 1. Blue Brain Supercomputer[3].

2. Need of Blue Brain

The human brain is an extraordinary creation of the nature as it is, it can think, process data and produce results within split seconds, which could take up to several hours for any man made machine compute. But despite its' marvelous qualities, a human brain is not the most reliable once the factor of time is considered. Also the capacity and potential of brain differs from person to person. The inherent quality of intelligence is not constant for all human beings and thus only a select few surpass the average intelligence levels. But the beyond average intelligence is lost with the death of the person.

Not only that, but even when alive a person's memory keeps deteriorating with time and some of the memories are stored in the sub-conscience state of mind which is not easily to accessible through the conscious state to begin with.

Thus, creating a virtual brain and uploading the natural brain not only helps in gaining more knowledge about the functioning and capabilities of the brain, but also preserving the memories, knowledge, personality and intelligence of a person, either dead or alive, for future reference; and also the research would greatly help in the field of medicine, paving way for finding new and better treatments for diseases, syndromes and conditions which were preciously deemed impossible due to either our limited knowledge and understanding of the brain or the limited access of the brain for experimentations.

3. Comparison between Actual Brain and Blue Brain

Table 1. Table Showing Comparison between Natural Brain and Blue Brain.

NATURAL BRAIN	SIMULATED BRAIN
INPUT The natural brain receives input through sensory organs with the help of sensory cells composed of neurons	INPUT The simulated brain receives inputs through machines replicating the functions of the sensory cells, like camera for eyes, which are attached to artificial sensory cells and neurons made of silicon chips.
INTERPRETATION Interpretation of the impulses received by the sensory cells is done through determining the states certain neurons are in as an effect of these impulses.	INTERPRETATION The effect of sensory impulses are stored in registers in the artificial neurons which can then be similarly interpreted as that in the natural brain.
OUTPUT By interpreting the states in which the neurons are, the brain is able to send impulses representing the appropriate response to the certain input to the sensory cells which further relate it to the proper sensory organ.	OUTPUT By interpreting the states stored in the registers of the artificial neurons, the simulated brain is able to replicate the functioning of the natural brain representing the output. And the output is further related to the appropriate machine through artificial sensory cells.
MEMORY Certain neurons maintain their states permanently which reproduced by the brain when required. These states represent the memory of a person.	MEMORY Through the use of secondary memory devices, states of the registers can be stored permanently which helps in replicating the function of real memory in the simulated brain.
PROCESSING Decision making is done in the brain by what is known as the nervous system or the neural circuitry. The neurons in the neural circuitry are responsible for representing the states of input, output and permanent memory.	PROCESSING The artificial neurons help in decision making through processing the data received in a similar manner as natural brain would do.

3.1. Actual Brain

- *Sensory Input*: The input our brain receives from our senses is known as the sensory input, and it is received from our senses through the sensory cells called neurons. Neurons send a message to the brain on receiving a signal from any of the senses. The sight we see through our eyes, the odour we smell through our nose, the texture or temperature we feel through our touch or skin, all these are sensory inputs. Anything that we perceive through the five senses is a sensory input.
- *Integration*: It is how the brain interprets the sense of touch, sight, smell, hearing and taste that are received through the sensory organs and transmitted by the sensory cell, neurons, into responses of the body.

- *Motor Output*: The response interpreted during integration is implemented with the help of neurons again. The signal to respond is sent by the brain to the effector cells, or the muscle cells or the gland cells through neurons which in turn perform the required action signalled by the brain. This response by our body is known as the motor output.

3.2. Blue Brain

- *Input*: Just like the natural brain, virtual brain also takes inputs, and just as in natural brain this input is taken by NEURONS. These neurons, as discussed previously, are artificially created using circuits and silicon chips; these also send electrical impulses to the virtual brain.
- *Interpretation*: The virtual brain uses registers for interpretation of the electrical impulses received via neurons. The different values stored in these registers invoke different states of brain accordingly.
- *Output*: As the registers invoke different brain states, a response related to the state is then sent by the brain to the neurons. The neurons of which body part is going to receive the signal to respond depends upon the state of the neurons in the brain at the time [4].
- *Memory*: It is possible to store some decision or states of the brain for later reference using secondary storage devices. The neurons can be commanded to store certain brain states for later retrieval
- *Processing*: Once the storing of states is done, computation is using these stored sates becomes possible. Logical and arithmetic calculations are performed in the neural circuitry and to do so current as well as stored data is utilised [4]; and thus, processing of data is performed.

4. Steps for Building Blue Brain

Following are the basic steps for building a proper functioning Blue Brain:

- Data Acquisition or Collection of Data
- Simulation of Data
- Visualization

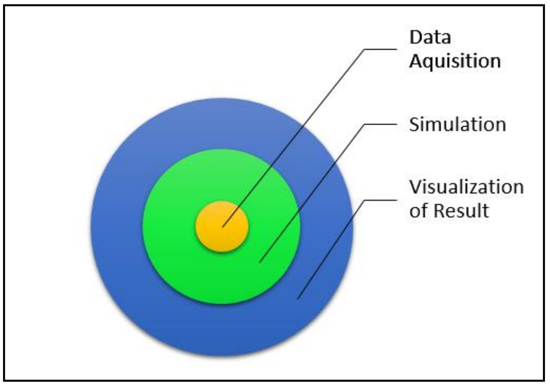


Figure 2. Steps of BlueBrain.

4.1. Data Acquisition

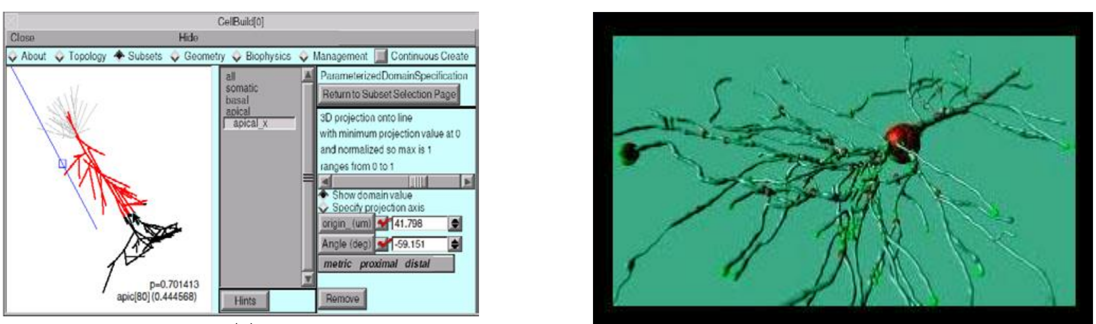
- For data acquisition we need to first figure out the different types of neurons by studying them and then catalogue them accordingly. To do so, brain slices are studied under a microscope and the shape of each individual neuron and its electrical activity is monitored [5]. Morphology and Neural Electrophysiology are used to study the neurons.

- **Morphology** is the study of the structural features, form and structure of an organism.
- While **Neural Electrophysiology (ephys)** is the analysis of the electrical properties of the brain cells, tissues and sensory cells in the nervous system. It is these properties which allow the nervous system to perform its various functions as any fluctuation in these properties produces a new result every time. A measurement of these changes can be performed on various scales like a single ion channel or even the entire brain. Study of these changes, measured in voltage or current, help in a better understanding of the working of human brain, the diseases and disoders related to it and effect of medical drugs on it.
- **Hodgkin-Huxley** (also known as conductance based model) is a mathematical model proposed by Alan L. Hodgkin and Andrew F. Huxley in 1952. In this model, it is described how action potential residing in the neurons, initiated and propagated through the nervous system. The electrical properties of excitable cells such as neurons, are represented as a set of non-linear differential equations in this model.
- Factors for categorising the neurons include their location within the cortex and their population density [5].
- The observations made from studying the brain cells can then be transformed into algorithm which can readily be made into a simulation.

4.2. Simulation of Data

Software used for simulation of data by the Blue Brain Project are as follows:

- **NEURONS**: It is software developed by Michael Hines at Yale University and John Moore at Duke University starting in the 1990s [4]. The software is primarily written in C, C++ and FORTRAN [2]. The software is under active development [4]. The main purpose of NEURONS is to create a working simulation of the natural brain sensory cells, neurons, such that it mimics them completely. To achieve this synthesizing of virtual cells is done using the algorithms obtained during the data acquisition phase. The algorithms are adjusted according to the age, species type, and disease profile of the animal being simulated. Each of the billion per cell protein is simulated [3]. A network skeleton is created first according to the different types of synthesised neurons. After which the cells are connected according to the algorithms and rules derived experimentally [2]. Finally the neurons are given life through functionalizing and simulating. Their emergent behaviour patterns are what is observed in the visualisation phase.



(a) (b)

Figure 3. a) and b) showing NEURON cell builder window and result respectively.

- **BBP-SDK**: BBP-SDK stands for Blue Brain Project-Software Development Kit and it is a set of software classes or APIS that is used by researchers for inspecting models and simulations. The Development Kit is a C++ library wrapped in Java and Python [2].

4.3. Visualization

- **RTNeuron**: RTNeuron is a software that was internally developed by the Blue Brain Project team. It is the application that is used primarily for visualization of neural simulations. It is written in C++ and OpenGL [2]. It is specifically developed for these neural simulations and thus cannot be used for other kinds of simulations. It renders a 3D representation of neurons generated by NEURONS by taking output from the Hodgkin-Huxley simulation produced in NEURON [5]. This helps in monitoring the activation potentials as they propagate between neurons and through a neuron. Researchers can interact with the model by stopping the animation whenever they want, starting it back again, and zooming in on any part desired. Whole cortical column as well as a single neuron can be rendered by the visualization, i.e., they are multi-scale.

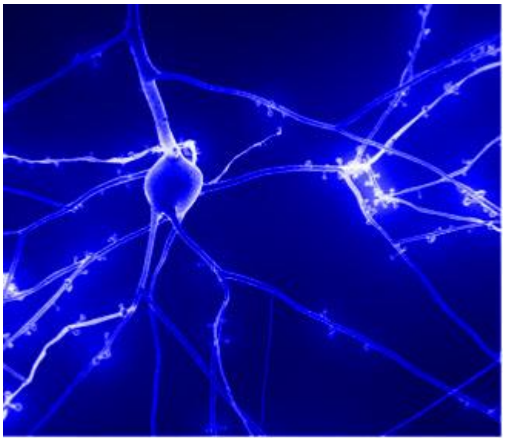


Figure 4. RTNeuron Visulisation of neuron

5. Introduction

One of the main focuses of the Blue Brain technology is storing the intellect, knowledge and personality of a human being in a digital form. Thus one of the main aims of Blue Brain is uploading the human brain in the virtual brain.

But the question may arise as to how can the human brain be uploaded into the virtual brain? The answer to that is: Nanobots.

Nanobots are very minute robots that can enter the blood stream of human beings and travel throughout the circulatory system. Research has already been started towards creating these minute machines which will be around the size of a nanometre, and even though a fully operational bot is claimed to be available only by 2030, prototypes have already been developed and are partially functioning [8].

These nanobots, by entering the human circulatory system and travelling to the spine and the brain, will achieve the ability to monitor the activity and structure of the central nervous system [5]. Because of this an interface will be created between the physical body and the computer which will be as close to the mind as one can get while the human is still alive. Nanobots can then give a complete scan of the structure of the brain and its activity with comprehensive readout of the connections in the brain. Once this information is uploaded in the computer it begins to function as the natural brain and becomes a substitute of our personality, i.e., the entire data in the natural brain is uploaded in the virtual brain's machine.

6. Steps for Building Blue Brain

Following are some basic requirements for building a Blue Brain System:

- Supercomputer with high performance processor
- Large storing capacity
- Wide interconnection network
- Software to replicate the sensory cells and brain functions

6.1. Hardware

- Supercomputers:
  - **Blue Gene/P** (IBM agreed to build a Blue Gene supercomputer for the Blue Brain Project, started by Mind Institute of the École Polytechnique Fédérale de Lausanne (EPFL), as the primary machine in 2005) [2]
  - **JuQUEEN** or Blue Gene/Q (JuQUEEN is a Blue Gene/Q supercomputer built by IBM for Jülich Research Center in Germany in May 2012) [16]
  - **Magerit,** a supercomputer developed by Technical University of Madrid and IBM in collaboration. It is housed in The Supercomputing and Visualization Center of Madrid (CeSViMa), Spain in 2005. [16]
  - **HPE SGI 8600**, a supercomputer developed by Hewlett-Packard was decided to be used for the new phase of the Blue Brain technology in July 2018.

(a) (b) (c)

Figure 5. a), b) and c) showing the supercomputers: Blue Gene/P, JuQUEEN and Magerit[5] respectively.

- Silicon Graphics [2]
- Commodity PC clusters [2].

6.2. Software

- **NEURON**: It is software developed by Michael Hines at Yale University and John Moore at Duke University starting in the 1990s [2].

- **BBP-SDK**: BBP-SDK stands for Blue Brain Project-Software Development Kit and it is a set of software classes or APIS that is used by researchers for inspecting models and simulations. The Development Kit is a C++ library wrapped in Java and Python [1].
- **RTNeuron**: RTNeuron is a software that was internally developed by the Blue Brain Project team. It is the application that is used primarily for visualization of neural simulations [3].

All were previously discussed in sections 4.2 and 4.3 in detail.

7. Applications

- *Gathering and Testing 100 years of data [9]:* One of the most beneficial applications is the development of a working model which gathers the knowledge about the microstructure and workings of the neocortical column of the last 100 years so that it can be tested.
- *Cracking the Neural Code:* The activity of building objects using electrical patterns by the brain is known as Neural Coding and the code thus generated is known as Neural Code. Thus, it is absolutely essential to create an apt copy of the Neural Code which can reproduce the emergent dynamics of the actual microcircuit, so that we may reveal the working of the neocortex processes and how it stores and retrieves information.
- *Understanding Neocortical Information:* It is possible to create accurate simulations only through predictions that may be generated in the neocortex. And to create an accurate replica of the Neural Code, iteration between simulations and experiments are a must.
- *A Way for efficient Discovery of Drugs for Brain Disorders:* An important application of the virtual brain technology is that it lets one perform any tests, experiments and analysis on it rather than the real brain. Thus, testing of new drugs and discovery of brain disorders and their treatment becomes extremely convenient and risk.
- *Preservation and utilisation of a person's intelligence alive and even after their death:* As discussed before, Blue brain will allow a new host for the knowledge, information and intelligence of a person while alive and even after their death. This would help in preserving essential characteristics of a person's personality, thought and intellect, and would serve in keeping the person 'alive ' even after death.
- *A Foundation for the Whole Brain Simulation [11]:* Another application of Blue Brain is that it creates a base for the future simulation and analysis of the brain and further research on the topic.
- *A Foundation for Molecular Modelling of Brain Function [8]:* As is the case with Brain Simulations, it has also built a foundation for the molecular modelling of brain functions by attempting to create an accurate replica of the neocortical column with whose advancement the complexity of the molecular model of the brain functions will increase gradually as well.

8. Comparison between Actual Brain and Blue Brain

Blue Brain is a very complex process and poses a lot of risks and difficulties. Here listed are some of the challenges it poses:

- ***Neural Complexity**:* The brain as we know it, is a very complex and delicate system, thus contributing to the fact that very little is known about this organ of the human body till date; Computations performed in the dendrites are complex and can affect the probability and frequency of neural firing [13]. The dendrites perform many complex computations, like inhibitory computations which deals with shunting internal cell voltage to resting potential or decreasing the potential [12]; other computations being generation of dendritic spikes, linear additions, sub-linear addition and super-linear additions.
- ***Scale**:* The Blue Brain technology, as discussed, relies on supercomputers as their main base. And even though largest supercomputers have thousands processors in them, it still is not enough as the human cortex has tens of billions of neu-

rons along with a quadrillion synapses [13]. Thus, the scale is huge.

- ***Non-portable equipment**:* Since the scale is so large, it is almost impossible to think about a system that wouldbe easy to port. The supercomputers used are enormous, weighing in tons and are thus non-portable.
- ***Complexity of the system**:* The Blue Brain system utilises the help of some of the most advanced software and hardware systems that are in themselves highly complex.
- ***Interconnectivity**:* Emulation of the human cortex in hardware represents a huge 'wiring' problem. A synapse represents a particular input to a neuron, and each neuron shares synapses with around 10,000 (a maximum of 100,000) other neurons [13]. And the axons responsible for delivering outputs to these neural inputs fan out to around 10,000 destinations as well [13]. Thus, each neuron, on an average, has around 10,000 inputs and 10,000 outputs, which in hardware terms is really hard to wire and connect and form a web of complex interconnected system [13].
- ***Power Consumption**:* Having around 50 billion neurons and 500 trillion connections, it is almost impossible to consume only 25 watts of power [10], which is how much power the human brain consumes; although nanotechnology and ultra-low power design promises a viable solution for it and in the future this may not pose to be that big of an issue.

9. Merits and Demerits

9.1. Merits

- Preservation and Restoration of memory of a person, dead or alive; e.g. especially effective in case of 'short-term' memory loss.
- Recollection of memories without any effort.
- Decision making even in the absence of the person [2].
- Preservation and utilisation of the intelligence of a person even after death [5].
- Understanding the activities and behaviour of wildlife [5].
- Invaluable research on the human brain and cracking the mystery that is human brain.
- Development of new drugs and discovery of the cause, effect and treatment of brain disorders without performing dangerous experimentations on the actual brain.

9.2. Demerits

- Extreme reliance and dependence on computers [5].
- Misuse of technical knowledge by others [2].
- Usage of large amount of power by computers, around 1MW.
- Even though memories would be better preserved, they may be subjected to other dangers which threaten their destruction, like computer viruses.
- The intelligence of a person may be misused if hacked into the system [5].
- It is an extremely costly and complex system.
- Development of an intelligent computer system threatens the future of humankind.

10. Steps for Building Blue Brain

Few technologies that work with or parallel to the Blue Brain Project and aim at achieving towards the same goal as the Blue Brain project are as follows:

- BRAIN Initiative
- Human Connectome Project
- Human Brain Project
- SyNAPSE

All of these projects and technologies **are similar to the Blue Brain Project** but they either differ in the method used to replicate the human brain or they differ in the section or region of the brain that they focus on replicating; thus, either helping the Blue Brain project in achieving its end goal or working parallel to the blue brain project and giving a new perspective as to how a virtual brain can be created or the preservation of the human brain and memories can be brought about.

The projects of **Human Connectome Project** and **BRAIN Initiative** *work with* the Blue Brain project and help it by providing the basis of a network topology as the aim of these projects is to map each neuron at certain states and stages in the brain, thus providing a connected map of the networking of the brain which determines how the different parts of the brain are linked together.

The **Human Brain Project** *works parallel* to the Blue Brain Project and is quite similar to it, but it differs in goal to the Blue Brain Project as instead of creating a virtual brain, i.e., reconstructing and simulating the human brain, it focuses on producing a working model of the human brain that will help in understanding the human brain, the effects of brain disorders and diseases and the computational capabilities of the brain. Henry Markam, who had previously worked on the Blue Brain Project, has developed the Human Brain Project. And even though both the projects will help in calibrating the brain, its capabilities and the disorders that arise in it, the Blue Brain will focus on asking “How it happens?”, while HBP will focus on asking “What happens? “ and “What we can do about it?”

Lastly, the **SyNAPSE** project which resulted from a collaboration between DARPA and IBM, also *works parallel* to the Blue Brain Project. The goal of this project, headed by Dharmendra Modha, unlike the Blue Brain Project, is to replicate the human brain and create a real copy of it, i.e., create a ‘real’ brain instead of a virtual brain. It strives to do so by giving a physical basis to the artificial brain by launching it in real time.

11. Conclusion and Future Scope

In conclusion, the Blue Brain is a rapidly growing technology which will allow the human brain to be digitally reconstructed in a short amount of time. Thus, helping in further in-depth research of one of the most complex organs of the human anatomy, i.e., the brain. As discussed, the technology of Blue Brain is not only beneficial to the field of medicine, but also the fields of research, psychology and artificial intelligence.

Its extensive application in the fields of neurology, psychology and neurosciences makes it an extremely valuable project. It also helps in the advancement of the technologies used in it like the technology of artificial intelligence. And while it still faces many major challenges before being accomplished completely, advancement in old technologies, introduction of new technologies and development of new systems, tools and features ensure the growth and future accomplishment of the project. While there are certain demerits of the project, the merits outweigh those marginally.

In August of 2012, simulations of mesocircuits that contained about 100 cortical columns were achieved, which represented an equivalent of a honey bee brain [2]. In 2015, scientist of EPFL graphed a quantitative model of a previously undiscovered relationship between the glial cell astrocytes and the neurons [3]. It shed light on the memory management of the brain with the help of the neuro-glial vascular (NGV) [1]. It is predicted that by the year 2023, we would achieve a fully functioning human virtual brain (consisting of roughly 86 billion neurons) provided the funding is sufficient [2].

In 2018, École Polytechnique Fédérale de Lausanne (EPFL) acquired Hewlett Packard Enterprise (HPE) for the new phase in the development and digital reconstruction of the mammalian brain the Blue Brain technology dubbed as 'Blue Brain 5'. It will use HPE SGI 8600 supercomputer which is much faster and efficient than the previous Blue Brain systems. HPE will focus exclusively on the simulation work-flows and compute-intensive challenges of the Blue Brain project.[17]

Even though there is still some time before we completely achieve this goal, and there still stand some challenges before Blue Brain can be completely realized and become functional for human beings, it is safe to say that in the near future there will exist the technology that will let humans upload their thoughts, ideas, intelligence and emotions, i.e., their brains into a computer device.

Acknowledgements

I am grateful to my guides and mentors at Amity University Uttar Pradesh, Lucknow, for their support and guidance. I am extremely grateful to my faculty members of Department of Computer Science & Engineering, ASET, Amity University Uttar Pradesh, Lucknow for their valuable guidance, sincere co-operation, keen interest, encouragement and constructive suggestions which helped me in completing this review paper. I am also grateful to any and all whose help, support and guidance have directly or indirectly resulted in the success of this review paper.

References

[1]. P. Babel, "Blue Brain- The Future Generation, "Research Journal of Computer and Information Technology Sciences, vol.3, no.2, pp.1-5, May 2015.

[2]. S. Verma, and B. Kohli. "Blue Brain," International Journal of Scientific and Research Publications, vol.5, no.10, 2015.

[3]. S. K. Avula, V. S. Pakale, S.V Kasidh, "Blue Brain-The Future Generation." International Journal of Application or Innovation in Engineering & Management vol.2, no.3, pp.306-311, March 2013.

[4]. M. Gidwani, A. Bhagwani, and N. Rohra, "Blue brain - the magic of man," in International Conference on Computational Intelligence and Communication Networks (CICN), pp. 607-611, Dec 2015.

[5]. S. Sharma, N. Payal, A. Kaushik, and N. Goel, "Blue brain technology: A subway to artificial intelligence," in Fourth International Conference on Communication Systems and Network Technologies, pp. 1106-1109, April 2014.

[6]. S. Haykin, "Neural Networks – A Comprehensive Foundation, "Pearson Education, Asia, Second Edition, pp.1-823, 2001.

[7]. D. Bansal and A. Sarkar, "HMM based predictive model of brain computer interface," Annual IEEE India Conference (INDICON), pp. 1-5, Dec. 2014.

[8]. J.M. Schwartz, and S. Begley. "The mind and the brain" Springer Science & Business Media, pp.1-97, Harper Collins, Canada 2009.

[9]. L. Lohi, "Blue Brain – The Future Generation", International Journal of Engineering Research & Technology (IJERT)RTPPTDM vol.3, no.30, Henry Markram's lecture, March 2008.

[10]. S. Hill and H. Markram, "'the blue brain project," in 30th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Aug 2008.

[11]. H. Markram," Builds a Brain in a Supercomputer," Nature Reviews Neuroscience, vol.7, no.2, pp. 153-160, June 2009.

[12]. P.A Calif," HPE Helps EPFL Blue Brain Project Unlock the Secrets of the Brain," Globe News Wire, Hewlett Packard Enterprise, July 2018.
https://globenewswire.com/news-release/2018/07/09/1534865/0/en/HPE-Helps-EPFL-Blue-Brain-Project-Unlock-the-Secrets-of-the-Brain.html