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Synthetic Brain Functional Network Modeling using Reverse Engineering- a Survey

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Abstract— Synthetic Brain refers to imitating a natural product i.e. human brain. Our goal is to reconstruct a digital system that will work like the brain. Although so much work has been done for making computer man like, still there are things which brain can do and computers cant. Brain understands pain, pleasure, intuition, perceived notion of success and failure but a machine cannot. We are on the way to study the operation of the brain, so that a system can be built which will overcome the shortcomings of a living being. Human brain can't work for so long as it get tired within a specific period of time but a system can work for days and months without getting affected. Also, sometimes the unfavorable situations in the personal life do not allow the brain to focus on the work in that case synthetic brain will help the smooth functioning. Other motivation for this project is the curiosity of consciousness and human mind. We can also give the proper treatment by understanding the exact causes of disfunctioning of the brain. For this, first we have to study its wiring and circuitry in the form of veins, cords and brain cells and build computer systems that work the same way, this can be done with the help of Reverse Engineering. Section I is the introduction of the project , Section II contains the literature review of the approaches that can be used for reverse engineering the brain, Section III briefs the tools, that has been applied by now, Section IV contains the proficiency achieved up to the work, Section V shows the research gaps and Section VI is the conclusion.

Index Terms— Cognitive Science · Reverse Engineering · Modeling and Simulation · Neurons · Visualization

INTRODUCTION

Synthetic Brain construction is a wide research area. Brain performs millions of operations according to different inputs. Sometimes, operations are self-processed i.e. without any input. Visual input comes across brain via sensory organ, eyes. Eyes capture the image and send it to the brain for further processing. The processing involves what is reflecting in the image, is it black and white or comprises of several colors. If colorful, how many colors are there and what are them, are they bright or dull, what is the percentage of hue, is it static or changing with time, why this image has been shown to our eyes, is it intentional or accidental, what message we can infer from that image, after receiving the message what could be the responses, among the possible responses which one we need to choose and so on. All such operations need to be performed by brain for a single visual input received by one sensory organ. Visual Cortex of the brain is responsible for cognitive function where images or objects are interpreted on the basis of the previously stored images in the visual memory [1]. In February 2013, a neural implant has been developed by which rats can sense infrared light.

Traditionally, a human body comprises of five types of sense organs which collects data for perception. Along with vision four others are- Hearing, Smell, Touch and Taste. Hearing is performed by Ears. It is the perception of sound.

Nose of a living being contains two nostrils which senses the smell. It is a chemical sense, where hundreds of olfactory receptors, each binding to a particular molecular feature [2]. Smell in the brain is done by olfactory system. There are olfactory receptor neurons which are different from other neurons. Some special kinds of neurons also exist in the nose of a mammal to detect pheromones [2].

Taste, which is also known as gestation is detected by tongue. It is also a chemical sense like smell. Taste is usually misinterpreted with flavor. Flavor is the combination of taste and smell which involves odor, texture and temperature [2].

Touch sensation is generated by neurons receptors present in the skin of a living being. Different types of touch sense are firm, brushing, itching etc. Touch receptors takes input from the movement of hairs present on the skin and passes it to spinal cord via sensory nerves. Thalamus and sensory cortex

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in the brain are responsible for further processing of touch sensation [3].

Reverse Engineering, as the name suggests is something that performs for engineering but in reverse direction. It is the process of analyzing a product, and segregation into its components. It is performed for extracting knowledge, design information, operational functions etc. and using the extracted information to re-producing something another. In this survey, we are reviewing the work done in the field of reconstructing the human brain. The flow diagram of Reverse Engineering has been shown in Fig 1.

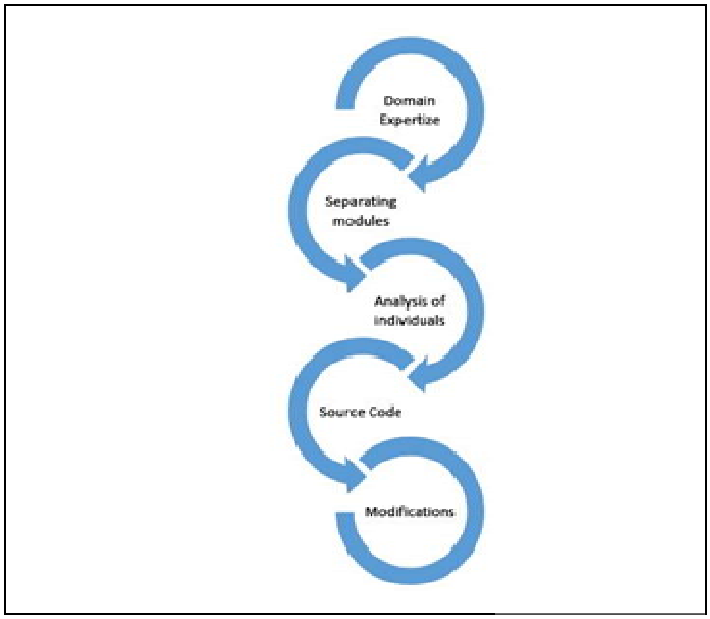

Fig 1: Steps involved in performing Reverse Engineering

LITERATURE REVIEW

In this section, the brief introduction of related literature is given. This includes the work that has been done by researchers in order to reconstruct the brain. Different researchers used different approaches to form the model of the brain.

A. *Modeling Abstraction And Simulation*

Brain has been model by researchers with the help of Very Large Scale Integrated (VLSI) circuits [4]. A recent hypothesis [5] suggests that vision processing can be modeled by a wave of spike propagation through a hierarchy of layers that can be viewed in Fig 2. Brain can be viewed on microscopic as well as macroscopic level. At macroscopic level, the brain appears as a highly clustered circuits which can communicate with other similar circuits. These circuits represent different regions of a brain. At microscopic level, cortical circuit organization is formed which offered a model for general purpose processing. Modeling abstraction is the level by level abstraction model. As we move upward in abstraction hierarchy, complex biological processes are being simplified into mathematical expressions.

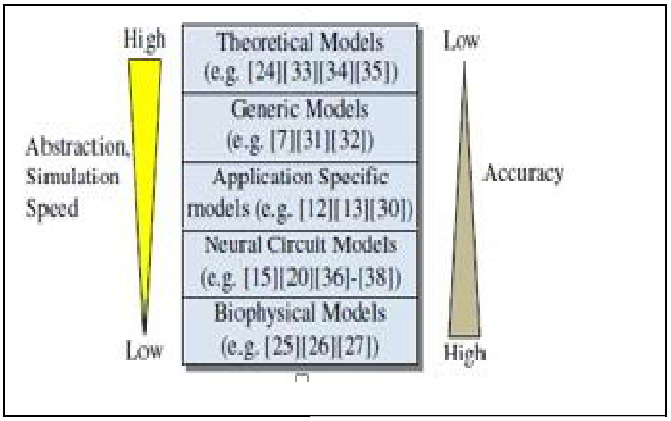

Fig 2: Levels of Modelling Abstraction [4]

B. *Blue Brain Technology*

In the recent research, an experiment has been performed with the visual brain. A supercomputer having very high processing speed and large storage capacity is treated as visual brain. [7] It has been performed in three steps: Data Acquisition, Simulation and Visualization of results [6]. In the first phase i.e. Data Acquisition, analysis of brain slices has been done by keeping it under microscope and capture the shape and electrical activities of individual neurons. Second phase simulation consists of input, interpretation, processing, memory and output. This has been shown in Fig 3. Sensory cells conveys the input by producing electrical impulses which is received by neurons and passes to brain. Brain interprets the impulses and stored in registers. Different values of registers correspond to different states of brain. On the basis of stored states, arithmetic and logical calculations has been performed in neural circuitry. Results are given to sensory cells again in

the form of electrical impulses [8]. Memory is required to store certain information received during experiment as well as the previously gathered. Third phase is visualization of results. Simulation has been performed iteratively thousands of time, with an individual neuron. To represent the relations between different iterations and the relation of one neuron to another, 3D graphs were used. Results of this experiment are very interesting. It gives a positive aspect for further researches. Some of them are:

a. Intelligent brain can work even after the death of a person,
b. Madness of a person can be removed by downloading the contents of the brain.

TABLE 1: Comparison of Natural Brain and Artificial Brain *[9]*

Phase	Natural Brain	Artificial Brain
Input	Sensory cells receive input, produce electrical impulses and pass it to brain with the help of neurons.	Process in artificial brain is same as natural except there are artificial neurons created by scientists using silicon chips.
Interpretation	Received input in the form of electrical impulses is interpreted by the states of neurons.	Here the values of registers are used to interpret the electrical impulses. Different values are already stored in registers for different states.
Output	After the processing of input, sensory cells present at different parts of body receive the output accordingly, to respond.	Depending on the value of the register, the output is given to artificial neuron.
Processing	According to our past experiences and current situation, decisions can be manipulated.	Similarly, decision making is done by stored states and received inputs.
Memory	For the remembrance of events, activities held, neurons stores certain states permanently, which can be retrieved anytime.	In synthetic brain also, we can store the states permanently in secondary memory and can retrieve on the basis of requirement.

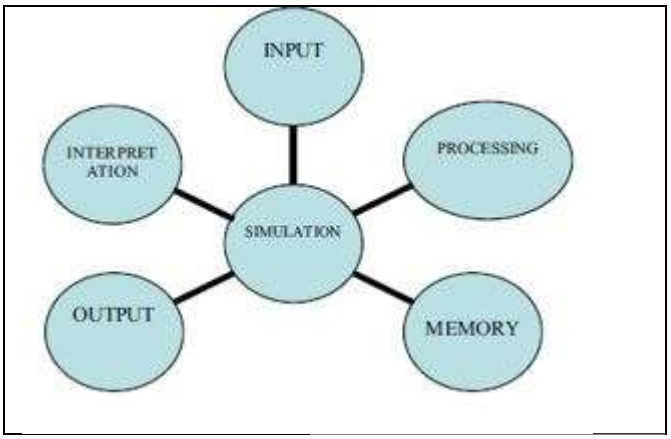

Fig 3: Phases of Simulation [6]

C. Cognitive Modelling

A research says, to understand cognition, reverse engineering of biological system is a best approach [10]. Computational neuroscience is the key activity for cognitive modeling [11]. Here, each neuron is represented in the form of equation:

$$sdV/dt = -V+ F, \quad (1)$$

where V is a membrane potential variable, and F is a forcing term. For neuron 2, F2 = w12 y1, where y is the output of neuron 1, and for neuron 1,

$$F1 = w21\ y2+I \quad (2)$$

where I is an injected current. The outputs are given by a piecewise linear function, h

where y = h(V) [13] (3)

After computation, algorithm, mechanism and biological substrate, relation has been shown between computational neuroscience and other modeling disciplines. Cognitive study includes all aspects of psychology, mental organization, linguistics, thoughts and computations [14]

Table 2: A Review of Research over the Years

Year	Paper Name	Results	Limitations
1999	Neuroinformatics as a Megascience Issue	Neuroscience data identify the unique cell types, their elements, and anatomical connections. Other data fill in the chemical substrates of function which include tens of thousands of biochemical, molecular, and genetic mechanisms which regulate and control brain structure and function	Lots of activities need to be done for development of brain a. training of scientists b. development of test beds for beta-testing c. motivate scientists so that they contribute published data d. establishing international cross disciplinary working groups to address highly focused problems and issues.
2000	Reverse Psychologism, Cognition and Content	Reverse Psychologism is helpful in studying cognitive science.	Theoretically, it can be achieved in two ways: strong and weak but practically strong reverse psychologism did not work.
2007	A Robotic Neural Net Based Visual-sensory Motor Control System that Reverse Engineers the Motor Control Functions of the Human Brain.	Each subsystem obeys the law of physics and are amenable to reverse engineering. With the help of visual neuronal correlate of modality circuit, they shed the light into neurophysiology of human brain.	Relationships between visual and kinematic sensors, the modalities of tactile and visual sensors are still needs to be researched.
2008	Reverse Engineering The Brain	A google mapped brain could lead to a map of human consciousness	Solving a fruit – fly brain will solve one fifth of the understanding of human brain
2009	Reverse Engineer the brain	To engineer a mind like intelligence into machines, quickest and cheapest way is reverse engineering the structure, function and dynamics of the brain	Simulating the effect of strokes, tumors or other types of neurological disorders such as Alzheimer's or Parkinson's etc.
2009	Mathematical and Computational Modeling of Neurons and Neuronal Ensembles	Expressed the Neurons and Neuronal Ensembles into mathematical expressions.	Due to modeling relations, particular behavior cannot be determined from computations.
2009	Complex brain networks: graph theoretical analysis of	Geometrical parameters are determined like short path length,	Suggested the approach to understand the physics of human brain, didn't achieve.

	structural and functional systems	high clustering and a degree distribution compatible with the existence of hubs, and a modular community structure	
2010	Cognitive Neuroscience: The Troubled Marriage of Cognitive Science and Neuroscience	It is now possible to combine the functional magnetic resonance imaging (fMRI), electroencephalography (EEG) and near infrared spectroscopy (NIRS). Techniques used are diffusion weighted imaging (2006) and dynamic causal modeling (2003) to establish the connectivity.	There is no single area of cognition which has standard theoretical account. For example- a single working memory consist of differed theoretical conceptions.
2010	Towards Reverse Engineering The Brain: Modeling Abstractions and Simulation Framework	Exploration of brain circuit models and frameworks for simulation of large scale Supervised Neural Network (SNN).	In deep learning SNN, learning is still unsupervised.
	ks		
2010	Once more with feeling : Reverse Engineer the Brain	Found the issues that will come across in reverse engineer the brain.	Neurological trauma is possibly the most difficult affliction to cope with as there is currently little that can be done to help.
2011	Reverse Engineering for Biologically Inspired Cognitive Architectures: A Critical Analysis	Complex systems can be understood with the help of line of decompositional analysis.	Brain like intelligence algorithms are sill he question of research.
2014	Study of the Brain Functional Network Using Synthetic Data	Compared four techniques among which, two are more prone to errors.	Modifications need to be done in algorithms
2015	Discriminative Structured Feature Engineering (DSFE) for Macroscale Brain Connectomes	Proposed an algorithm DSFE for structuring human brain connectome	Even after developing macro scale , multivariate exploratory analysis of large databases are still need to be researched
2015	The intrinsic geometry of the human brain connectome	Comprehensive treatment of topology of human brain which can adapt multimodal data.	Removing nodes with the lowest 21.5 % of nodal clustering coefficient minimally impacts structural connectome's intrinsic geometry.
2016	BRAINtrinsic: A	Developed a tool for	It is hard to comprehend these

	Virtual Reality-Compatible Tool for Exploring Intrinsic Topologies of the Human Brain Connectome	analyzing intrinsic high level structural and functional properties of a complex architecture.	strict numerical quantities without a map to help guide relative locations.

TOOLS

After reviewing the research papers consist of experiments, certain tools have been come across.

D. iBrain

It is a simulation and visualization tool for activation of brain areas on a realistic 3D brain image [17]. It is constructed by modifying the software A-Cell. It captures the 3D brain image and enlarges an anatomical region which is initially in millimeters to a considerable extent. Hence makes easy for researchers to calculate the activation pattern. iBrain can reproduce the activation pattern after getting the information and match with the previous one. By this tool, with the help of a single cell, whole brain can be transformed.

E. Eureqa

Eureqa is a software tool which performs evolutionary symbolic regression on brain imaging data [10]. Symbolic regression is a type of regression analysis that searches the space of mathematical expressions to find the model that best fits a given dataset, both in terms of accuracy and simplicity [12]. Schmedit et Al, developed a genetic programming package named eureqa, which is used to express relationship between different selected regions of the brain. An experiment has already been performed by using eureqa. They analyze the behavior for two different input datasets. First, when brain receives the single subject performing two different but related tasks while the second is, when it receives a single subject performing no task. Later state of brain is known as resting state. EEG signals are recorded and converted into FMRI. Blood oxygen level dependence (BOLD) signals are used to represent the activation in response to a stimulus signal. Whenever a regression is performed, a BOLD signal has been generated for that region. For getting the relationship, a graph is drawn where x axis indicates independent signals whereas y axis shows dependent variables. The regions which contains relationship, their intersection point has been highlighted. There may be very strong, strong, weak, very weak or no correlation.

PROFICIENCY

The research work that has already been done in the field of developing synthetic brain is commendable and has achieved a great proficiency. The interactions discovered between brain regions have not been claimed yet. Even they are proved to be true by other researchers. Mathematical computations are validated as we can see their proofs. iBrain software helped understanding the functioning of brain at very small i.e. macroscopic level.

RESEARCH GAPS

In this survey, we observed that there are some problems which remain to be solved. Some of them are

a. Most of the experiments performed up till now for the virtual brain considered the brain having around 10,000 neurons but in reality, it may be more than that. As neurons are continuously dying and reproducing their population so we can predict a fix number of neuron for a particular duration of time.

b. All the regions of a brain are not considered for finding the relationship. Only on some selected regions, experiments have been performed.

c. Accuracy can be improved by changing or improving the structure of soft computing techniques.

VI. CONCLUSION

Related Research shows that developing the artificial brain first requires geometry of brain to be clearly specified. After understanding complete functional network of the brain, the process steps up to actions and reactions of different components of brain on the basis of inputs received through neurons. On the basis of learning, responses of brain can be manipulated.

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