Blue Brain Technology

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Abstract— Human brain is the most valuable creation of God. The man is intelligent because of the brain. "Blue brain" is the name of the world's first virtual brain. That means a machine can function as human brain. Today scientists are in research to create an artificial brain that can think, response, take decision, and keep anything in memory. The main aim is to upload human brain into machine. So that man can think, take decision without any effort. After the death of the body, the virtual brain will act as the man .So, even after the death of a person we will not lose the knowledge, intelligence, personalities, feelings and memories of that man that can be used for the development of the human society.

Keywords: Neurons, Sensory System, Supercomputers, RTNeuron, Neuroscience, Microscopy, Brain Modeling

I. INTRODUCTION

The Blue Brain System is an attempt to reverse engineer the human brain and recreate it at the cellular level inside a computer simulation. The project was founded in May 2005 by Henry Markram at the EPFL in Lausanne, Switzerland.

Goals of the project are to gain a complete understanding of the brain and to enable better and faster development of brain disease treatments. The research involves studying slices of living brain tissue using microscopes and patch clamp electrodes. Data is collected about all the many different neuron types. This data is used to build biologically realistic models of neurons and networks of neurons in the cerebral cortex. The simulations are carried out on a Blue Gene supercomputer built by IBM, hence the name "Blue Brain". The simulation software is based on Michael Hines's NEURON, together with other custom-built components. As of August 2012 the largest simulations are of micro circuits containing around 100 cortical columns such simulations involve approximately 1 million neurons and 1 billion synapses. This is about the same scale as that of a honey bee brain. It is hoped that a rat brain neocortical simulation (~21 million neurons) will be achieved by the end of 2014. A full human brain simulation (86 billion neurons) should be possible by 2023 provided sufficient funding is received.

II. WHAT IS BLUE BRAIN?

The IBM is now developing a virtual brain known as the Blue brain. It would be the world's first virtual brain. Within 30 years, we will be able to scan ourselves into the computers. We can say it as Virtual Brain i.e. an artificial brain, which is not actually a natural brain, but can act as a brain. It can think like brain, take decisions based on the past experience, and respond as a natural brain. It is possible by using a super computer, with a huge amount of storage

capacity, processing power and an interface between the human brain and artificial one. Through this interface the data stored in the natural brain can be up loaded into the computer. So the brain and the knowledge, intelligence of anyone can be kept and used for ever, even after the death of the person.

III. NEED OF VIRTUAL BRAIN

Today we are developed because of our intelligence. Intelligence is the inborn quality that cannot be created .Some people have this quality, so that they can think up to such an extent where other cannot reach. Human society is always in need of such intelligence and such an intelligent brain to have with. But the intelligence is lost along with the body after the death. The virtual brain is a solution to it. The brain and intelligence will be alive even after the death. We often face difficulties in remembering things such as people names, their birthdays, and the spellings of words, proper grammar, important dates, history facts, and etcetera. In the busy life everyone wants to be relaxed.

Can't we use any machine to assist for all these? Virtual brain may be a better solution for it. What will happen if we upload ourselves into computer, we were simply aware of a computer, or maybe, what will happen if we lived in a computer as a program?

IV. HOW IT IS POSSIBLE?

First, it is helpful to describe the basic manners in which a person may be uploaded into a computer. Raymond Kurzweil recently provided an interesting paper on this topic. In it, he describes both invasive and noninvasive techniques. The most promising is the use of very small robots, or nanobots. These robots will be small enough to travel throughout our circulatory systems. 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 between each neuron. They would also record the current state of the brain. This information, when entered into a computer, could then continue to function like us. All that is required is a computer with large enough storage space and processing power.

V. WORKING OF NATURAL BRAIN

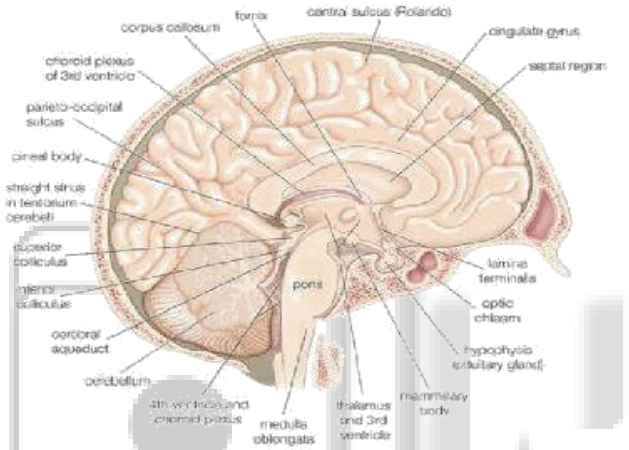
A. Getting to know more about Human Brain

The brain essentially serves as the body's information processing centre. Itreceives signals from sensory neurons (nerve cell bodies and their axons and dendrites)in the central and peripheral nervous systems, and in response it generates and sendsnew signals that instructthe corresponding parts of the body to move or react in someway. It also integrates signalsreceived from the body with signals from adjacent areasof the brain, giving rise to perceptionand consciousness. The brain weighs about

1,500grams (3 pounds) and constitutes about 2 percent of total body weight. It consists of three major divisions;

- The massive paired hemispheres of the cerebrum
- The brainstem, consisting of the thalamus, hypothalamus, epithalamus, subtha - lamus,midbrain, pons, and medulla oblongata
- The cerebellumThe human ability to feel, interpret and even see is controlled, in computer like calculations, by the magical nervous system. The nervous system is quite like magic because we can't see it, but its working through electric impulses through your body.

One of the worlds most "intricately organized" electron mechanisms is the nervous system. Not evenengineers have come close to making circuit boards and computers as delicate and precise asthe nervous system. To understand this system, one has to know the three simple functionsthat it puts into action; sensory input, integration &motor output.



B. Function of Human Brain

1) Sensory Input

When our eyes see something or our hands touch a warm surface, the sensorycells, alsoknown as Neurons, send a message straight to your brain. This actionof getting informationfrom your surrounding environment is called sensory inputbecause we are putting things inyour brain by way of your senses.

2) Integration

Integration is bestknown as theinterpretation ofthings wehavefelt, tasted, andtouched with our sensory cells, also known as neurons, into responses that the bodyrecognizes. This process isall accomplished in the brain where many, many neuronswork together to understand theenvironment.

3) Motor Output

Once our brain has interpreted all that we have learned, either by touching ,tasting, or usingany other sense, then our brain sends a message through neurons to effecter cells, muscle or gland cells, which actually work to perform our requests and act upon our environment.

4) Nose

Once the smell of food has reached your nose, which is lined with hairs, it travels to anol factory bulb, a set of sensory nerves. The nerve impulses travel through the olfactory tract, around, in a circular way, the thalamus, and finally to the smell sensory cortex of our brain, located between our eye and ear, where it is interpreted to be understood and memorized by the body.

5) Eye

Seeing is one of the most pleasing senses of the nervous system. This cherished action primarily conducted by the lens, which magnifies a seen image, vitreous disc, which bendsand rotates an image against the retina, which translates the image and light by a set of cells.The retina is at the back of the eye ball where rods and cones structure along with other cellsand tissues covert the image into nerve impulses which are transmitted along the optic nerveto the brain where it is kept for memory.

6) Tongue

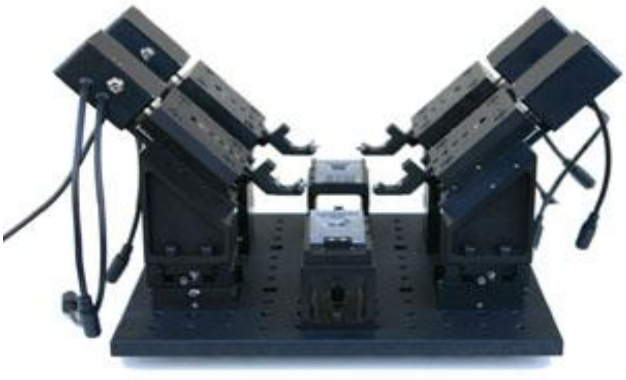
A set of micro scopic buds on the tongue divide everything we eat and drink into four kindsof taste: bitter, sour, salty, and sweet. These buds have taste pores, which convert the tasteinto a nerve impulse and send the impulse to the brain by a sensory nerve fiber. Upon receiving the message, our brain classifies the different kinds of taste. This is how we can refer the taste of one kind of food to another.

7) Ear

Once the sound or sound wave has entered the drum, it goes to a large structure called thecochlea. In this snail like structure, the sound waves are divided into pitches. The vibrationsof the pitches in the cochlea are measured by the Corti. This organ transmits the vibrationinformation to a nerve, which sends it to the brain for interpretation and memory.

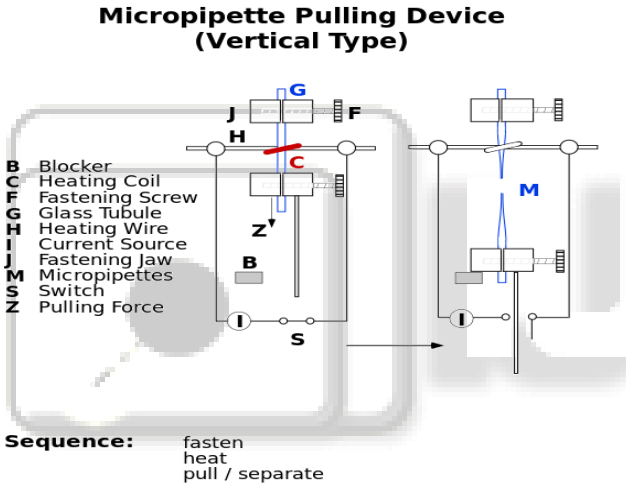
VI. WHAT IS A PATCH CLAMP ELECTRODE?

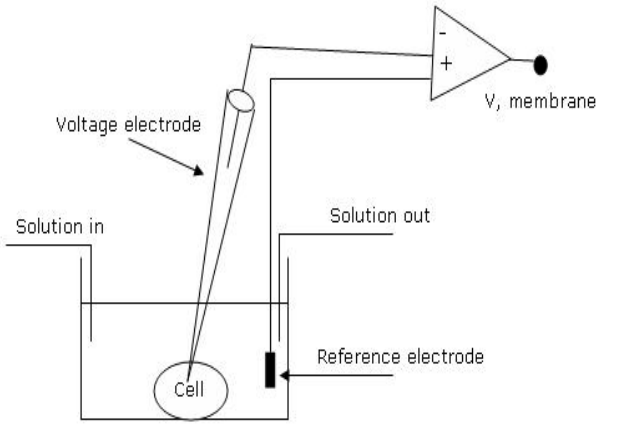
- The patch clamp technique is a laboratory technique in electrophysiology that allows the study of single or multiple ion channels in cells.
- The technique can be applied to a wide variety of cells, but is especially useful in the study of excitable cells such as neurons, cardiomyocytes, muscle fibers and pancreatic beta cells.
- It can also be applied to the study of bacterial ion channels in specially prepared giant spheroplasts.
- Patch clamp recording uses, as an electrode, a glass micropipette that has an open tip diameter of about one micrometer, a size enclosing a membrane surface area or "patch" that often contains just one or a few ion channel molecules. This type of electrode is sealed onto the surface of the cell membrane, rather than inserted through it.



- In some experiments, the micropipette tip is heated in a microforge to produce a smooth surface that

assists in forming a high resistance seal with the cell membrane.
- The interior of the pipette is filled with a solution matching the ionic composition of the bath solution, as in the case of cell-attached recording, or the cytoplasm for whole-cell recording.
- A chlorided silver wire is placed in contact with this solution and conducts electric current to the amplifier. The investigator can change the composition of this solution or add drugs to study the ion channels under different conditions.
- The micropipette is pressed against a cell membrane and suction is applied to assist in the formation of a high resistance seal between the glass and the cell membrane (a "gigaohm seal" or "gigaseal," since the electrical resistance of that seal is in excess of a gigaohm).
- The high resistance of this seal makes it possible to electronically isolate the currents measured across the membrane patch with little competing noise, as well as providing some mechanical stability to the recording.





VII. Computer Hardware / Supercomputers

A. Blue Gene/P

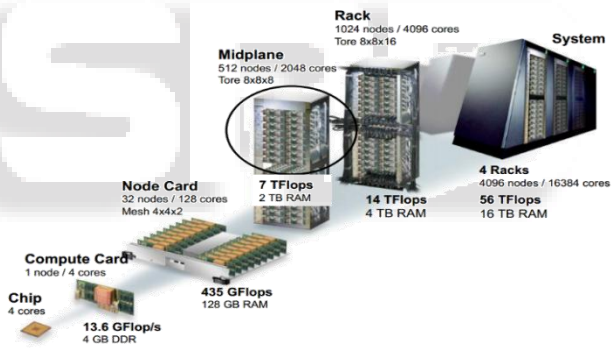
The primary machine used by the Blue Brain Project is a Blue Gene supercomputer built by IBM. This is where the name "Blue Brain" originates from. IBM agreed in June 2005 to supply EPFL with a Blue Gene/L as a "technology demonstrator". The IBM press release did not disclose the terms of the deal. In June 2010 this machine was upgraded to a Blue Gene/P. The machine is installed on the EPFL campus in Lausanne (Google map) and is managed by CADMOS (Center for Advanced Modelling 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. The brain simulations generally run all day, and one day per week (usually Thursdays). The rest of the week is used to prepare simulations and to analyze the resulting data. The supercomputer usage statistics and jobr history are publicly available online - look for the jobs labelled "C-BPP".

Blue Gene/P technical specifications:

- 4,096 quad-core nodes (16,384 cores in total)
- Each core is a PowerPC 450, 850 MHz
- Total: 56 teraflops, 16 terabytes of memory
- 4 racks, one row, wired as a 16x16x16 3D torus
- 1 PB of disk space, GPFS parallel file system
- Operating system: Linux SuSE SLES 10
- Public front end: bluegene.epfl.ch and processing log

This machine peaked at 99th fastest supercomputer in the world in November 2009. By June 2011 it had dropped to 343th in the world. It has since dropped out of the top 500. See the Blue Gene/P ranking on the TOP500 list.



B. Silicon Graphics

A 32-processor Silicon Graphics Inc. (SGI) system with 300 Gb of shared memory is used for visualisation of results.

C. Commodity PC clusters

Clusters of commodity PCs have been used for visualisation tasks with the RTNeuron software. A research paper published by the BBP team in 2012 describes the following setup:

- 11 node cluster, 3.47 GHz processors (Intel Xeon X5690)
- 24 GB RAM, 3 Nvidia GeForce GTX 580 GPUs
- Full-HD passive stereo display connected to two GPUs on head node
- 1 Gbit/s, 10 Gbit/s ethernet, 40 Gbit/s QDR InfiniBand

It's not known where this cluster is physically located - either in the BBP lab itself, in an EPFL data center, or elsewhere.

VIII. INFRASTRUCTURE

A. Main components of the infrastructure

The Blue Brain workflow depends on a large-scale research infrastructure, providing:

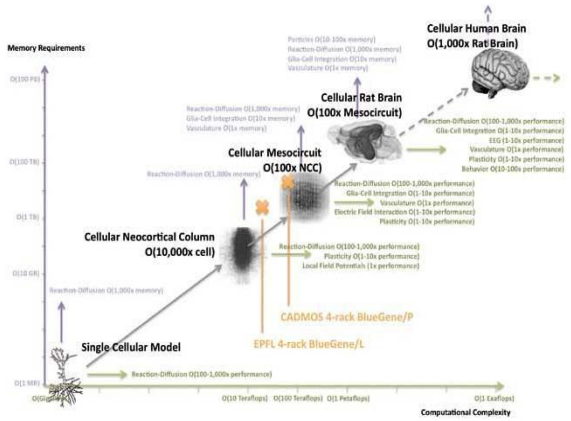
- State of the art technology for the acquisition of data on different levels of brain organization (multi-patch clamp set-ups for studies of the electrophysiological behavior of neural circuits, Multi-electrode Arrays – MEAs allowing stimulation of and recording from brain slices, facilities for the creation and study of cell lines expressing particular ion channels, a variety of imaging systems, systems for the 3D reconstruction of neural morphologies);
- An IBM 65,536 core Blue Gene/Q supercomputer for modeling and simulation (hosted at CSCS) which has extended capabilities for data-intensive supercomputing (BlueGene Active Storage);
- A 40 node analysis & visualization cluster
- A data center providing networked servers for use in data archiving and neuroinformatics.

B. Data acquisition infrastructure

The success of the Blue Brain project depends on very high volumes of standardized, high Infrastructure provides the physical equipment necessary for this work. Most of the experimental equipment is currently made available by the EPFL Laboratory of Neural Microcircuitry (LNMC). The planned Human Brain Project, if accepted, will massively increase the range of data sources.

C. High Performance Computing

The Blue Brain workflow creates enormous demands for computational power. In Blue Brain cellular level models, the representation of the detailed electrophysioloy and communication of a single can require as many as 20,000 differential equations. No modern workstation is capable of solving this number of equations in biological real time. In other words, the only way for the project to achieve its goals is to use High Performance Computing (HPC). The Blue Brain project's simulation of the neocortical column incorporates detailed representations of 30,000 neurons. A simulation of a whole brain rat model at the same level of detail would have to represent up to 200 million neurons and would require approximately 10,000 times more memory. Simulating the human brain would require yet another 1,000-fold increase in memory and computational power. Subcellular modeling, modeling of the neuro-glial vascular system and the creation of virtual instruments (e.g. virtual EEG, virtual fMRI) will further expand these requirements.



In the initial phase of its work the Blue Brain project used an IBM BlueGene/L supercomputer with 8,192 processors. Some years ago, it used a 16,384 core IBM BlueGene/P supercomputer with almost 8 times more memory than its predecessor. Today, it uses an IBM BlueGene/Q supercomputer with 65,536 cores and extended memory capabilities hosted by the Swiss National Supercomputing Center (CSCS) in Lugano.

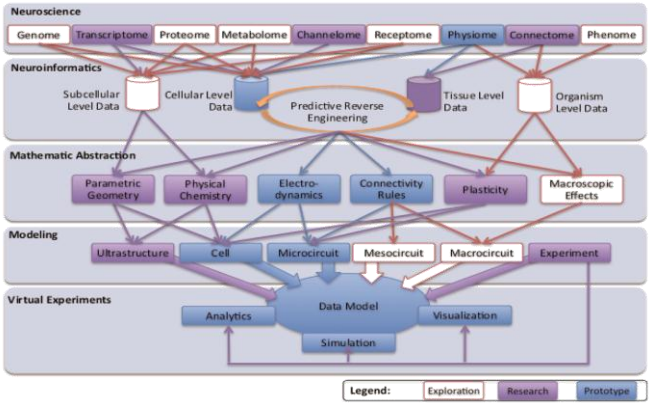
D. Neuroinformatics

Neuroinformatics is the second step in the Blue Brain workflow. The goal is to extract the maximal possible information from data acquisition in the previous step. To achieve this goal, the project has designed a set of prototype workflows supporting the acquisition, curation, databasing, post-processing and mining of data (protocols, experimental conditions, results) from Blue Brain experiments and from the literature.

One of the project's key strategies will be *Predictive Reverse Engineering.*

Biological data at different –omics levels displays complex cross-level structures and dependencies, amenable to discovery by informatics-based tools Together, these dependencies constrain the structure and functionality of neural circuits, at many different levels. Predictive Reverse Engineering exploits these constraints to fill in gaps in the experimental data. Predictive Reverse Engineering has already been successfully applied in several different areas (prediction of the spatial distribution of ion channels in 3D model neurons, prediction of neuronal firing properties from expression data for a selected set of ion channels, prediction of synaptic con¬nectivity from neuronal morphology). In future work, the project will extend the use of Predictive Reverse Engineering to new domains, including the prediction of the transcriptome from limited expression data, and the prediction of data for one species (e.g. humans), from data collected in other species (rat, mouse, cat, primates).

E. Workflows



The architecture of the Blue Brain Facility takes the form of a network of workflows, in which each step in every workflow is supported by a set of dedicated software applications. The key steps are:

- Neuroscience: systematic, industrial-scale collection of experimental data making it possible to describe all possible levels of structural and functional brain organization from the subcellular, through the cellular, to the micro-circuit, meso-circuit and macrocircuit levels;
- Neuroinformatics: automated curation and databasing of data, use of Predictive Reverse Engineering to predict unknown data from a smaller sample of known data or from data describing other levels of brain organization;
- Mathematical abstraction: definition of parameters, variables, equations, algorithms and constraints representing the structure and functionality of the brain at different levels of organization;
- Modeling: building geometric and computational models representing different levels of structural and functional brain organization;
- Virtual experiments: use of models for virtual experiments and exploratory studies requiring - Experiment Configuration: configuration of the experiment to exactly define or replicate the stimulation and recording protocols, initial conditions, and protocols of a biological experiment;
- Simulation: simulation of the evolution of model states (firing dynamics, voltages, synaptic strengths etc.); replication of previous in vivo experiments (application of specific patterns of simulation, administration of a drug etc.), design and implementation of new experiments; -
- Visualization: use of advanced techniques to display the structure and dynamics of simulations and (in the medium-long term) to interactively "steer" and "navigate" the simulation;
- Analysis: analysis of simulation results, initially for model validation, subsequently for simulation-based investigations of brain function and dysfunction, diagnostic tools and possible treatments.

The Blue Brain Project (BBP) has implemented prototype versions of the software applications needed to support the different steps in the workflow. Each application or component is composed of a steadily expanding set of sub-components (e.g. a sub-component to collect a specific class of data). Sub-components are developed in a well-defined three-stage process, beginning with exploration (identification of required data, estimation of data volumes, study of data availability), continuing with research (definition of data representations and their integration in the model, automation of the data acquisition process) and concluding with prototype development (definition of software architecture, implementation of software, implementation of required workflows). In the rest of this report, we will clearly indicate the stage of development reached by different components and subcomponents. The Blue Brain Project has adopted an incremental development strategy in which the capabilities of the facility are gradually enhanced through step-by-step addition of new subcomponents. The end result will be a completely transformed facility with the capability to model and simulate:

- The brain or any region of the brain of any species, at any stage in its development;
- Specific pathologies of the brain;
- Diagnostic tools and treatments for these pathologies. The geometric and computational models of the brain produced by the facility will reproduce the structural and functional features of the biological brain with electron microscopic and molecular dynamic level accuracy.

F. Neuroscience

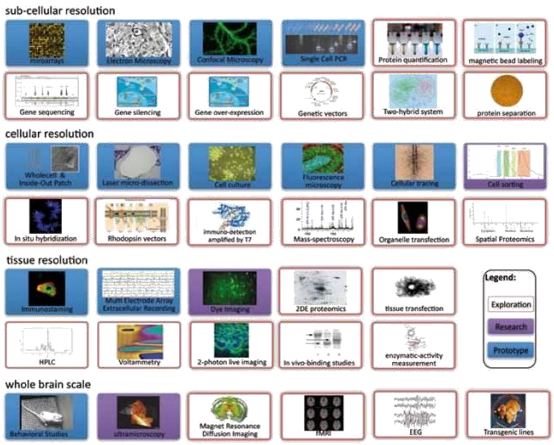
Data acquisition is the first step in the Blue Brain workflow and involves different levels of effort and standardization, from exploratory experiments, collecting preliminary data and testing techniques, to industrial-scale efforts to collect large volumes of standardized data.

The goal is to collect multiomics data describing every different level in the functional and structural organization of the brain. The project will collect structural information which includes information on the genome, the transcriptome, the proteome, the biochemicalome, the metabolome, the organellome, the cellome, the synaptome, extracellular space, microcircuits, mesocircuits, macrocircuits, vasculature, blood, the blood brain barrier, ventricles, cerebrospinal fluid, and the whole brain.

The information collected will be used to define parameters and geometric models describing the structural organization of the brain. Required functional informa¬tion includes information on gene transcription, protein translation, cell biology processes, signaling, receptor functions, biochemical, biophysical and electrochemical processes and properties, neuronal and synaptic information processing, micro-meso-macrocircuit information processing, whole brain information processing, metabolism, development, adapatation, learning, perception, cognition, and behavior.

This information will be used to define variables, equations, computational models and algorithms representing the brain's functional organization. Together the structural and functional information will make it possible to describe all possible levels of brain organization

from the subcellular, through the cellular, to the microcircuit, mesocircuit and macro-circuit levels.



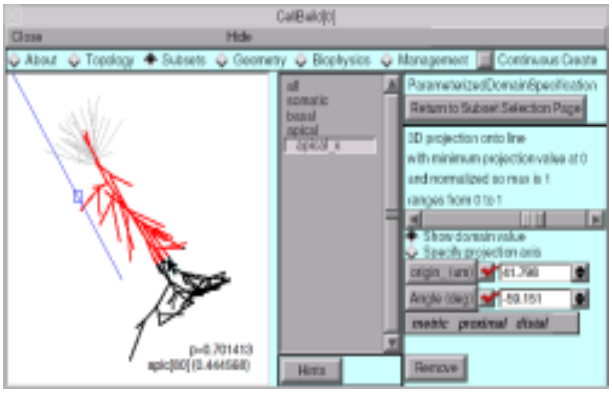
G. Virtual experiments

1) Goals

The ultimate goal of the Blue Brain Facility is to enable neuroscientists to conduct virtual experiments and exploratory studies testing hypotheses, diagnostic tools and treatments. This step in the Blue Brain workflow supports such studies by providing facilities for configuring the models, setting up virtual experiments and high performance simulations, visualization and analysis, all based on a single, unifying data model.

2) Simulation environment

The Blue Brain Facility provides simulation through the Simulation Environment, based on a Blue Gene/P super-computer. Any virtual experiment involves the simulation of biophysical processes at different levels of brain organization. In the Simulation Environment, these are represented by models integrating the data acquired and managed during the first two steps in the Blue Brain workflow, with the mathematical abstractions developed in the third step. The Simulation Environment generates numerical solutions for these models, guaranteeing accurate representation of causal relationships across different scales in time and space and allowing users to interact with the model.



3) Analytics

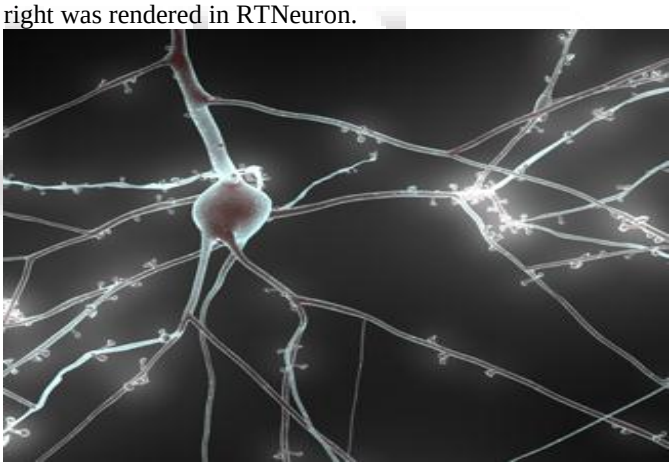
In silico studies require many different kinds of analytical data ranging from the time stamp for a single event -to EEG measurements covering the whole brain. The Analytics Environmentleverages the Data Model (see below) to provide a reliable framework for the development of reusable, potentially interactive tools for analytics. The framework is designed to support cohosting of simulations and analytics tools on the same machine.

4) Visualization

The Visualization Environment provides the interface between the user, modeling tools (Builders) and the simulation and analytics environments, with which it shares a common data model. The Visualization Environment provides users with tools allowing them to display and navigate the structural, transient and analysis data generated by these tools and environments. These tools include virtual instrumentsallowingt users to display in silico brain structures in the same way they appear during experiments with biological samples.

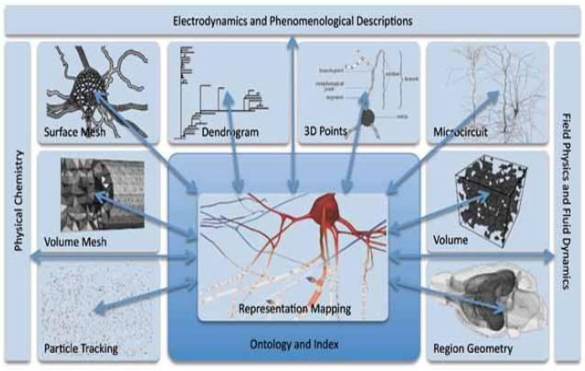
RTNeuron:

RTNeuron is the primary application used by the BBP for visualisation of neural simulations. The software was developed internally by the BBP team. It is written in C++ and OpenGL. RTNeuron is ad-hoc software written specifically for neural simulations, i.e. it is not generalisable to other types of simulation. RTNeuron takes the output from Hodgkin-Huxley simulations in NEURON and renders them in 3D. This allows researchers to watch as activation potentials propogate through a neuron and between neurons. The animations can be stopped, started and zoomed, thus letting researchers interact with the model. The visualisations are multi-scale, that is they can render individual neurons or a whole cortical column. The image right was rendered in RTNeuron.



5) Data model

Modeling and simulating the brain requires the integration of structural and functional information spanning multiple orders of magnitude in space and time. The Blue Brain Data Model, which evolves continuously, provides a unifying "spatial scaffolding" for mathematical models representing different aspects of the brain on different spatial and temporal scales or serving different purposes (e.g. visualization vs. simulation). All Blue Brain modeling, simulation, analytics and visualization are based on instances of the model.



IX. 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 petaflops and was ranked the world's 8th fastest supercomputer in June 2012. It's likely that this machine will be used for BBP simulations starting in 2013, provided funding is granted via the Human Brain Project.

In October 2012 the supercomputer is due to be expanded with additional racks. It is not known exactly how many racks or what the final processing speed will be.

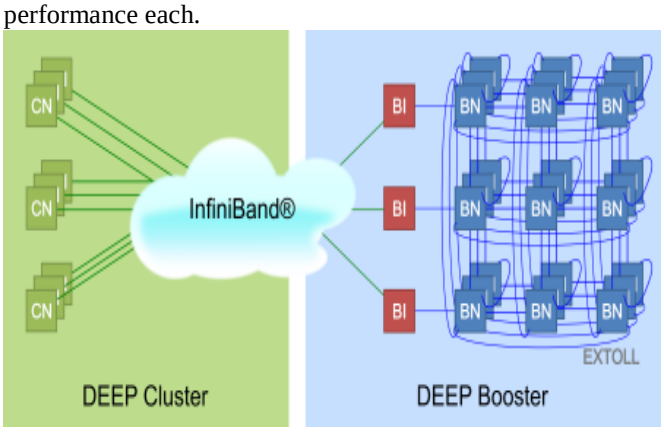
The JuQUEEN machine is also to be used by the JuBrain (Jülich Brain Model) research initiative. This aims to develop a three-dimensional, realistic model of the human brain. This is currently separate from the Blue Brain Project but it will become part of the Human Brain Project if the latter is chosen for EU funding in late 2012.

X. DEEP - DYNAMICAL EXASCALE ENTRY PLATFORM

DEEP (deep-prroject.eu) is an exascale supercomputer to be built at the Jülich Research Center in Germany. The project started in December 2011 and is funded by the European Union's 7th framework programme. The three-year protoype phase of the project has received €8.5 million. A prototype supercomputer that will perform at 100 petaflops is hoped to be built by the end of 2014.

The Blue Brain Project simulations will be ported to the DEEP prototype to help test the system's performance. If successful, a future exascale version of this machine could provide the 1 exaflops of performance required for a complete human brain simulation by the 2020s.

The DEEP prototype will be built using Intel MIC (Many Integrated Cores) processors, each of which contains over 50 cores fabricated with a 22 nmprocess. These processors were codenamed *Knights Corner* during development and subsequently rebranded as *Xeon Phi* in June 2012. The processors will be publicly available in late 2012 or early 2013 and will offer just over 1 teraflop of performance each.



XI. A TIMELINE OF THE BLUE BRAIN

2002 - Henry Markram founds the Brain Mind Institute (BMI) at EPFL.

2005 - June - EPFL and IBM agree to launch Blue Brain Project, IBM installs Blue Gene Basic simulation of single neurons achieved.

2007 - November - modelling and simulation of first rat cortical column.

2008 - Cortical column construction and simulations Neocortical column (10,000 cells) Research on determining position and size of functional cortical columns.

2009 - June - BlueGene/L replaced by BlueGene/P, doubling of processors Simulations of cortical construction continue.

2013 - February - decision on Human Brain Project funding of €1 billion over 10 years from the EU Simulations using NEURON software ported to the Blue Gene/Q system in Jülich.

2014 - Cellular-level simulation of the entire rat brain neocortex, ~100 mesocircuits NEURON simulation software ported to the DEEP Cluster-Booster prototype system in Jülich.

2023 - Cellular-level simulation of the entire human brain, equivalent to 1,000x the size of the rat brain.

XII. ADVANTAGES AND DISADVANTAGES

A. *Advantages*

(1) We can remember things without any effort.
(2) Decision can be made without the presence of a person.
(3) Even after the death of a man his intelligence can be used.
(4) The activity of different animals can be understood. That means by interpretation of the electric impulses from the brain of the animals, their thinking can be understood easily.
(5) It would allow the deaf to hear via direct nerve stimulation, and also be helpful for many psychological diseases. By down loading the contents of the brain that was uploaded into the computer, the man can get rid from the madness.

B. Disadvantages

Further, there are many new dangers these technologies will open. We will be susceptible to new forms of harm.

(1) We become dependent upon the computer systems.
(2) Others may use technical knowledge against us.
(3) Computer viruses will pose an increasingly critical threat.
(4) The real threat, however, is the fear that people will have of new technologies. That fear may culminate in a large resistance. Clear evidence of this type of fear is found today with respect to human cloning.

C. Applications

(1) Gathering and Testing 100 Years of Data.
(2) Cracking the Neural Code
(3) Understanding Neocortical Information Processing
(4) A Novel Tool for Drug Discovery for Brain Disorders
(5) A Global Facility
(6) A Foundation for Whole Brain Simulations
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