frontiers FOR YOUNG MINDS

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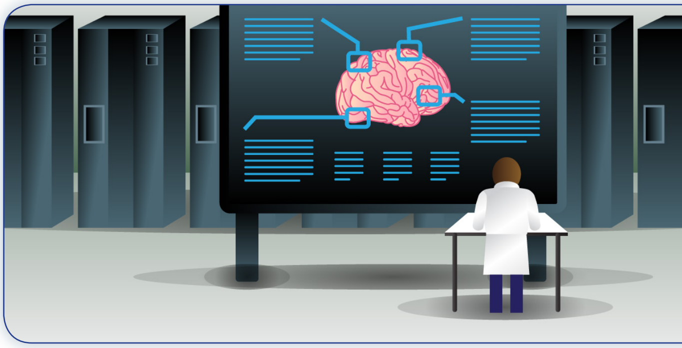

Brain projects think big

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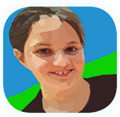

Abby
11 years old

When you read these words, hundreds of millions of nerve cells are electrically and chemically active in your brain. This activity enables you to recognize words, sense the world, learn, enjoy, and create new things, and be curious about the world around you. Indeed, our brains – those of *Homo sapiens* – are the most fascinating physical substances ever to have emerged on earth, some 200,000 years ago. The brain is so curious and ambitious that it strives to understand itself and cure its fragile elements when it becomes sick. However, despite important recent advances in brain research, we still do not know how to put the pieces of the brain puzzle together. It is because of this that, very recently, several mega brain research projects have started around the world. We play a part in one them – the Human Brain Project (HBP) [1]. Its main aim is to systematically catalog all that we know about the brain, to develop ingenious experimental and theoretical methods to probe the brain, and to put together all that we have learned into a computer model of the brain. All of this is possible since our brain itself have designed powerful computers, the Internet and sophisticated mathematics and software tools, which will soon be powerful enough to model in the computer something as complex as the human brain. This project will provide a new and deeper understanding about our brain, help us to develop better cures for its illnesses and, eventually, also teach us how to build smarter-learning computers. Importantly, our brain needs just a few meals a day (and maybe some additional sweets) to do it all – much more energetically efficient than even a simple computer. Let us then tell you the story of the HBP.

BIG BANG HUMAN BRAIN

The universe started with the Big Bang some 13,500 million (billion) years ago. Then very recently, about 200,000 years ago, another "Big Bang" happened – *Homo sapiens* appeared on earth. It has many genetic similarities with other species such as the chimpanzee and, even more so, with other hominids such as the *Neanderthals* who lived with us until 30,000 or so years ago. But we are very unique in one particular sense, in that our brain evolved to become amazingly creative. We transmit information among us via sophisticated spoken and written language, we create art and science, and we envision new ideas and eventually build new things (toys, airplanes, cell phones, computers) like no one on earth ever did. What makes the human brain so creative, with its elementary constituents, such as nerve cells and their connections ("synapses"), and the neural network that they form in various brain regions (see Figure 1) is still a puzzle.

THE HUMAN BRAIN PROJECT

On January 28, 2013, thousands of scientists all over the world held their breath. The European Community was about to announce which among 26 competing research projects would win 1 billion Euros for a period of 10 years. That evening, the two winners were announced: Graphene (led by Swedish universities) and the Swiss-based Human Brain Project (HBP). Both these European "flagship projects" involve hundreds of laboratories and thousands of scientists, students, and technicians. The two winning projects promise to bring about a revolution in nanomaterials (Graphene) and in understanding the brain (HBP).

The fundamental idea upon which the HBP is based was conceived about 10 years earlier, in the brain of Prof. Henry Markram and his colleagues in a project called the "Blue Brain Project" (BBP) [2]. The idea was twofold: (i) That understanding the brain requires a systematic approach to collect and database all available information about the brain, like the different cell types (like different types of trees in the forest), the different pattern of electrical activities composed of elementary signals, "the spikes," that nerve cells generate (Figure 1), and the connections that neurons form among themselves (synapses) to create functioning brain circuits. (ii) That all available brain data must be assembled in a computer and simulated mathematically, to make sure that the huge number of bits and pieces composing the modeled brain tissue will communicate correctly, and generate a collective activity similar to the one observed in the real brain. This digital copy of real brain tissue should help us understand how the biological tissue composing the brain operates. We already have many examples where a detailed realistic computer model could guide experiments and complement knowledge that remains experimentally inaccessible – for example, because of ethical reasons. In other words, the computer copy of the brain will enable us to perform virtual experiments that are otherwise hard or impossible to perform on the real biological tissue.

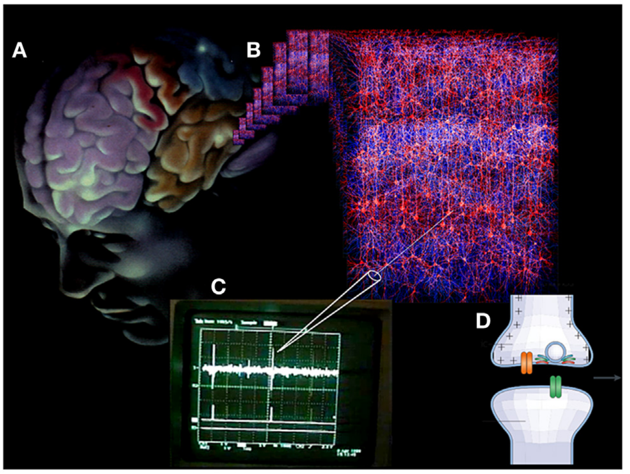

FIGURE 1 - Brain ingredients.
A. The brain with its different regions and the cortex below the skull.
B. A typical column-like circuit of the mammalian cortex (2-mm thick below the skull, with tens of thousands of neurons per square millimeter and 4 km wires).
C. The "spike," typical electrical "bit" that each nerve cell generates.
D. The synapse, chemical device connecting nerve cells to each other.

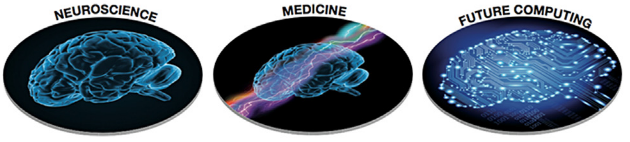

FIGURE 2 - The three main goals of the Human Brain Project (HBP). Left: collecting all brain-related data in the computer. Middle: developing new medications for brain diseases based on computer copies and simulations of brain processes. Right: learning from the brain how to develop a new generation of energy-efficient, learning, and powerful computers.

Figure 3A shows examples of the success of the BBP. It depicts a small piece of a young rat's brain, called "the cortical column," located at the neocortex just below the skull (Figure 2). This is a unique and repeating building block of the mammalian brain (mouse, rat, cat, monkeys, humans), containing some 30,000–100,000 nerve cells in a cubic millimeter, some 100 million synapses and about 4 km of wires. Figure 3A shows the anatomical structure of this column, whereas Figure 3B shows the electrical "spiking" activity (coded in colors) of this tissue, simulated in the powerful super "Blue Gene" IBM computer in Lausanne, Switzerland.

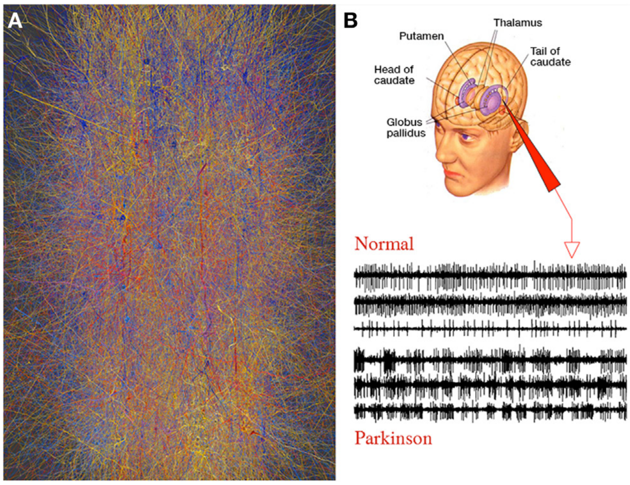

FIGURE 3 - The cortical column, the building block of the mammalian cortex and the focus of the Blue Brain Project.
A. Computer model of the cortical column performed as part of the BBP. When activated by an electrical stimuli, neurons in the network start to fire spikes (coded in red).
B. Each particular spiking activity in a specific network in the brain represents a given brain state ("sleep," "love," "recognizing face," "moving a hand," etc.). When the brain is sick, the normal spiking activity (top trace at lower right) changes to an abnormal activity (low trace at bottom right). The case shown is for a Parkinsonian brain state.

From the initial success of the BBP emerged the much-expanded vision of the HBP. This has three main research thrusts. First, we want to bring the integrative understanding of the brain itself to a new level – first the mouse and then the human brain. For this, we will develop new methods for data sourcing brain information from research labs and from hospitals. Then, we will extend models and simulation as already done in the BBP from a single cortical column to much larger brain areas, eventually to the whole brain. For this, we will need a new way of collaboration among hundreds of scientists. We will build an internet-accessible platform for scientists – something like a marriage between Google Earth, Facebook, and a weather forecast – where they can post and read the latest news and data, as well as work together on a shared database to build models and analyze them. Operating such an advanced platform will require today's and tomorrow's most powerful computers, as to faithfully simulate very large brain tissue models containing many millions of mouse brain nerve cells, and billions of human brain nerve cells. This is much more complex than what we did until today with our computers.

Second, we want to transform the way we do research of mental diseases; this is the clinical facet within the HBP. The brain is a wonderful, creative, and emotional machine but it is fragile – especially (but not only) at old age, when devastating diseases such as Alzheimer's, Parkinson's, depression, and sleep disorders tend to appear. The central claim of the HBP is that if we want to repair the brain then we must have an accurate computer model of the regions responsible for a particular disease. Namely, if a computer model can generate activity mimicking that of a diseased brain (e.g., during Parkinson's, see Figure 3B), then we will find out what generated this wrong activity in the computer model and, since we ourselves built the modeled network step by step, we should be able to understand what goes wrong that induces this disease-like network activity in the computer. Such a scientific interaction with the digital replica of the diseased brain region will provide systematic ways to repair the "sick computer" and thus will target the specific elements that are responsible for the corresponding disease (e.g., certain synapses/connections that malfunction, or specific neuron types that erroneously fire electrical signals).

Third, we will try to learn from the brain itself how to develop the next generation of brain inspired supercomputers. After all, the brain is the ultimate proof that a physical system, built from a huge number of interacting and plastic microchips (nerve cells), could perform miraculous computations at very low energy cost. In this way, the brain will teach us how to build computers that, in turn, will help us to understand the brain.

For all these activities, the question within the HBP is how to "tell the story" of our scientific findings to young minds like yourself, and to the public as a whole? The HBP is supported by the public and aims to help the brains of us all when needed. Everybody who is curious should get astute answers to his/her questions related to the HBP. For this, we plan to open a "brain corner" in many science museums worldwide, where we will send information about the most recent and important results emerging from the HBP. We will develop blogs and forums to interact with you and discuss your questions, ethical or otherwise. In many ways, we will make you part of the HBP, relying on your unique curious brain.

These are exciting brain-times, as the plastic and creative human brain came to a point where it had developed theoretical tools (mathematics) and technologies (computers; brain scans; and electrical, optical, and genetic devices) that made us closer to understand the brain in amazing and deep new ways. And so we should all be ready for, and be part of, the next human jump, where the brain will find ingenious ways to understanding, and repairing, itself.

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Abby, 11 years old

I currently live in Israel, but I lived in NYC and I loved it. I like wall climbing, dancing, watching TV, scuba diving, and I love learning new things about how our world works. Oh, I also love the Weird-but-True books. You should try reading them too.

AUTHORS

Idan Segev

Professor in Computational Neuroscience at the Hebrew University of Jerusalem, where he received his B.Sc. (1973) in Mathematics and Ph.D. (1982) in Experimental and Theoretical Neurobiology. His work is published in the top journals such as Science, Nature, PNAS and he received several awards including "best teacher" in international brain courses. In recent years, his group worked jointly with several experimental groups worldwide in an endeavor to model a whole piece of the mammalian cortex with the ultimate goal to unravel how local fine variations within the cortical network underlie specific behavioral function and may give rise to certain brain diseases or to a healthy and "individual" brains. His recent digital course in Coursera was viewed by 50,000 students worldwide. Idan Segev takes a keen interest in the connection between art and the brain.

Felix Schürmann

Why is it so easy for my calculator to multiply two numbers, but my brain gets bored doing the same? I studied physics to learn how many great minds have come up with so many good answers. Only this thing with the computers and the brains need a little bit more thinking. This is why I enjoy working on the Human Brain Project!