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Neurotechnology

Growing a Brain in Switzerland

By Manfred Dworschak

A network of artificial nerves is growing in a Swiss supercomputer -- meant to simulate a natural brain, cell-for-cell. The researchers at work on "Blue Brain" promise new insights into the sources of human consciousness.

The machine is beautiful as it wakes up -- nerve cells flicker on the screen in soft pastel tones, electrical charges flash through a maze of synapses. The brain, just after being switched on, seems a little sleepy, but gentle bursts of current bring it fully to life.

This unprecedented piece of hardware consists of about 10,000 computer chips that act like real nerve cells. To simulate a natural brain, part of the cerebral cortex of young rats was painstakingly replicated in the computer, cell by cell, together with the branched tree-like structure of the synapses.

The simulation was created at the Technical University in Lausanne, Switzerland, where 35 researchers participate in maintaining this artificial brain. It runs on one of the world's most powerful supercomputers, but soon even that computer will be too small. The goal is to build a much bigger electronic thinking machine -- one that would ultimately replicate the human brain.

A project this ambitious would have been ridiculed a few years ago. "Today we have the computers we need," says biologist Henry Markram, 44, the project's director. "And we know enough to begin."

Markram knows about the problems his group can look forward to. "But if we don't build the brain," he says, "we'll never understand how it works." In fact, there have been tremendous advances in brain research for years; but answers to the big questions are as elusive as ever. How does consciousness develop within the electric orchestra of cells? How exactly does a spark of intellect ignite from the interplay among genes, proteins and messenger substances?

The Lausanne model, dubbed "Blue Brain," is the most radical attempt so far to investigate the mystery of consciousness. The idea is seductively simple: To determine how the mind emerges from biology, replicate the biology. It's a task that requires enormous patience and attention to detail, a process that ultimately means mimicking nature one molecule at a time.

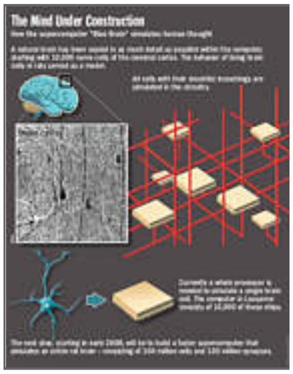
Though the first artificial brain may seem simple, it will be a useful model. Brain researchers can use it to reproduce functions from the real organ and test their theories. As they build in new processes, the model grows ever more detailed -- a sort of wiki project of the mind. It also offers an important advantage over a natural brain, since it lets researchers monitor each and every (simulated) mental activity in the machine.

But -- has there *been* mental activity?

The newborn "Blue Brain" surprised the designers with its willfulness from the very first day. It had hardly been fed electrical impulses before strange patterns began to appear on the screen with the lightning-like flashes produced by cells that scientists recognize from actual thought processes. Groups of neurons started becoming attuned to one another until they were firing in rhythm. "It happened entirely on its own," says Markram. "Spontaneously."

Building the electronic rat brain

Ten thousand artificial nerve cells have been interwoven in Lausanne, and the researchers aim to increase the number to one million within the next year. Which doesn't mean they're satisfied: The work is scheduled right now to last beyond 2015. By then, unless the project proves too ambitious, Markram and his team hope to be ready for their primary goal: a computer model of an entire human brain -- right now almost a sheer flight of fancy, given the 100 billion cells they would have to engineer.



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Graphic: the mind under construction

Skeptics wonder what the purpose is of painstakingly replicating things when scientists have so little understanding of their purpose and function. Indeed, no one will know, within the foreseeable future, what exactly happens in the circuits of the replicated brain -- except that whatever it is, it looks seductively authentic to an outside observer.

Perhaps the only ones who could have known are the scores of rats that carry on a shadow-like existence in this supercomputer. Researchers opened thousands of rat skulls over the years, removed their brains, and cut them into thin slices, which they kept alive. Then they directed tiny sensors at the individual neurons. They listened to the cells firing neurons, and intercepted the responses coming from the adjacent cells.

The brain slices were exposed to a variety of electrical impulses. The impulses reflected the stimuli that may have been received by the laboratory rats' brains when the animals smelled cheese or were startled by a shape. The cells reacted -- just as they did when the rats were still alive -- by sending electrical charges through the neuroplexus. The researchers' measuring devices recorded all signals until the brain slices expired.

In the end, the researchers at Markram's lab collected the entire repertoire of behavior of hundreds of types of cells in every conceivable situation in a rat's life -- stored in endless tables. This vast stockpile of data let the researchers start building their digital doppelgänger.

The price of uncompromising realism

Henry Markram, a South African by birth, has spent the last 15 years studying the interplay among brain cells. He learned to use brain-impulse sensors in the Heidelberg laboratory of Dr. Bert Sakmann. Sakmann had developed a method of applying suction to individual gray cells using tiny glass tubes, prompting the cells to release their electric signals. In 1991 he was awarded the Nobel Prize in Physiology or Medicine for his research. His student, Markram, further developed the method until he was able to monitor several cells at the same time -- a number that he has now increased to twelve. "That was the breakthrough," says Markram. "We had paved the way to the artificial brain by the time we arrived at communication between the cells."

Researchers working on this puzzle, though, still expect to receive a few lessons in applied modesty, given the overwhelming complexity of the brain. It took months to complete a copy of the first brain cell to be transferred to the computer. The digital cell model is based on millions of formulas -- that much data is needed to achieve fairly natural behavior. The computing capacity the project requires is correspondingly high. A whole processor is currently needed to simulate the behavior of a single cell.

But this is the price of uncompromising realism. A nerve cell's capacity to process electric signals is almost unfathomable. It reacts to incoming stimuli using tiny pores, known as ion channels, tens of thousands of which are distributed across its surface. Electrically charged particles slip in and out of the cell through these gateways. The cell takes part in the orchestra of thought by opening or closing its ion channels. This is how it prepares itself to fire; this is also how it sends signals to neighboring cells, through thin protrusions known as axons.

The computer model also includes ion channels, and their distribution almost mirrors the original. "However, at this level of precision it would be impossible for us to produce millions of cells manually," says Markram. The solution required a stroke of boldness: "We had to industrialize it."

Technology recapitulates biology

Today the Blue Brain project essentially has its own factory to produce artificial brain matter, so the computer can clone nerve cells almost automatically. The system's production line can produce whole series of neurons, one after another. Its memory contains close to 400 types, differentiated by shape. The stored neurons could be used to construct thinking tools of any size, in principle. Before they can be approved for use, though, the individual cells are randomly provided with individual characteristics -- because in the actual brain, no two cells are identical.

While none of this is especially challenging for a supercomputer, the real work starts when the time comes to link 10,000 non-identical cells to one another in a way that mirrors nature. The result is a particularly tricky 3-D puzzle, because each cell has about 10,000 protrusions with which it attempts to connect to other cells. The computer, in other words, must rotate and twist all cells in the space until their conductors are connected -- correctly -- at a total of 100 million points of contact.

The first phase of the project, which is currently underway, simulates a tiny part of a rat's cerebral cortex known as a cortical column, a dense tangle of interconnected cells about two millimeters long and half a millimeter in diameter. The cerebral cortex of all mammals, including man, consists of such cortical columns. Once evolution had hit upon a successful model, it apparently saw no reason to modify it significantly.

Cortical columns are all-purpose tools, equally suited to provide sharp vision, acute hearing and complex reasoning. "We see it as a sort of miniature brain," says Markram. "With only one of these columns, we would certainly be capable of processing environmental stimuli, though only in a very blurred way."

The cells in the Lausanne brain model still lack their chemical insides. They simulate the abundance of electric signals being exchanged, but not the molecular machines that produce them. The artificial cells do not contain proteins, which, in real cells, combine to form ion grids, for example. More important, the genes that are switched on to produce these proteins are also absent.

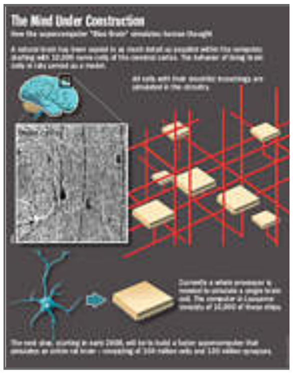
"We will incorporate the molecules later," says project manager Felix Schürmann. "In the next few months we'll focus on fine-tuning the model we already have." The researchers repeatedly test their circuits, comparing their behavior with the results from the rat experiments. Only when there are no longer any significant differences is the simulation ready for the next phase.

The team expects to begin replicating a whole rat brain by early next year. For that purpose, however, the current computer will no longer be sufficient and the researchers will need a new supercomputer, the world's fastest. But even that level of computing speed won't be enough for long, as the team scrambles up the ladder of life forms. "We'll model a cat brain, a primate brain and finally a human brain," says Markram confidently, as if there's no reason to doubt the feasibility of such a goal. Each step along the way will likely need the latest generation of supercomputer.

Is it even possible?

Computer giant IBM has provided the machinery for Blue Brain from the beginning. The company has positioned itself for some time as a supplier of supercomputers for the scientific community, lured by a rapidly growing market. The Lausanne brain simulation is therefore also a chance for IBM to gather experience in new and daunting challenges.

The researchers in the Blue Brain group are already working with IBM experts on the plans for a computer that would operate at nearly inconceivable speeds -- the kind of machine needed to simulate the human brain. It would be an absurd undertaking if it were based on current technology. A computer capable of running such a simulation would be a colossus the size of several soccer fields. "And we'd have an electric bill of $3 billion a year," says Markram. But the outlook changes considerably when Markram accounts for the rapid growth in performance in chip technology. "By 2015 we will have arrived at a level of energy consumption that we could certainly afford."



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But the question is, is all the cost and effort worth it? "Half the research community will say our project is nonsense," says Markram. "In their view, the brain is far too complex to allow for successful replication." In fact, there are an almost infinite number of possibilities to connect only a few million brain cells. How could it ever be possible to decide which of those combinations will produce consciousness? "That's a fundamental misconception," says Markram. "We aren't interested in the theoretical number. After all, evolution found a biological solution."

The researchers in Lausanne believe they can reach this solution one step at a time. The more detailed information about brain biology they incorporate into the simulation, the easier their remaining work becomes. This is because many theoretically possible but meaningless brain combinations will be eliminated. What will remain, the researchers believe, are valid combinations that could give rise to thought.

It's a daring bet on the future. The Blue Brain group lacks neither funds nor pioneering spirit. Its researchers do not hesitate to place it on par with the human genome project. They are convinced that just as the genome project has decoded man's genetic makeup, their project in Lausanne will decipher the fundamental biological tools of his capacity for thought.

If all goes well, the results of research in Lausanne will not be the only data incorporated into the brain model. The Brain Mind Institute alone, which Markram co-directs, employs up to 125 researchers, but it could theoretically draw on the collective research of the global scientific community. "We now have about 35,000 publications a year in neuroscience," says Markram. "No single researcher knows even one percent of that. We won't get anywhere without a model that integrates all of this fragmented knowledge."

Once Blue Brain operates reliably, fellow scientists from the around the world will be invited to use it to try out their new discoveries and theories. The project laboratory also includes a screening room where simulations can be viewed in real time. Researchers watching the simulation can distinguish individual cell groups and watch as cascades of excitation patterns not unlike toppling dominoes surge through the tissue. They can simulate flying around in the cerebral cortex or watch in slow motion as millions of ion channels systematically open and close.

But the main purpose of the artificial brain, say its creators, is to make new types of experiments possible. For example, what happens when damage is inflicted on certain types of cells whose function still isn't determined? How many cells can be switched off until the behavior of the surviving cells around them becomes erratic, or the entire circuit breaks down? Scientists know that a similar process occurs in the brains of epileptics and Alzheimer's patients. Armed with current methods, which by their very nature are based on external observation, medical science has gained only a schematic picture of the processes in these patients' brains. Using Blue Brain, researchers would simply fly to the crisis zones inside a virtual skull.

Such studies are conceivable, though, only in a model that mirrors biology. The so-called neural networks that other researchers have developed for years are very different. A neural network is also meant to behave like a brain, somehow, but how the likeness is achieved -- the circuitry underneath -- is more or less irrelevant. Someone building a cow using this principle would be content with any milk machine that moos and produces the occasional cowpat.

"That doesn't help us to understand the biology," says Markram. The researchers in Lausanne are interested in the real cow: "Our first priority is that we never use tricks to achieve the correct result," says project manager Schürmann. "If something goes wrong in the simulation, our only option to improve it is by incorporating new biological knowledge."

One day the research could even open a door to real life for their artificial brain. This wouldn't present much of a technological challenge. "We could simply connect a robot to the brain model," says Markram. "Then we could see how it reacts to real environments." But Blue Brain will be given a taste of real life only after it has performed flawlessly in the laboratory. Until then its environment won't be very exciting -- nothing but an air-conditioned mainframe room, and standard stimuli derived from textbook data.

Translated from German by Christopher Sultan

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