Explaining consciousness with a supercomputer

Out of the Blue

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Henry Markram is going to simulate the human brain in a supercomputer – so he says. Earlier simulation results of a small substructure in a rat brain were not published – so it seems. Still, the project might receive one billion euros to become a new European flagship initiative.

There is a thin line between new scientific ideas that are crazy but will one day become mainstream, and those that will remain crazy forever. Useful concepts, like the quantum nature of the microscopic world, were accepted and refined by the scientific community – with some reluctance at first. Unfounded speculations, in contrast, will either be forgotten or take the road to pseudoscience. Phrenologists, for example, have still not managed to prove their claims that personality can be measured by bumps on the skull that were assumed to reveal the brain structure beneath. Today, phrenology has been forgotten. Its proponents have failed to grasp the basic notion of science relying on open communication, independent review and falsification.

One laptop per neuron

Henry Markram, a professor of neuroscience at the Swiss École Polytechnique Fédérale de Lausanne (EPFL), appears to be teetering somewhere on that thin line between the two worlds. Markram wants to understand the brain by modelling it in a supercomputer. This impressive project has already brought him an invitation to talk at the TED conference operated by the US-American charity, Technology Entertainment Design, which has the aim to "bring together the world's most fascinating thinkers and doers" like Bill Gates, Julian Assange and Richard Dawkins. It was at this conference that Markram announced, "Our mission is to build a detailed realistic computer model of the human brain" and "we can build the brain in ten years." Not exactly a cautious claim!

The conference was held in 2009. Markram had started four years earlier, when he launched the Blue Brain Project (BBP), a collaboration between the EPFL and IBM with the goal of "reconstructing the brain piece by piece and building a virtual brain in a supercomputer", according to the BBP website.

The outline of the project was published by Markram in *Nature Reviews Neuroscience* (2006, 7:153). IBM delivered the supercomputer Blue Gene/L – hence the name of the project – with 8,192 processors, each simulating one neuron. Their goal back in 2005 was "the modelling and simulation of the first rat cortical column". The cortical column is a substructure of the brain that spans the six layers of the grey matter, the cortex. It is a column that is a few millimetres high and less than a millimetre wide, composed of several thousand neurons. According to Markram's website, it is "the elementary unit of the neocortex".

Cortical columns

Markram's group painstakingly described a cortical column in the somatosensory area of young rat brains. With electrodes (patch-clamp), the electrophysiology of some neurons was determined. Simultaneously, a dye was injected to trace the neurons' shape under the microscope. Then they were categorised into 32 different types, their arborisations of dendrites and axons compartmentalised. They were cloned, experimental errors were repaired and they were assigned many different properties. Even some randomness was in-

troduced to obtain approximately 10,000 individual neurons. The supercomputer then established the likely positions of the synapses between the neurons; many parameters, such as the density of synapses, were refined with known, experimentally-determined distributions (Kozloski *et al.,* 2008, *IBM J Res Dev* 52:43). In 2007, the website announced "the end of the modelling and simulation of the first rat cortical column".

Data not published

It was such a success that Markram was allowed to present his project at the World Economic Forum in Davos, Switzerland the same year. Science correspondents went dizzy about the BBP, reporting that a guy in Switzerland was going to build the brain and explain consciousness to us very soon. Articles appeared from the USA to Australia, on the BBC website as well as in the *National Geographic,* in English, French or German – all were fascinated by the prospect of unravelling the mysteries of the brain. The dream of any scientist!

There is something important, however, that journalists blissfully ignored in this wonderful story, something that is usually essential, to back Markram's claims and justify the massive media coverage: the publication of the results. Terrence Sejnowski from the Salk Institute in La Jolla, USA, for example, commented the project laconically, "Since there are no publications we don't know how far Markram has gotten." Similarly, Richard Hahnloser, Kevan Martin and Rodney Douglas, three neuroscientists at the Swiss Eidgenössische Technische Hochschule Zürich (ETHZ), the national rival of the EPFL, complained in a letter to a national newspaper that "a scientific result without publication and independent scrutiny is like a car without wheels".

Processor unit with two microchips belonging to BlueGene/L housed at the EPFL

The only materials available to the scientific community to evaluate the "successful simulation" of the rat cortical column are videos of public lectures and advertisements of the project in the internet (*http://bit.ly/20ldrQ, http://bit.ly/9AKkSQ, http://vimeo.com/8977365*). A point that Martin criticises further, "Unfortunately Markram's claims of discovery have been stated repeatedly in public, but not published, neither has he presented any significant results in any scientific forum we know of."

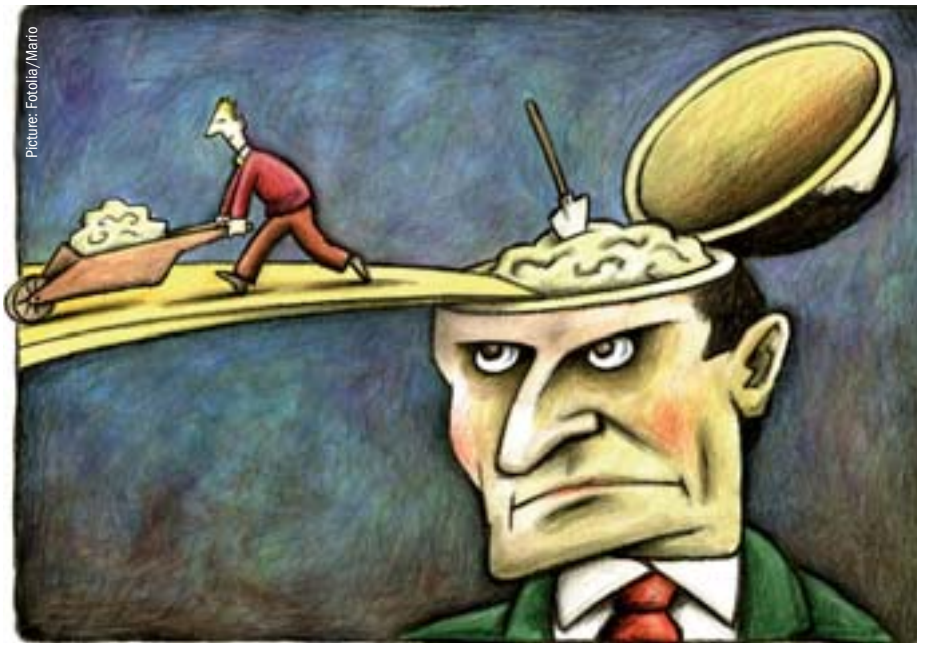
This is not to say that Markram has not published at all. On the contrary, his group is very prolific. Even his critics from the ETHZ acknowledge this when Douglas says, "Markram has published excellent experimental work." Indeed, Markram's website is full of publications in highly regarded journals. There are reviews, methods papers or experimental results but the search

for the simulation results is in vain. This immediately raises the question as to why his most known project is not published. Did IBM not allow Markram to publish the results? Did the journals reject the article? Were the results simply not worth publishing? Douglas, for example, considers it possible that the exponentially-accumulated data posed an exponential problem to the project management.

Whatever the reason, Markram can only claim to do science if he allows his peers to measure the scientific standard of his work. They need to be able to thoroughly understand what he has done and judge the validity of his claims.

Leaning Column of Lausanne

This eagerly awaited publication would also have to contain the precise definition of a cortical column since Markram states, "The holy grail for neuroscience is to understand the design of the cortical column." His own definition is spread out in public talks and on his website. Cortical columns "are connected in an intricate but consistent way", "operate much like microcircuits in a computer" and are "repeated millions of times across the cortex". "They were so successful in evolution that what we humans did is to duplicate them over and over and add more and more of them to the brain until we ran out of space in the skull."


Picture: Fotolia/Mario

From the human skull straight to a supercomputer?

The problem is, as Douglas puts it, "Many experts in the field question the existence or significance of cortical columns, or how such a thing is defined." Indeed, even Markram acknowledges this by asking, "Are the columns in fixed anatomical locations or are they dynamically assigned and what anatomical and physiological properties are operating to shape their dimensions?" (Markram, 2008, *HFSP J.* 2:132)

A cortical column thus is a concept that does not correspond to a clearly defined anatomical feature, such as a neuron or the layers of the cortex. In the fifties, it was discovered that a column of neurons spanning the whole thickness of the cortex would respond to the stimulus of a single sensory neuron (Mountcastle *et al.*, 1957, *J. Neurophysiol.* 20: 374). The concept has since been developed and has now led Markram to claim that the cortical column is the basic structure in the mammalian brain. The original assumption, however, that their pure number would define the cognitive capabilities, was shown to be wrong (Rakic, 2008, *Proc. Nat. Acad. Sci.,* 105: 12099-100). Some even go as far as to state that "although the column is an attractive concept, it has failed as a unifying principle for understanding cortical function" (Horton and Adams, 2005, *Phil. Trans. R. Soc. B* 360:837). Douglas, therefore, summarises the situation by stating, "To the extent that Markram makes his own definition, he can surely say correct things about the cortical column!"

Hence, knowing the complexity of simulating something relatively small like a rat cortical column, Markram's plan to simulate something that is a million times larger, namely the human brain, appears even more daunting. Unimpressed by his critics, however, Markram seems entirely convinced of the capabilities of the future brain model, "We will be able to teach it languages and it will have intelligence."

Hypothesis free simulation

This is an unfounded claim, as it assumes that when one builds a model, something completely new can emerge, which, in addition, will be understandable to us. Martin questions precisely this principle, "Everything that a simulation can ever generate or explain is an expression of the pre-programmed rules of a model. These outputs must somehow already be entailed in the logic of the model that is given by the programmer. Thus, the model cannot explain phenomena that lie outside its scope." His colleague Hahnloser jokingly summarises the project, "Insert many measurement details into a model, including many assumptions about the unknown network, and then try to notice something interesting happening..."

How to "confuse the public"

This might be a purely philosophical argument. Even if the model were possible to create a hypothesis free simulation, the task of understanding the complexity of the results should rather cool down the ambitions. Just take a look at the roundworm *Caenorhabditis elegans,* which only has 302 neurons and several thousand synapses. "Still, young researchers are just about to study whether the roundworm sleeps at all – looking at behaviour rather than simulations," explains Hahnloser.

All this does not stop Markram from making big promises. For example, that we would be able to have models of mental illnesses. "It's going to be a new diagnostic tool that sits in a hospital. You will be able to run a simulation of it before the doctor gives you some medicine." Animal experiments would no longer be necessary as "we cannot keep doing animal experimentation forever". Martin dislikes these arguments, "Markram makes a claim that is anti-science." And he accuses Markram of suggesting that experiments with real brains will no longer be needed, as his brain model will be sufficiently accurate.

Until now, scientists have not commented openly about the project. But the murmurs can clearly be heard behind refusals to comment on the BBP. In newspaper reports the unnamed scientists are sceptical,

too. Actually, they were said to have complained about the waste of talent and money that the BBP represents. Talent, however, is probably not wasted since the approximately 40 people currently working for Markram do publish good experimental work and are clearly successful in attracting funds and attention.

Human claim projects

As for the money, the BBP project was entirely financed by internal funds from the EPFL, mainly federal funds. How large a sum is unclear but the equivalent of 7.5 million euros was paid for the supercomputer alone. No external, independent funding agency got involved. Together with twelve partner institutions from around the world, Markram has just been awarded a 1.5 million euro grant from the European Commission (EC) to formulate a detailed proposal for a new Human Brain Project. It is supposed to become a new Future Emerging Technologies (FET) Flagship initiative of the EC, awarded with another one billion euros over ten years. The new project should be announced in May, although the grant obviously is not based on previously published results. This surely is an insult to all those scientists who exposed themselves to public scrutiny and have not received funding.

Perhaps the biggest problem is public trust. Science largely depends on it in order to be funded and to attract young academics. The journalists, however, based their articles on claims and speculations. So the only thing the public knows is that someone from a reputable institution is building a brain in the computer and is explaining consciousness to them. Accordingly, one newspaper reader wrote in a comment, "It's just to increase their public profile and further their careers but I think some of them end up believing their own hype."

The last time the public heard about a science project with a similarly big claim was when the Human Genome Project was announced. This, however, was a totally different story. To determine the sequence of billions of base pairs is not on the same level as understanding consciousness. What is similar, though, is that big promises were made in advance, which finally could not be delivered – and that the one person making the biggest claims is getting all the media attention. That person, Craig Venter, arguably had and has a stimulating effect on many fields of genomics. Contrary to Markram, however, Venter's work got published and could be checked.

Big promises in advance

We can all hope that Markram's claims result in another useful tool for scientists. To evaluate its usefulness, however, the details are needed. For the moment, these are clearly lacking and, thus, Hahnloser quite rightly adds, "What distinguishes the BBP from the Human Genome Project is that it is not open."

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