Breaking the brain code

"Scientists are trying to create artificial life, but we have not yet managed to cross the border between material that is not alive, and life."

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ONE CAN’T ACCUSE IDAN Segev, professor of computational neuroscience at the Hebrew University, of not thinking big. He compares the Blue Brain project - an attempt to create a detailed synthetic brain by reverse-engineering the brain all the way down to the molecular level, on which he is working along with a group of European colleagues - to projects on the scale of the Manhattan atom bomb project, the Apollo moon landing and the Human Genome Project.

?When the project is completed, it will have implications as important as those other major scientific endeavors,? asserts Segev. ?Without a full computer model of the human brain, we will never fully understand the brain. And we must understand the brain, both for curing diseases that are causing a great deal of suffering and are very costly, and, yes, simply because we are curious and we want to understand.? 

The Blue Brain project, headquartered in Lausanne, Switzerland, and using the IBM Blue Gene supercomputer previously used for genomic studies (hence the name Blue Brain), is initially focused on simulating the rat’s cortical column, which is the smallest functional unit of the neocortex in all mammals, including humans. This column consists of about 10,000 nerve cells that are heavily connected to each other by approximately a billion connections (synapses). But it certainly will not stop at one rat column, or even the whole rat brain? the mid-term goal is to develop a generic facility that could allow rapid modelling, simulation and experimentation of any brain region, and the longer-term goal is no less than to simulate the physiological process of the entire human brain.

Israelis, led by Segev, are playing a key role in this effort, which is aimed not only at understanding the
brain? with its hundreds of billions of neurons? but also at repairing diseased cells and tissues. When the Blue Brain project is completed, this simulated brain, if appropriately linked to sensors (touch, vision, hearing, etc.) and if it includes the capability to learn and adapt to its environment, may learn to speak and develop intelligence very similarly to the way a human brain does. This detailed model will shed light on one of the most mysterious elements in the universe? the emergence of consciousness itself.

?Given current trends, by about 2030 we should have the requisite complexity to create a fully functioning, highly detailed artificial brain,? predicts Segev, ?and unless we are fundamentally wrong in how we view the brain, it will develop human-like characteristics as it interacts with the world.?

What implications will such a profound event have on human history?

Segev is a bundle of intensity. The 61-year-old professor, with his long unkempt hair sometimes standing on end as if he were touching a live wire, barely pauses to take a breath as he explains complex concepts at high speed in his office in the Silverman Building on the Hebrew University of Jerusalem?s Edmond J. Safra campus at Givat Ram. As he delves with ease into topics that are technical and at times even philosophical and theological in nature, he is frequently interrupted by important telephone calls, as befits a man running multimillion dollar projects.

But the focus always returns to the intricate workings of the brain, a subject that obviously holds as much fascination for Segev as when he first began his career as a researcher.

He begins by pointing to a more prosaic and immediate goal of his work, which is expected to serve as an essential building block to the more ambitious goal of simulating the human brain. ?We need to find a way of ?databasing? brain information,? he says, explaining that by this he means finding a way to store the results of studies of the brain conducted around the world in a single format that can be accessed by any other researcher to facilitate the sharing of findings. Since there is no single laboratory in the world that will do all the work involved in brain simulation, an effort of such immense proportions needs the basic tools for efficient collaboration worldwide.

?In genetics, for example, if a person?s genome is decoded, as has been done for several people so far, it can be compared to the genome of another person, or a mouse genome, a chimpanzee?s genome, and so on,? says Segev. ?The comparable comparison cannot be accomplished right now in brain studies, and that is hampering development in the field. If one researcher conducts, say, fMRI (functional Magnetic Resonance Imaging) scans, his or her results cannot easily be compared to other fMRI studies of the brain. Researchers publish papers with their results, but the raw data they worked on remains locked away, without being accessible to others.

?So an immense amount of data compiled over the past century in brain studies cannot be pulled up in a shared database for the use of brain researchers. We need to develop a unified format to store brain research data, get researchers to adopt it, and then have it uploaded into an open-access database.?

SEGEV WAS FORMERLY HEAD OF Hebrew University?s neurobiology department in the Silberman Institute of Life Sciences, and co-founder and director of the prestigious Interdisciplinary Center for Neural Computation (ICNC). He received his bachelor?s degree in mathematics and biology, his master?s in neurobiology, and his doctorate in experimental and theoretical neurobiology at the Hebrew University.

He spent several years working as a researcher at the US National Institutes of Health (NIH) and a few months at MIT, but virtually all his career has been spent at Givat Ram and devoted to understanding the brain.
Segev’s funding comes from Israeli and international grants, including the NIH. Recently, the Edmond J. Safra Philanthropic Foundation, headed by Safra’s widow, Lily, donated $50 million for the founding of a major brain research center at the Hebrew University.

For the brain-simulation goal, initial efforts have been focused on cortical columns, which are the elementary building block of the brains of all mammals. A single cortical column measures 1mm by 1mm by 2mm and contains over 10,000 brain cells, a billion synapses and some four kilometers of “wiring.” Every visual angle that the visual brain recognizes, and each directed movement of a hand, are controlled by a single cortical column devoted to that specific activity.

Experiments, for example, have been conducted on kittens whose eyes were covered by goggles that blocked their vision at lines 45 degrees from horizontal. The lack of visual stimulation at that angle caused the kittens to develop visual systems in their brains that were blind to seeing objects placed at 45 degrees? and physiologically, the damage was localized to a single cortical column in the visual system of the cat.

According to Segev, within the past three years, huge progress has been achieved in obtaining anatomical and physiological data on the cortex, thus enabling detailed simulating of a generic cortical column of a mouse. The more experimental progress achieved, that much more of a complete brain will be uncovered and understood via such detailed computer simulation.

In five to 10 years, the full simulation of a mouse brain should be possible.

But the reader should not get the impression that for applications beneficial to human beings we will need to wait until an entire human brain simulation is attained, or even until a complete artificial mouse brain has been created.

?Even with a model of a single cortical column, one can answer many important questions,? says Segev. ?For example, what goes wrong in the brain of an autistic mouse (yes, there are such creatures) can be studied by comparing the activity in the simulated cortical column of an autistic mouse with the simulation of such a column in a healthy mouse. Progress in understanding Parkinson’s and Alzheimer’s diseases can similarly be attained by analyzing the results of detailed computer simulations of brains of mice suffering from those diseases.?

Detailed brain studies indicate that virtually all neurological disturbances, from Alzheimer’s to mood disorders such as schizophrenia and bipolar disorder, originate in signaling failures in brain circuitry. Yet to date, out of 560 distinct identified brain-related disorders in medical manuals, scientists have not yet managed to construct a single exact explanation for where the signaling failure occurs.

Simulation-based research in neuroscience, however, holds the promise of dramatically enhancing scientific advances by providing a means to test hypotheses using predictive models of complex biological processes. ?We hope that a full replica of a working brain will enable us to target the source and consequently cure most of these diseases, without the need for endless experimentation,? explains Segev. ?We need to get the richness of understanding of brain connectivity, the types of nerve cells involved and the specific connections that they form with each other. Repairing brain disorders will become increasingly important as the population ages. We cannot keep extending life without finding cures to the diseases of old age.?

The higher and faster life expectancy rises around the world, the greater the burden of the costs of neurological disorders on both individuals and society. Alzheimer’s disease alone costs the United States taxpayer some $2 billion a year. Segev expects that advances in detailed brain studies and computer
The simulation could be the precursor to a revolution in pharmacology for brain disorders.

Today, we too often treat only the symptoms, not the underlying causes, he complains.

Pharmacology is still mostly based on trial and error, without the theoretical understanding that is so fundamental for an astute scientific work. What happens in pharmacological studies is that immense numbers of mice are given different concentrations of certain medical compounds that are under consideration, the results are studied, and then if some mice show improvement, conclusions are drawn.

That enables us to treat symptoms, which is of course very important, but it does not lead to greater understanding of the underlying causes, which is what we really need for breakthroughs. This trial-and-error approach for developing medication will change in the near future?

Disease treatment will perhaps be the most prominent side benefit of the Blue Brain project, but, as with the moon landing, which supplied a long stream of spin-off technologies in materials science, telecommunications and other fields, Blue Brain is expected to provide, as side benefits, improvements in areas such as computers, communication, data analysis, three-dimensional visualization, genetics and robotics.

The comparison to the moon landing project is raised often, partly because the Blue Brain project is seeking to benefit from funding that the EU recently set aside for flagship projects that are grandiose, have clear and identifiable goals, will further humanity and gather a lot of attention, with the subtext being competition between the EU and the United States for scientific prestige. Europeans express pride in the super particle accelerator at CERN in Switzerland that has recently gone operational and is expected to produce breakthroughs in high energy physics, and seek to add to their list of scientific successes.

Toward that end, the EU will be granting between 1 billion and 3 billion euros per group to teams that run an approved flagship project. Blue Brain, of which Segev is a member, hopes to win flagship status. If out of that my team gets a million euros a year over ten years for my research, that is a dream for me, he says. The competition will be tough, however; some of the competing projects include proposals for creating quantum computers and humanoid robots.

Segev expects that if the fully functioning artificial brain emerges by about 2030, it will develop human-like characteristics as it interacts with the world. His prediction is very close to a similar prediction by inventor and futurologist Ray Kurzweil regarding the date by which artificial human brains will be attained.

Segev knows this and attributes the similarity in expectations to the fact that both he and Kurzweil are extrapolating from current trends, but Segev prefers to avoid following Kurzweil?s further predictions, such as the eventual melding of humans and computers.

Nonetheless, he predicts that the world will be completely different in 20 years? time, partly as a result of advances in brain studies.

Some of the differences that will take place in our lives will be at least as sweeping as those brought about by the industrial revolution and the current information revolution.

Just the possibility of creating an artificial human brain causes many people profound discomfort, raising philosophical, ethical and even theological questions. Galileo?s studies of the motion of heavenly bodies in the 17th century were the catalyst to conceptual upheavals that had profound effects. One wonders what upheavals may come from deep study and understanding of our very brains, where our thoughts and emotions originate.
If a machine can be constructed that thinks in every way a human does, for example, is it part human? Can it be said to have a soul? Would achieving that goal mean that the materialist reductionists are correct in saying that we, too, are ultimately but machines? It is not pleasant to think of ourselves as machines, but in all my studies of the brain I have not seen a soul running in the brain, laughs Segev. All I have seen are physical materials, electrical signals and chemistry. Yes, we are machines, machines that can generate all the beauty, the sense of self, of feelings and creativity.

This is not a trivial statement, and can be the subject of debate. But as a scientist, what tests can I conduct other than exploring the material of the brain? How can I test for the existence of a soul? What does that even mean from the scientific perspective? Segev, however, is quick to correct what he perceives as misconceptions regarding the hurdles involved in getting an artificial machine to the point at which it replicates the dynamic actions of a human brain.

No static model can replicate a dynamic system like the brain, he says. To create a working artificial brain, you need to give it a surrounding, a hand, a leg, a body that acts on the world, and sensors that transform the world around us (visual, auditory, etc.) into brain signals.

Brain and body are interrelated. A brain needs to learn the statistics of the world in order to interact with it. For a fully-functioning artificial brain in the physical reality around us, we will need to give the brains sensors interacting with the world. There is no stand-alone entity that can develop without interface with its surroundings.

Segev also cautions against over-simplistic comparisons between the brain and computers as we know them today, such as conceptions that once the basic circuitry of the brain is understood it will be an easy matter to transfer memories between one brain and another, or simply to download understanding of a foreign language directly into our brains.

There is no standard way of transferring memories or concepts, he says. We will not be able to transfer them using a USB stick. Each brain codes these things in its own idiosyncratic way, with a personal, specific code that results from its own particular life experience. It is not bits and bytes, as in a computer. The connections (synapses) in a brain change all the time, which is very different from the way a computer is hardwired. There is a lot we do not yet understand in the dynamics of the brain, and we thus develop methods, such as learning theory, in order to understand the way brains code concepts and store memories.

Considering all the potential hurdles and the staggering amount that we do not yet know leads Segev to speak in more humble terms for a moment.

Am I a megalomaniac? Perhaps. I recognize that things may not go according to this ambitious plan. We may run into a serious conceptual barrier. Look at something as simple as C. elegans [a small roundworm]. We still have not created a single working simulation of the operation of C. elegans, with its 302 nerve cells in total, and yet we are talking about simulating a cat brain, a human brain. Scientists are trying to create artificial life, but we have not yet managed to cross the border between material that is not alive, and life. We need to admit this with humility combined with unbounded ambition to break the brain code.

I am motivated by a desire to understand how the brain works and to repair it when sick, not a desire to duplicate myself in an artificial machine, Segev says. We split the atom because we wanted to understand the atom. That had a lot of other effects, but there is no alternative. We, human beings with our
highly sophisticated brain, have a need to understand?

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