7000 scientists are going to spend 3 billion dollars for recreating the human brain

They are sending a silicone brain in Space

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O Artificial Intelligence beats humans at the game of chess

o Two top projects encompass the potential of developed countries to realize an undertaking unparalleled in its scale and complexity.

o The Bulgarian connection is Prof. Stoyan Markov

Is it possible to create an accurate 3D digital model of the brain?
It is! Or at least this is what 7000 scientists from 27 countries believe.

In the next few years they are going to spend at least 3 billion dollars on accomplishing their task – to “copy” the brain at the level of neurons, axons, dendrites and synapses (see the box to learn more about the structure of the neural cell) and implement it on an especially designed computer platform with greater performance than the human brain.

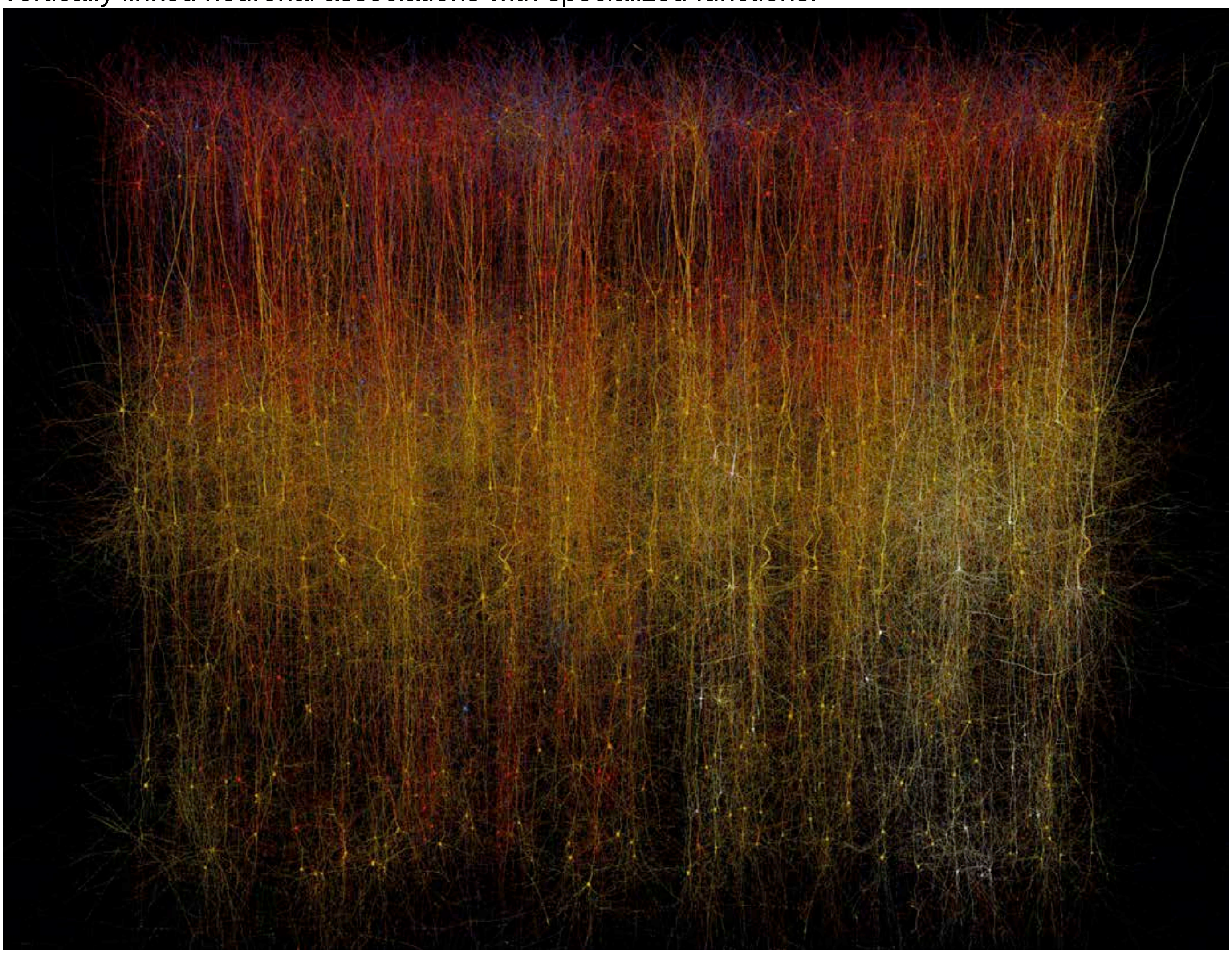
Is it possible for the digital brain to perform better and more efficiently than its analogous counterpart? „It is possible. The artificial intelligence made by men combined with supercomputer capabilities is already better at chess than humans”, says Prof. Stoyan Markov - Bulgarian connection in the undertaking. (Who is Stoyan Markov? – read in the box). Then he goes on to tell us what is needed to happen so that a “silicone brain” – i.e a 3D digital model of the human brain can be successfully designed.

- Is it realistic to think that an accurate three-dimensional digital model of the human brain can ever be created, Prof. Markov?
- In general yes, it is. Science has already made significant advancements in copying one of the most complex human organs.

-How complicated is that?
- A lot. The brain is a three-dimensional object. It is the most perfect creation of nature, the fruit of the evolution of living beings in the last 400 million years. It is believed to be made up of about 86 billion nerve cells. The total number of their synapses, i.e. the intermediaries between axons and dendrites is over 13,000 billion – that is 13 trillion. This explains why it is so complicated to recreate the brain in an ultra-high resolution model.

- What is it that needs to be done?

- In order to reconstruct the exact geometric pattern of the brain, the three x, y, z coordinates of each neuron must be determined. Scientists from the Harvard Mahoney Neuroscience Institute believe that they have between 1,000 and 10,000 synapses on their surface. From each synapse, one needs to trace the axon that connects it to another neuron. Each synapse is described by three differential equations. To get an idea of the tremendous difficulties that accompany the creation of the super-precision 3D geometric model of the brain, just consider the complex tangle of axons and neurons interconnected in a network in the rat brain with 31,000 cells, 41 million synapses and 56 vertically linked neuronal associations with specialized functions.



The neural network of the rat visual center, which was read within the Blue Brain project.

- You say that every synapse is described by three differential equations?

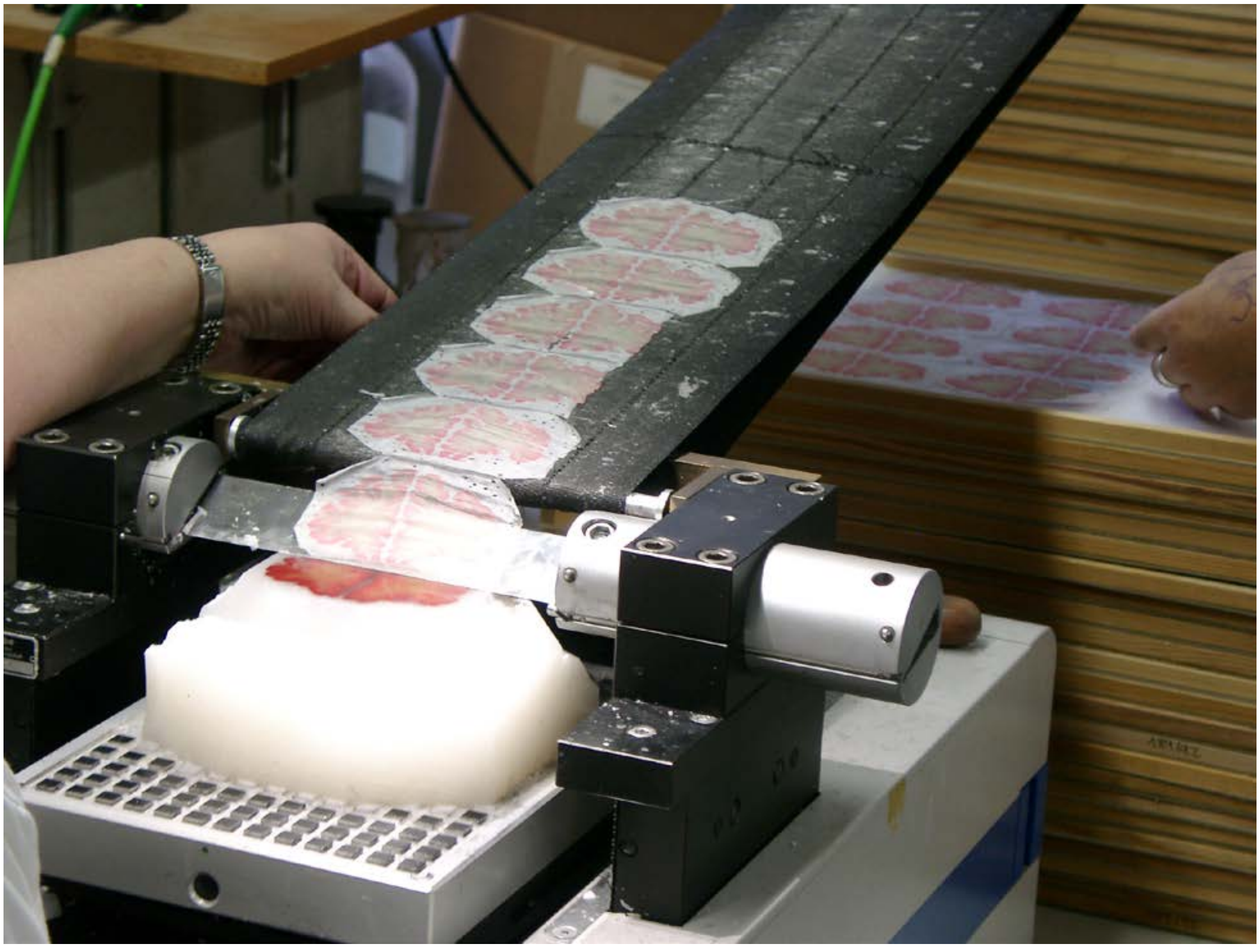
Yes, this is a very small part in the process of recreating the brain. In 1963, Sir John Eccles, Alan Hodgkin and Sir Andrew Huxley received the Nobel Prize for Physiology and Medicine for their discoveries about the ionic mechanisms involved in the processes in the peripheral and central parts of the membrane of the neural cell. Based on this discovery, they mathematically described the physiological response of neurons. The model is a system of six ordinary differential equations, three of which are non-linear.

- **Can you explain what is actually happening in the brain and what exactly needs to be recreated in its silicon equivalent?**

- The electrical signal carried by the axon activate its ion channels so that calcium ions can pass through. They bind to specific proteins and open a vesicle (a little bubble) containing molecules from the neurotransmitter group. The bubbles are located on the surface of the membrane that surrounds the synapse. The molecules, by diffusion, fall into the cavity of the synapse and after about a millisecond reach the membrane of the cell. The stimulating neurotransmitters bind to the sodium channel receptors on the cell membrane. When their concentration exceeds the critical level, the neuron passes into an excited state.The pyramidal cell membrane potential increases from -70 millivolts (resting potential) to - 55 millivolts. The channels open, the sodium ions enter the cell and the membrane potential continues to increase. The channels open even more widely and the intensity of the ion flow increases. For about 2 milliseconds, the membrane's potential reaches +30 millivolts. At this point, because of the difference between its potential and the potential of the environment, a spike occurs. The sodium channels close and the potassium channels open. Potassium ions leave the cell and the potential of the membrane decreases to about - 80 millivolts (hyper polarization) for about 2 milliseconds. After 20 milliseconds, the cell returns to its neutral state with the help of the sodium-potassium pump. After a number of pulses is emitted to restore its physiological state, the cell remains inactive for about 450 milliseconds. Cell dendrites collect neurotransmitters generated in response to the stimulating and blocking impulses that come from the neurons associated with the cell, and it responds only to an average of the impact effected by a group of cells rather than an incidental occurring in a single cell. These are the complex processes that need to be read and expressed in the silicone brain.

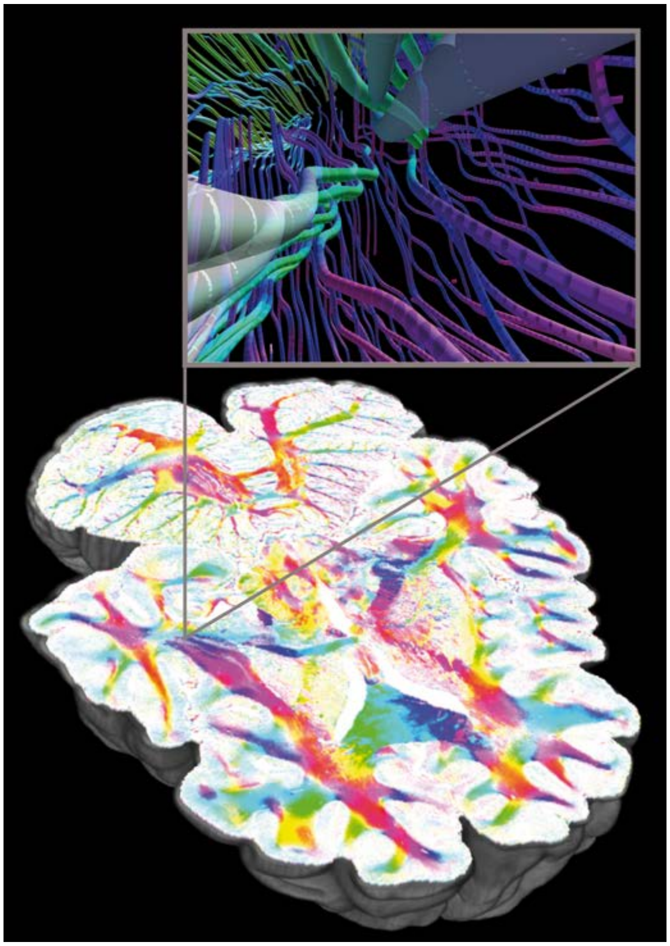
- How exactly can the microstructure of the brain be read?

- In order to read and recreate the microstructure of the brain, it is cut into 7400 histological sections, with 20 micrometers thickness each.



The brain is cito into 7400 histological sections, each 20 micrometers thick, that are oriented towards each other with an accuracy of no less than 1 micron.
Each slice is fixated with the help of a glass frame. The slices are oriented towards each other with an accuracy of no less than one micron.
In order to read the three-dimensional structure of thin slices of the human brain, semiautomatic readers are used.

This semiautomatic reader reads the 3D structure of thin slices of the human brain thanks to the property of myelin to develop pseudo-stereo images in polarized light. Tiled image size is 100,000x100,000 pixel. Pixel size – 1,3 μmx1,3 μm. File size- 40 GB. The anatomic networks on the slices include several million neurons. But the optical 3D reconstruction of the axons in such huge structures has a low resolution and is virtually unusable. To obtain a precise and accurate map, the cut is optically divided into squares measuring 10 by 10 microns. The method used is called highly-selective double immunohistochemical labeling - a sort of fluorescent marker. This is an expensive but accurate method for identifying cells. The markers connect only to one cell type and these cells glow when the cut is viewed under a fluorescence microscope.



In order to obtain an accurate and precise map, each slice is optically cut into squares measuring 10 by 10 microns. The CCD matrices reproduce the images of the squares with an accuracy of less than a 1 micron.
One expects the production of automatic machines for reading neural networks on the cuts to begin within 3-4 years.

- **How will this happen?**

- By using a supercomputer that connects the images of the squares in the order in which they have been read in the optical equivalent of the histological slice. The amount of information in the 3D image of the slice is about three terabytes.

Currently, there is a very complex program for object identification and 3D path tracking. It identifies the neurons and associates them to their three coordinates. The axons that come out of each cell get tracked from square to square in order to find out which cells it is connected with through its dendrites. The program sometimes gets confused by this tangle of axons. It stops working and asks the operator to continue tracking manually. The operator decides when to switch the process to automatic mode again. These interruptions considerably slow down the process of creating the three-dimensional geometric model of the cut, so new algorithms are being sought out.

- What has been achieved so far?

- For several years, two Blue Brain and Human Brain projects have been running alongside each other. The outcome of the two projects from 2005 to 2013 was that a precise model copying the visual center in the rat brain was created. It includes 1.86 billion neurons and 11.1 trillion synapses and was simulated on the Blue Gene / Q supercomputer called JUQUEEN, which has 24,576 CPUs (393,216 cores) and 3,93 Terabyte memory. The model was solved using the programs from the Neural Simulation Tools (NEST) library. The current simulation results were compared to the processes that took place in the visual center of the rat brain by exposing them to the same external impact. They practically matched, and so the model was verified. It was disturbing that the most powerful supercomputer in Europe at the time took 40 minutes to simulate 1 second of activity in the rat visual center. This was cause for some serious reflection afterwards.

The JUQUEEN Supercomputer at the Research Center in Jülich, Germany

The enormous difference between the rat and supercomputer brain performance showed that the classical architecture proposed by the genius Hungarian mathematician and Nobel prize laureate John von Neumann has exhausted its capabilities.

- What is the reason for the low performance of the supercomputer as compared to the brain?

One reason is that at every 10 microsecond interval, information needs to be exchanged between the computer memory where the current state of the synapses is written and the computational cores of the processors in charge of solving the system of equations describing each neuron. The size of the data flow is over 3 terabytes. None of the well-known communication networks can withstand such a load and so they clutter. The second reason is that at each step the 12 billion differential equations describing the rat's visual center must be solved anew. Obviously, such a big number of computations takes a long time to complete.

- How can that be changed?

- We went back and thoroughly studied the anatomical structure of the rat's visual center.

The retina is composed of photo receptors and four cell types: bipolar, ganglionic, horizontal and amacrine. Ganglion cells are typical neurons. They are located at the exit of the retina and their axons form the optic nerve. They are virtually divided into groups and each group connects with a basic microstructure of the visual center, such as the cerebral cortex columns where about 55 different nerve cell types can be found. Thus, the image projected onto the retina is divided into portions that are distributed between the columns and processed simultaneously.

About 82% of the visual information is processed in columns. About 18% is formed by the exchange of signals between each column and its closest neighbors. Hence the conclusion that The "Neural computer" has to be a weakly connected system built up of internally strongly connected modules capable of simultaneous processing of the information distributed between them.

- Is it possible to design such a "neural computer"?

- The idea was implemented by IBM in 2014. The company produced a specialized chip and attempted to recreate in silicon environment "gray matter" (the neurons) and the short communications between them that are implanted into the cores of the chip. Each core of the chip can simulate 256 neurons and 64,000 synapses. Its memory is 104,448 bytes. 65 536 bytes are allocated to recording the synapse state; 31,232 bytes to the states of neurons and their parameters; 6,656 bytes for neuron addresses -, and 1024-bytes – for recording the delays of signals on the axons. All together, the chip can integrate 1 048 576 neurons and over 2.62 billion synapses.

- What are the other metrics of this super neural computer?

- 5.4 billion transistors are packed in 4096 cores in a chip with 28 nanometer technology. The chip consumes only 100 milliwatts and runs 400 billion operations per second per watt. The consumption of standard processors is about 700 watts at the same performance.

- You're talking about 2014, and now it’s 2017 already. Has there been any major development since then?

- This year, a 7-nanometer chip is supposed to be put to experimental production and it will be able to pack about 86 billion three-dimensional FINFet transistors.

- What is a FINFet transistor?

- It’s a single pole transistor with two “doors". On both sides of each "door" there are shutters that interrupt the movement of the "wandering" electrons that are generated by the quantum tunnel effect. The chip will possibly integrate 8 million neurons and 10 billion synapses. If this happens, it will open the way for the creation of neuro-computers. Europe and Japan are also developing with very high density neuro-chips.

- When do you expect the digital model of the brain to be completed?

-It is difficult to predict whether this is going to happen in the next 6 or 15 years.

- What does it depend on?

- On a lot of things. For example, on the time when machines for automatic reading of anatomical slices of the brain with precision of one micrometer can be constructed and introduced in serial production. The task also depends on when the programs for axon automatic tracking will be developed – i.e to track along which neurons the axon runs and to which of their dendrites it is connected with. It is also important when the three-dimensional atlas of the brain at the level of micro-centers and communication between them will be completed.

- Are you optimistic about this?

- I expect the high-resolution 3D models of the visual and hearing centers to be designed within 2-3 years.

A lot of effort and resources are being invested to make it possible to understand precisely how the centers unifying the images perceived through the eyes and the sound captured by the ears function. And how the notion of meaning is associated with this "unified image". In other words, how you recognize that a cup is a cup when you see it. Or how the eyes start looking for a cup among the other objects and move the hands towards it when one hears the statement: “Take the cup!”.

- This function is probably subject to change due to external influences?

- Yes, it is - Neurophysiological and psychological experiments have shown that the central nervous system changes its functional organization in response to significant internal or external factors. The big question here is where the learned information is stored, which brain centers store images, scenes, signs of identification and classification of objects, the verbal inventory, professional skills as a form of conditioned reflexes and many other things, how associative memory is formed and what Is the process of recording in the permanent memory.

- **Does Science now have answers to these questions?**

- One accident has given us a lot of knowledge about how memory is formed and where it is found. In 1953, Henry Gustav Molesson underwent the world's first surgical operation in which his hippocampus was completely removed.

After the surgery, he didn’t remember anything and lost his spatial orientation. His amnesia was full and the 27-year-old did not even recognize his relatives. Otherwise, Henry remained a normal person. He kept his high IQ (118), spoke well and was able to paint. He died on December 2, 2008 at almost 82 years of age. Currently, dozens of teams are actively studying the micro centers of the hippocampus and the surrounding brain structures that regulate behavior, emotions and memory.

- **How much of the human brain's capabilities will be reproduced by its three-dimensional digital model?**

- Nobody can predict this with accuracy. In the language of informatics, the pyramids in the columns of the neocortex and the columns themselves are hardware with built-in base software that implements the functions of each microstructure of a brain center. The basic software is realized by the network of axons, synapses and neurons. Due to its plasticity, the network undergoes dynamic changes, i.e. the base software is highly responsive. Before creating the model and embedding it in the neurocomputers, we would not know which features are genetically preset in the brain.

- **That is, the faster the model is designed, the closer we are to the goal?**

- On the one hand - yes. On the other hand, we must keep in mind that the brain is also a "chemical machine," the behavior and reactions of which are also determined by the impact of signaling, suppressing, activating and regulating biomolecules and the cascades of biochemical processes. It won’t be ever possible for the latter to be reproduced in silicone models.

This may not be necessary. These molecules are vital to the functioning of the brain, but they are not needed for the digital model of its normal functioning. It could be implemented in a silicon environment.

If the higher cerebral cortex functions can be realized only by biochemical and physiological processes at the five functional levels - neurons, neural networks, micro centers, centers, and the brain as a whole, the model will not copy the brain functionally.

This is the great unknown, on which the ultimate success of the Human Brain Project depends. But the biochemical processes that arise during states of fear, fury and stress can not be reproduced.

- What could be the Bulgarian contribution to these ambitious and highly complex projects?

- Good question. I hope it would not be too immodest to say that our contribution can be mainly in the field of supercomputer development – a field we have been working on for years.

- Can you tell us a little more about Bulgaria’s contributions?

- In 1982, The Deputy Chairman of the Academy of Sciences of the USSR - Academician Evgeny Pavlovich Velihov introduced me to the Director of the Institute of Space Studies at the Academy - Academician Roald Zinnurovich Sagdeev. He proposed to create a joint team to design a computing cluster with a performance of over 100 million operations per second. In 1984, the first cluster with the Isot 1014 Central machine and 10 ES 2706 matrix processors with a productivity of 120 million operations per second was produced in Bulgaria. Prof. Vladimir Lazarov was Chief engineer of the machine and Assoc. Prof. Plamen Daskalov was Chief engineer of the matrix processors. I was the chief designer of the cluster. This was the first and only HPC system that was produced within the Council for Mutual Economic Assistance (COMECON).

Since 1986, several such systems have been delivered to the USSR. The most powerful - with ten matrix processors - was installed at the Space Research Institute in Moscow. Several dozen trajectories were calculated on it for the Vega-1 and Vega-2 spacecraft in order for it to enter the tail of the Halley comet.

The trajectories had to be chosen so that the concentration of dust and particles was minimal so as not to scratch the lenses of the television cameras because the European satellite Giotto, used at the same time, was "blinded" and could not capture the inside of the comet.

On October 12, 1987, the American magazine Aviation Week and Space Technology published the following message: "A large Soviet computer using 10 parallel

CPUs connected to an IBM-compatible central machine came into operation at the Space Research Institute of the Academy of Sciences of the USSR. The system, which came into operation 6 weeks ago, has a maximum productivity of 120 million floating point operations per second. This will give the institute the opportunity to solve complex theoretical and applied problems and give it modeling capabilities. The system has already been used to solve complex problems such as simulating Large Eddy Flows. The computer was demonstrated to a journalist of the magazine during his visit to the Space Research Institute last week. The hardware was supplied by the Bulgarian ISOT and the software was developed by the Institute of Space Studies. "

- They recognize Bulgaria’s contribution, and this was happening during the Cold War? I can not believe it.

- As you can see - yes. According to unconfirmed official information, the complex has calculated in real time the trajectory of the Buran spacecraft as it entered the stratosphere and its transition from hypersonic to supersonic velocity. In order to slow down, the ship entered and left the stratosphere several times. Each time the landing trajectory on Baikunur airport had to be recalculated and a correction of the angle of attack and its position in space before its entry into the stratosphere had to be made.

- What was the next step for Bulgaria?

- In April 2008, the Blue Gene / P supercomputer was delivered at a price about 23% lower than the market price for this class of machines. It consisted of two racks and an accelerator. One of the conditions was that the supercomputer would also be used by the IBM Research Laboratory in Zurich.

- Are you saying that we are cooperating with IBM?

- Yes, the framework for cooperation between IBM and Bulgaria in the field of supercomputer applications was set by the Director of the IBM Zurich laboratory- Dr. Matthias Kaiserswert and the then Minister of Finance- Assoc. Prof. Plamen Oresharski.

In 2014, Intel, Hewlett-Packard and the National Center for Supercomputing Applications jointly designed the prototype of the heterogeneous Tera and Peta FLOPS supercomputers that were to be produced in the European Union. An original architecture of a weakly connected system with strongly connected computing nodes was designed. For that we used Intel’s many-core processors and Intel Xeon Phi coprocessors.

The supercomputer was produced by Hewlett-Packard Bulgaria and was installed at the end of 2015 in the hall where the first computers of the Bulgarian Academy of Sciences used to be deployed in the 1970s.

- What are the parameters of this supercomputer?

- The maximum performance of the Avitohol system which costs 4 million lv is 400 TeraFlops. Later, the Czech supercomputer Salomon with 2 PetaFLOPS and the Italian Marconi with 13 PetaFLOPS performance were produced. They use the same construction and architecture as Avitohol.

- Let's go back to creating a three-dimensional digital model of the brain. What will be it’s practical benefits?

- I do not know. I have a few guesses. I assume that in the near future spacecraft robots with embedded brain patterns will be sent to explore the deep cosmos and nearby planets. People can not endure flights of hundreds of years. To be sent to such missions, spacecraft must be loaded with large amounts of air and water, have large areas planted with plants to be used for food and air recycling, have full recycling facilities for all waste, hospital, repair facilities and many other life-sustaining and protective structures - something that is not feasible. In addition, people live shortly and have to give birth to children. In a population with a small number of astronauts, the generation is likely to degenerate genetically. There will not be enough people with different specialties to teach children. Such ships would be enormous in size, very heavy and expensive. To reach speeds of several hundred kilometers per second and to maintain the equipment on board, one will need engines with tens of millions of horsepower. In short –designing such ships will be a technical and financial absurdity.

Therefore, it is more feasible to send in outer space the electronic eyes and ears of people as well as centers for integration, classification and interpretation of information, associative memory centers and decision-making centers. The Silicon Brain will be aided by powerful chemical and physical laboratories and supercomputers with built-in capabilities to analyze and derive unknown laws and phenomena from huge volumes of unstructured data.

I assume the same approach will be used to study the depths of the ocean and its bottom.

I guess that robots with implanted intellectual abilities will also replace humans when it comes to weapons. The soldier is the weakest link in the battle. He is subject to fear and wants to save his life. So in the next generation of weaponry and combat equipment, robots will probably be instilled, and human beings will control them from a distance outside the field of combat. The first examples of this kind are already put into service - unmanned airplanes, automatic reconnaissance means, autonomous combat machines. So maybe soon the combats will be fought by machines with "high intellectual abilities".

This is going to be fifth general change of weaponry that humanity will witness - from flint hammers and stone arrow heads to this day, but perhaps this will save mankind from the next global world war, just like atomic weapons have been saving it up to now.

But the most significant impact everyone will face will be the combination of global digital networks, automated production lines, and comprehensive intelligent management and control systems that are set to make dramatic changes to manufacturing, trade, transport, services and everyday life. This is going to be the fourth industrial revolution. Many professions are going to disappear and large groups of people would not be able to find a job. That is why, governments will have to find mechanisms to engage them with some functions and pay them at least the minimal wages. Otherwise, we would be facing a social revolution.

Text boxes

Human Brain Project

Started in 2000 with the Blue Brain project

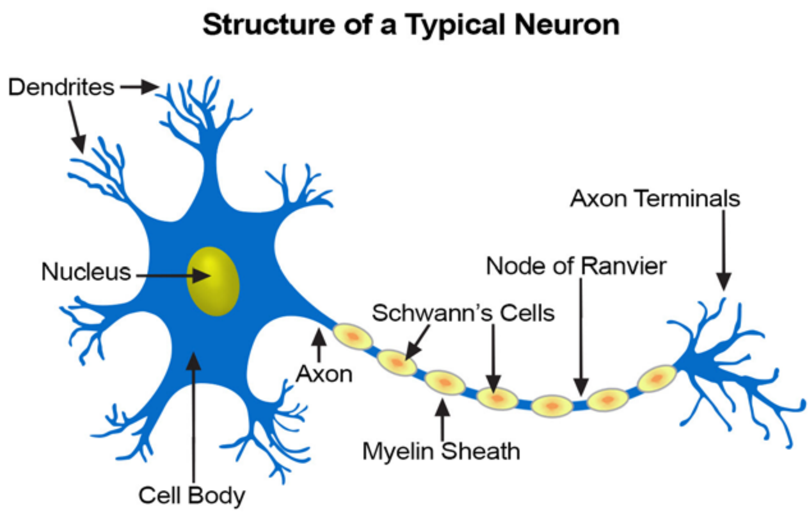
Altogether, 116 universities, research laboratories and national institutes from 19 European countries, along with 52 participants from additional countries have been collaborating on the development of the Ultra Precise 3D Human brain model.
7,000 scientists and researchers in 23 disciplines from Austria, Belgium, Cyprus, Denmark, Finland, France , Germany, Great Britain , Greece, Hungary, Israel, Italy, the Netherlands, Norway, Portugal, Slovenia, Spain, Sweden , Switzerland, Canada, China, Japan, India, Russia and USA will spend at least $ 3 billion to tackle the seemingly impossible task. 1.2 billion EUR has been allocated by the European Commission for the implementation of the Human Brain Project, about $ 1 billion - from the US, about $ 300 million - from Japan, about 230 million - from Canada. According to a document published by the China State Council, the development and deployment of AI is seen as a strategic opportunity to the country, and will be worth 10 trillion yuan (1.49 trillion USD) to the nation’s economy by 2030 .(http://www.gov.cn/zhengce/content/2017-07/20/content_5211996.htm)

Prof.Dr.Dr.med. Katrin Amunts is Chair of the Science and Infrastructure Board of the Human Brain Project

Prof.Dr.Dr. Thomas Lippert is Director of HPC in the European Human Brain Flagship Project and Coordinator of the European Research Projects PRACE and DEEP

Partnership for Advanced Computing in Europe (PRACE)
850 million EUR for 10 years
Consortium “Partnership for Advanced Computing in Europe - PRACE “is an association of 25 countries: Belgium, Bulgaria, Cyprus , the Czech Republic ,Croatia , Denmark, Finland, France, Great Britain, Germany, Greece, Hungary, Israel, Italy, Ireland, Norway, the Netherlands, Poland, Portugal ,Spain, Slovakia, Slovenia, Sweden ,Switzerland and Turkey.The series of projects launched by the EC and the Consortium in 2008 involve 47 universities and research centers. The research and investment budget for 2008-2018 is around € 850 million.

Chair of the PRACE Council Prof.Dr. Anwar Osseyran



Anatomy of the nerve cell

In order to conceive of brain recreation, one needs to know the anatomy of the neuronal cell - the neuron, whose size is from 5 to 120-150 microns.

Axons come out of each neuron. These are conductors of the electrical impulses that each nervous cell generates in an excited state.

Their ends connect to dendrites of other cells, and the transmitted signals predetermine whether the cell will go into an excited state, be blocked, or remain neutral.

Dendrites sum up the signals that come from the several thousand cells connected with that cell.

The axons are covered with a myelin sheath that isolates them from each other. When it is destroyed, a "short circuit" of a kind takes place between the axons. This is the cause of multiple sclerosis and some other diseases.

Periodically, the myelin sheath of the axons is interrupted by Ranvier's nodes, which ensures a high transfer rate of the electrical impulses on the axons - up to 150 meters per second.

Prof. Dr.Sc. Stoyan Markov CV

Stoyan Markov was the Deputy Prime Minister of Bulgaria from 1986 to 1988 and a Chairman of the State Committee for Research and Technology. Some call him as the mastermind behind Bulgaria's modern electronics and informatics and one of the fathers of the Bulgarian Supercomputer. From 1979 to 1989 he was responsible for the development of electronics, the creation of new products and systems, as well as the technologies for their production. He decided on what projects one would work on and carried personal responsibility for the outcome, including for the Bulgarian supercomputer.

He defended his Ph.D. thesis in the field of Computer Sciences in 1974 and was awarded a Dr.Sc. in High Performance Computing in 1988. From 1989 he has been Professor in the Bulgarian Academy of Science. Since 2008 he has the Head of the National Centre for Supercomputer Applications in Bulgaria, which hosts the most powerful supercomputer on the Balcan Penicula

After the 1992, Markov won a position at guest scientist at the European Center for Nuclear Research (CERN) in Geneva - the one that became globally famous with the so called "nuclear collider" and the Higgs boson discovery.

Bulgarian Supercomputer Avitohol and Prof. Stoyan Markov