Bernstein Network for Computational Neuroscience

Bernstein Newsletter

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10/2009

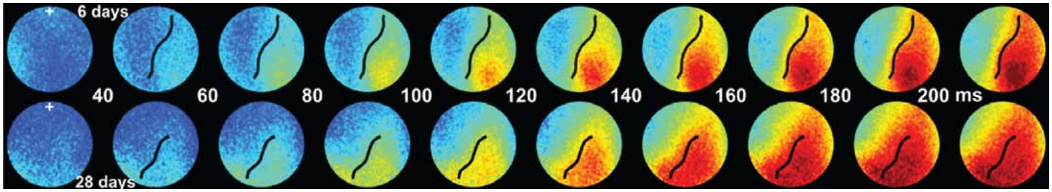
Nerve cells provide neighborly aid

The visual cortex of the brain analyzes and processes neuronal signals originating from the retina. When parts of the retina are injured, the corresponding regions in the visual cortex no longer receive any input signals. The respective spot in the visual field gets proverbially "dark" – a scotoma forms. Plasticity processes in the brain's visual cortex can, at least partly, restore the ability to see: after reorganization of the network, the cells that are deprived of input signals from the retina receive input signals from other cells. But which cells provide this new input? In order to find an answer to this question, Dirk Jancke, Bernstein Group for Computational Neuroscience Bochum – in a cooperation project with Ulf Eysel, Medical Faculty at the Ruhr-University of Bochum – observed regeneration processes after retinal lesions in rats. The researchers showed that strengthening of neuronal connections to neighboring cells of the visual cortex play an important role here.

The image that falls on the retina is projected to the visual cortex in such a way that topology is maintained; neighboring regions on the retina are processed by neighboring neurons in the visual cortex. The cells in the visual cortex, however, do not only receive input signals from the retina; they are also widely interconnected. The scientists around Jancke managed to show that these contacts are further strengthened during regeneration processes. "For quite some time, there have been studies describing such plastic processes. Until now, however, these processes could not be visualized functionally over relatively large areas of the visual cortex," Jancke explains.

The scientists from Bochum observed the processes in the visual cortex with a new method that makes use of voltage-sensitive dyes. They change their fluorescence when cells receive or send electrical signals. By applying this imaging method, the activity of neuronal cell populations can be captured with high spatial and temporal resolution. Shortly after the retinal lesion, the cells in the affected region of the visual cortex showed no or only little activity. But within only a few weeks after the lesion, neuronal activity waves increasingly spread from neighboring regions into the affected region. "Cortical nerve cells, which are suddenly deprived of direct input after a retinal lesion, are at least enabled to look around the corner again thanks to the connection to still-functional distant neighbors," Jancke points out. Lacking image information is replaced by information from neighboring regions. The restoration of the function of cortical neurons after injuries is a central subject in neuroscience. The retinal lesion model provides an ideal access in order to systematically explore the basic principles of such neuronal reorganization processes in the cortical network.

Source: Palagina G., Eysel U.T., Jancke D. Proc. Nat. Acad. Sci. (USA), 6. May, 2009.



Neuronal activity (ascending in amplitude from green, yellow, red) in the cortical visual cortex six days (top) and 28 days (bottom) after a retinal lesion. After regeneration, the activity of neighboring regions increasingly spreads into the region affected by the retinal lesion (above the black line).

Can you show me the way to Marienplatz?

The robot of the future acts autonomously. It is no longer restricted to an industrial environment, where the only movements it has to make are pre-programmed. In the future, robots shall be utilized as intelligent helpers in various working environments, and they shall be capable of autonomously performing different tasks, depending on the situation. This also implies the ability to specifically search for the information needed for the completion of a task. By constructing their "ACE", Martin Buss and Kolja Kühnlenz from the Bernstein Center for Computational Neuroscience together with their colleague Dirk Wollherr and a team of scientists from the Technical University of Munich have now created a robot that has successfully taken this step towards autonomy. "ACE" stands for "Autonomous City Explorer". ACE can navigate in an urban environment without a GPS or city map, by approaching pedestrians and asking them for directions. In a field trial, the robot has already managed to ask its way from the Technical University of Munich to Marienplatz. On the way, however, the ACE is confronted with a great number of problems it has to solve.

First of all, the robot must find pedestrians it can approach and ask for directions. For this purpose, the system is equipped with a camera head, which it uses to search for image patterns of faces. Once the robot has detected a pedestrian it contacts him/her via a loudspeaker and screen. The robot asks him/her to show the way to the target destination by stretching out the arm. Since the ACE is equipped with several cameras, it can also determine the distance from each point that is captured by the camera. By means of image data, ACE calculates the pedestrians' body postures and thus the direction in which it must proceed. Via a touch-screen, the pedestrian can enter additional information about where to proceed.

ACE - "Autonomous City Explorer"

In order to be able to navigate, ACE must know its position and what its direct surroundings look like. He uses two lasers to scan the area. A forwardly-directed laser detects objects and obstacles; a downwardly-directed laser examines ground characteristics and recognizes e.g. curbs. Additionally, ACE measures his own movement on the basis of the rotation of its wheels. The different pieces of information are computed; they tell the robot, which area in its closer surroundings is navigable. Then, ACE searches for the shortest way to the target destination within this area.

When reaching a crossroad, ACE needs help, because crossing the street on its own would be too dangerous. Traffic lights and traffic signs help the robot to realize that he has reached a crossroad. The robot was programmed with more than 10 000 images of traffic signs and traffic lights so that it is able to reliably recognize crossroads. At crossroads, a member of the research team – wearing a T-Shirt with checkerboard pattern – serves as an orientation guide. The robot recognizes this pattern and follows the staff member by using a tracking system. In the trial, it took ACE about five hours to cover the distance of approx. 1.5 km from the TU Munich to Marienplatz. On its way, the robot asked 31 pedestrians for directions.

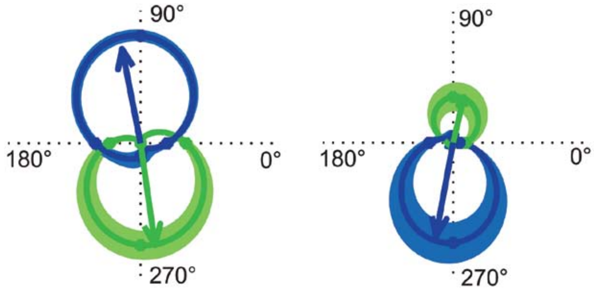
Source: Bauer, A., Klasing, K., Lidoris, G., Mühlbauer, Q., Rohrmüller, F., Sosnowski, S., Xu, T., Kühnlenz, K., Wollherr, D. & Buss, M. Int J Soc Robot (2009) 1: 127–140
Siehe auch: www.ace-robot.de

How the brain plans goal-directed movements

Many of our movements are specifically based on what we see. In many cases, however, the same visual environment may provoke entirely different actions. Sometimes we catch the ball flying towards us, sometimes – when afraid – we duck to avoid being hit by the ball. Thus, visual information as well as context information is used when planning motor activity. Scientists around Alexander Gail from the German Primate Center and the BCCN Göttingen have now shown how the brain computes different information when planning motor activity.

For analyzing the neuronal bases of motor planning, the scientists conducted an experiment on macaques. The monkeys were shown a specific point in the periphery of a computer screen. Simultaneously, they received information via a symbol about whether to reach out in the direction of the point or in the opposite direction. During the experiment, the scientists recorded the neuronal activity in two brain regions: the Parietal Reach Region (PRR) and the Dorsal Premotor Cortex (PMd).

As it has already been known from previous experiments, neurons in these brain regions encode the movement plan: For example, a certain neuron becomes active every time the monkey reaches out in the upper-right direction. The new experiments show that the neuronal representation of a movement plan depends on the behavioral context in which the movement takes place. In both brain regions, Gail and his colleagues were able to identify the principle of context-dependent "gain modulation". In association with motor planning, gain modulation has so far only been known as a mechanism for integrating different sensations. Gail and his colleagues have now shown, for the first time, that this principle also plays a central role in integrating behavioral context. In their work, the scientists confirm predictions from previous theoretical calculations in the computer model.



Selectivity of two neurons for the direction of a planned movement. The left neuron reflects the movement plan towards (green curve) and away from (blue) in the same way. As regards the right neuron, the strength of the activity – but not its directional dependency – depends on the task.

The behavioral context, however, has different effects on the two brain regions. Most of the neurons in the PMd send their signals with higher frequency when the monkey is not supposed to reach out in the direction of the point, but in the opposite direction. Possibly, the neurons are more active when performing this more difficult task, thus suppressing the reflex to reach-out in the direction of the point. Consequently, the PMd is rather responsible for the planning of indirect movements. In the PRR, the neurons specify the direction accurately when performing a reach-out movement towards the point; on the other hand, they work much less accurately when performing the task of reaching out in the opposite direction. Therefore, it is possible that this brain region is rather responsible for reflex, stimulus-controlled movements.

The results are also significant for medical applications. By means of so-called Brain Computer Interfaces, severely paralyzed patients shall be enabled to control a computer or prosthesis only by means of their brain activity. For this, the movement plan must be read out from the brain. The results achieved by Gail and his colleagues show that for these applications also the context, in which the movement is made, must be taken into account.

Gail, A., Klaes, C. & Westendorff, S. J Neurosci. 2009 Jul 29;29(30):9490-9. // Brozovic, M., Gail, A., Andersen, R.A. J Neurosci 2007 27: 10588-96.

Theo Geisel

From chaos to brain

"After my diploma thesis, I was slightly bored with physics", Theo Geisel admits. Today he is Managing Director of the Max Planck Institute for Dynamics and Self-Organization and founder of the Bernstein Center for Computational Neuroscience in Göttingen. "During university studies, the great moments of physics are taught in compact form; the first own steps into the everyday life of research, however, turned out to be much more modest than expected." But then Geisel discovered the field of nonlinear dynamics also known as 'chaos theory' when it was still emerging. "If it hadn't been for that, I might have quit physics and become a musician". Music is still a great passion of the theoretical physicist. The by far greater part of his creative efforts, however, flows into science. In 1994, he was awarded the highest German research award – the Gottfried-Wilhelm-Leibniz Prize – and in 2009, he received the Gentner-Kastler Prize of the German Physical Society and the Société Francaise de Physique. In honor of his 60th birthday, a symposium was organized in Göttingen on 31 July, 2009.

For more than 30 years now, Geisel has been dealing with chaotic systems. "Chaotic dynamical systems are deterministic systems," he explains – i.e. they are predictable in principle. They are called 'chaotic', because tiny differences in the initial conditions may lead to large deviations in the course of time – the proverbial wing beat of a butterfly could possibly influence the weather. In the early 1980s, Geisel was the first to introduce a mathematical model for so-called 'Lévy Random Walks' when he investigated certain chaotic systems. It describes seemingly random motions with subsequent steps of very different lengths. What is characteristic of this system is that also large steps occur frequently and there is no typical scale for the fluctuations of step lengths, their variance is infinite. With this work, he gave the starting signal for a field of research that introduced 'Lévy Random Walks' into many different disciplines of physics, biology, climate research and financial mathematics. In his own working group for example, Geisel and his colleagues applied this method to semiconductor nanostructures. The method received worldwide attention in 2006, when Geisel, together with Dirk Brockmann and Lars Hufnagel, analyzed human travel behavior and described it by Lévy processes. Especially in times of avian and swine flu, they have thus made a major contribution to improve the accuracy of epidemic forecasts.

When Theo Geisel became professor of Theoretical Physics in 1989 in Frankfurt, he had already begun to apply methods of nonlinear dynamics to neuronal processes. "Thanks to our collaboration with scientists at the Max Planck Institute for Brain Research in Frankfurt, we had access to experimental data of unprecedented detail obtained with newly developed techniques," Geisel says. At the time, two different focuses were established in Geisel's working group, which nowadays would be assigned to Computational Neuroscience. One of these topics dealt with the development of the visual cortex, the part of the cerebral cortex that processes visual information. Just like most processes in biology, also these highly complex structures are formed under the influence of self-organization. Cells with different tasks are not randomly distributed in the visual cortex, but rather in a pattern with certain regularities, so-called "neural maps". Neural maps were investigated intensely with new experimental methods (optical imaging) in the 1990s. Geisel and his coworkers Fred Wolf, Klaus Pawelzik and Hans-Ulrich Bauer accompanied these works with theoretical studies that explain the pattern formation processes in the visual cortex.

The other focus pertains to a phenomenon discovered in the late 1980s. Groups of nerve cells send neuronal impulses in a common rhythm – they are said to synchronize. There is evidence that this synchronous activity contributes to the strengthening of certain neural states as well as to the formation of memory. In collaboration with Udo Ernst and Klaus Pawelzik, Geisel developed a model that could explain the emergence and properties of neuronal synchronization. Their work was based on a model of the American mathematician Steven Strogatz, which, although applicable to the synchronous blinking of fireflies, was not ready to capture essentials of the nervous system. Geisel and his colleagues extended the model to integrate two basic characteristics of the nervous system: on the one hand, it allows for inhibitory neuronal connections and, on the other hand, for temporal delays resulting from the finite speed of signal transmission between nerve cells. This model has enabled mathematical studies of synchronous network oscillations, thus providing the basis for later investigations in Geisel's working group devoted to questions such as: How does the behavior of the network depend on network topology? Which role do temporal delays play? How fast are synchronous states reached, and is there a 'speed limit for thinking'?

Geisel explains the behavior of the model as follows: "The network activity converges towards a state in which certain groups of neurons fire in synchrony. In this state, however, and under the condition of excitatory coupling, the system is very sensitive to small perturbations which can lead to the synchronization of new groups of neurons." This makes sense also from a physiological point of view: The nervous system should not get stuck in a synchronous state, but should be receptive to new stimuli. This phenomenon was examined mathematically in Geisel's group in 2002 by Marc Timme during his PhD thesis. "Due to the mathematical approach, we can ask and answer specific questions and reveal the origins of the observed phenomena,"

Neuronal orientation prefe-rence map. Cells in the visual cortex preferentially respond to edges and contours in a particular orientation. Cells of the same orientation preference are depicted in the same color.

Geisel says. In this case it lead to the discovery of so-called unstable attractors. Another dynamic characteristic of the brain was studied by Geisel together with Anna Levina and Michael Herrmann in 2007. The transmission of signals in the brain produces sequences of neural activity of very different size that allow it to explore the full spectrum of possible responses. The scientists were able to show that this is a phenomenon of 'self-organized criticality' and mathematically clarified the conditions underlying it.

In the course of his academic career, Theo Geisel has addressed many different scientific questions and has pursued the most interesting ones until today. Currently, with his working group he studies a variety of research topics – from semiconductor nanostructures to phenomena of the nervous system. Moreover, Geisel's life is still accompanied by music: He enriches scientific symposia or institute parties by playing the saxophone together with his institute's Jazz band.

Bernstein Focus: Neuronal Basis of Learning

Our ability to remember glues our lives together, over short as well as long time periods. We know where we are and what we are currently doing thanks to our short term memory. The fact that we remember our childhood, people and events can be attributed to our long term memory. Every event we memorize changes our brain a little and leaves its traces. Every human thus has a slightly different brain, shaped by what he or she has learned throughout life and the experienced gathered.

With the new funding initiative „Bernstein Focus: Neuronal Basis of Learning“ the Bernstein Network now gains eight new joint research projects that will approach questions of learning and memory formation in the coming five years. The Federal Ministry of Education and Research (BMBF) supports the initiative with around 16 Million Euro.

Brain development, therapies after stroke, learning through imitation, decision making or short term memory – the topics investigated in the different joint research projects are very diverse. All of the projects though have one thing in common: a close cooperation between researchers from the experimental sciences and experts from theoretical neurobiology. The research results from the funding initiative will lead to new applications not only in the clinical field, but also in technology as for example in the development of autonomous robots and driver assistance systems.

http://www.nncn.de/nachrichten-en/fokuslernen

bfnl

The joint research projects:

- Memory in Decision Making
  Coordinator: Dorothea Eisenhadt (Freie Universität Berlin) / Principle Investigators: Randolf Menzel, Martin Nawrot, Raul Rojas, Bertram Gerber, Martin Riedmiller
- Visual Learning
  Coordinator: Siegrid Löwel (Universität Jena) / Principle Investigators: Knut Holthoff, Christian Hübner, Otto Witte, Fred Wolf
- Sequence Learning
  Coordinator: Onur Güntürkün (Universität Bochum) / Principle Investigators: Hubert Dinse, Henrik Mouritsen, Klaus Pawelzik, Constance Scharff, Martin Tegenthoff
- Ephemeral Memory
  Coordinator: Hiromu Tanimoto (Max-Planck-Institut für Neurobiologie, Martinsried) / Principle Investigators: Andreas Herz, Giovanni Galizia, Paul Szyszka
- State Dependencies of Learning
  Coordinatoren: Petra Ritter (Charité Universitätsmedizin Berlin und Humboldt Universität Berlin), Richard Kempter (Humboldt-Universität Berlin) / Principle Investigators: Susanne Schreiber, Michael Brecht, Uwe Heinemann, Hubert Dinse, Jan Born, Burkhard Pleger
- Plasticity of Neural Dynamics
  Coordinator: Christian Leibold (Ludwig-Maximilians-Universität München) / Principle Investigators: Felix Felmy, Benedikt Grothe
- Complex human learning
  Coordinator: Christian Büchel (Universitätsklinikum Hamburg-Eppendorf) / Principle Investigators: Klaus Obermayer, Shu-Chen Li, Jürgen Gallinat, Andreas Heinz
- Learning Behavioral Models
  Coordinator: Gregor Schöner / Principle Investigators: Ioannis Iossifidis, Christian Igel, Laurenz Wiskott, Hannes Edelbrunner

Bilateral Funding Scheme

With the new funding scheme 'Germany - USA Collaboration in Computational Neuroscience', the German Federal Ministry for Education and Research (BMBF) and the National Science Foundation (NSF) support German-American research co-operations in the field of Computational Neuroscience. The first impulse to this research initiative arose at the German-American Workshop "Growing Connections in Computational Neuroscience", which took place in Munich in June 2008 with support of the BMBF and NSF.
http://www.bmbf.de/press/2657.php (press release of the BMBF)

CNS 2009

For the first time, this year's annual meeting „CNS" of the Organization for Computational Neuroscience took place in Germany and was opened by State Secretary Prof. Dr. Frieder Meyer-Krahmer on July 18th in Berlin. With the support by the Bernstein initiative, Germany has a strong, internationally recognized scientific community in the field of Computational Neuroscience. This was, as Prof. Ranu Jung, president of the Organization for Computational Neuroscience, pointed out, a major criterion for selecting Germany as meeting venue. With more than 650 scientists, this year's conference broke all records in terms of participant numbers. The local organizing committee was headed by Dr. Udo Ernst (Bernstein Group Bremen).

Exchange with Sloan Swartz Centers

For the second time, an exchange program between the Bernstein Network and the Sloan Swartz Centers, the leading research institutes in the field of Computational Neuroscience in the USA, takes place this year. Ten doctoral students and postdocs of both organizations have the possibility to visit the annual conference of the respective other organization. The exchange is supported by the Swartz Foundation and the organizer of the Bernstein Conference (this year, the Bernsteon Focus: Neurotechnology, Frankfurt).

Personalia

Marlene Bartos, BCCN Freiburg, returns from the University of Aberdeen (Scotland) as Lichtenberg Professor to the University of Freiburg. With the Lichtenberg-Professorship, the Vokswagen Foundation supports excellent scientists in innovative fields of research and teaching.

Upcoming Events

Date	Title	Organizers	URL
30.Sept. - 2.Oct., Frankfurt/M	Bernstein Conference on Computational Neuroscience	J. Triesch, Ch. v.d. Malsburg, R. Mester (BFNT Frankfurt)	http://bccn2009.org/
12. - 16. Oct., Freiburg	NWG Course 2009	S. Rotter, S. Grün, U. Egert, A. Aertsen, J. Kirsch (BCCN Freiburg)	www.bccn-freiburg.de/news/events/nwg-course2009
17. - 21. Oct, Chicago	Neuroscience 2009	Society for Neuroscience	http://sfn.org/am2009

The Bernstein Network

Bernstein Centers for Computational Neuroscience (BCCN)
Berlin – Coordinator: Prof. Dr. Michael Brecht
Freiburg – Coordinator: Prof. Dr. Ad Aertsen
Göttingen – Coordinator: Prof. Dr. Theo Geisel
Munich – Coordinator: Prof. Dr. Andreas Herz

Bernstein Focus: Neurotechnology (BFNT)
Berlin – Coordinator: Prof. Dr. Klaus-Robert Müller
Frankfurt – Coordinators: Prof. Dr. Christoph von der Malsburg, Prof. Dr. Jochen Triesch, Prof. Dr. Rudolf Mester
Freiburg/Tübingen – Coordinator: Prof. Dr. Ulrich Egert
Göttingen – Coordinator: Prof. Dr. Florentin Wörgötter

Bernstein Focus: Neuronal Besis of Learning
Visual Learning – Coordinator: Prof. Dr. Siegrid Löwel
Plasticity of Neural Dynamics – Coordinator: Prof. Dr. Christian Leibold
Memory in Decision Making – Coordinator: Prof. Dr. Dorothea Eisenhardt
Sequence Learning – Coordinator: Prof. Dr. Onur Güntürkün
Ephemeral Memory – Coordinator: Dr. Hiromu Tanimoto
Complex Human Learning – Coordinator: Prof. Dr. Christian Büchel
State Dependencies of Learning – Coordinatoren: Dr. Petra Ritter, Prof. Dr. Richard Kempter
Learning Behavioral Models – Coordinator: Prof. Dr. Gregor Schöner

Bernstein Groups for Computational Neuroscience (BGCN)
Bochum – Koordinator: Prof. Dr. Gregor Schöner
Bremen – Koordinator: Prof. Dr. Klaus Pawelzik
Heidelberg – Koordinator: Prof. Dr. Gabriel Wittum
Jena – Koordinator: Prof. Dr. Herbert Witte
Magdeburg – Koordinator: Prof. Dr. Jochen Braun

Bernstein Collaborations for Computational Neuroscience (BCOL)
Berlin-Tübingen, Berlin-Erlangen-Nürnberg-Magdeburg, Berlin-Gießen-Tübingen, Berlin-Constance, Berlin-Aachen, Freiburg-Rostock, Freiburg-Tübingen, Göttingen-Jena-Bochum, Göttingen-Kassel-Ilmenau, Munich-Göttingen, Munich-Stuttgart

Bernstein Award for Computational Neuroscience (BPCN)
Dr. Matthias Bethge (Tübingen), Dr. Jan Benda (Munich), Dr. Susanne Schreiber (Berlin)

Chairman of the Bernstein Project Committee: Prof. Dr. Ad Aertsen
Deputy Chairman of the Project Committee: Prof. Dr. Theo Geisel

Imprint

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