Bernstein Centers for Computational Neuroscience

BCCN Newsletter

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06/2006

Predicting epileptic seizures – pure chance?

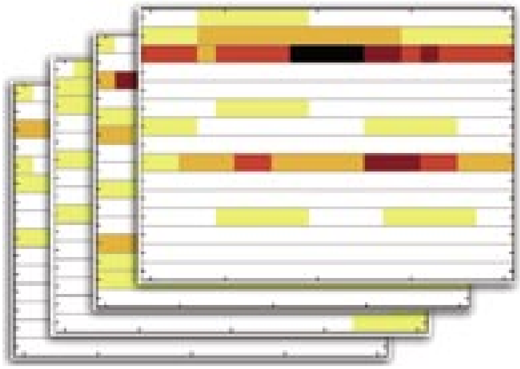
Scientists at the BCCN develop a procedure to evaluate algorithms that predict epileptic seizures

Epilepsy is a widespread neurological disease that is characterized by the spontaneous and hitherto unpredictable incidence of seizures. Being able to predict those seizures would open new possibilities for therapeutic intervention. Approaches exist to identify characteristic modifications of brain activity that precede a seizure by mathematical analysis of the electroencephalogram (EEG). However, it is still a matter of debate how reliable these methods are in forecasting seizures and whether they are superior to pure guess work. The interdisciplinary research teams of Andreas Schulze-Bonhage and Jens Timmer at the University Freiburg and the Bernstein Center for Computational Neuroscience in Freiburg have now developed a standardized evaluation procedure that can compare different mathematical prediction algorithms and assess their clinical applicability.

The evaluation criteria of the Freiburg researchers take into account not only the sensitivity of these algorithms, but also the occurrence of false alarms in a given time period. Moreover, their 'Seizure Prediction Characteristic' also considers temporal aspects of the prediction. At what time interval following the prediction does the seizure occur and how accurately can the seizure onset be predicted? With this catalogue of criteria at hand, the researchers check whether certain algorithms are indeed capable of predicting seizures or no more reliable than chance.

Currently, the Freiburg team is establishing a worldwide unique EEG database with long-term recordings by the Freiburg University Hospital. The database will be used to evaluate seizure prediction algorithms with the statistical method that they developed. First results indicate that a prediction method that uses a quantification of synchronous nerve cell activity is indeed better than prediction by chance. Once the validation of the method is completed, it will finally be possible to challenge the unpredictability of epileptic seizures – a major improvement in the patients' quality of life and an important step in the development of new treatment opportunities.

Source / Quelle: Schelter, B., Winterhalder, M., et al. (2006). Testing statistical significance of multivariate time series analysis techniques for epileptic seizure prediction. CHAOS 16, 013108 (2006)



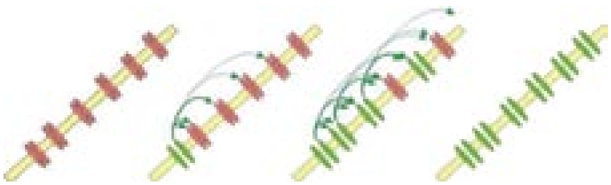
Time course of seizure prediction characteristic (using the Freiburg procedure, color-coded) for different patients. Each line represents a different combination of EEG electrodes.

Neurons: faster than theory allows

A new model explains the high flexibility and speed of signal transduction in the mammal brain

Neurons transmit information in form of electrical voltage changes at the cell membrane. This is done in a very selective manner. A typical cell of the cerebral cortex 'interprets' a combination of several thousand signals every second and responds by sending out impulses itself – often less than a dozen in the same time window. In 1952, Alan Lloyd Hodgkin and Andrew Fielding Huxley described in a mathematical model how neurons filter and selectively transmit information on the basis of measurements from squid neurons. The Hodgkin-Huxley model has since then served to explain the signal processes in all neurons. Björn Naundorf and Fred Wolf from the Bernstein Center for Computational Neuroscience in Göttingen and the Max Planck Institute for Dynamics and Self-Organization, together with Maxim Volgushev from the Ruhr-Universität Bochum, have recently found that the Hodgkin-Huxley model cannot describe the emergence of neuronal impulses in the mammal brain.

Every living cell maintains a voltage difference across its cell membrane. Nerve cells use this voltage difference to process and transmit messages. A neuronal impulse, also called 'action potential', corresponds to a reversal of the membrane potential. According to the Hodgkin-Huxley model, an action potential is initiated when the voltage across the nerve cell membrane changes up to a certain threshold value. Voltage gated sodium channels react to this voltage change by opening up so that sodium ions can pass through the membrane. This leads in turn to a further increase of the membrane potential and the opening of additional sodium channels. An avalanche-like reaction is triggered, eventually leading to a reversal of the membrane potential.



Graphical representation of the cooperative working model of sodium channels and the rapid onset of action potentials of mammalian nerve cells. Due to their cooperative manner of opening, a strong influx of sodium already sets in during the first 200 microseconds.

With unprecedented accuracy, Wolf and his colleagues have examined the speed and threshold of action potentials in nerve cells of the cerebral cortex of the mammalian brain. They were able to show that action potentials are initiated extremely rapidly in this area. A strong influx of sodium already sets in during the first 200 microseconds, all sodium channels thus appear to open almost simultaneously. At the same time, however, the researchers found that the threshold values at which action potentials were initiated were very variable. A high variability of the threshold value and a rapid onset of the action potential, the researchers found, cannot be unified in Hodgkin-Huxley-type models. Wolf and his colleagues therefore postulated a new mechanism that can explain the behavior of the nerve cells. According to the new model, when a sodium channel opens, it influences other sodium channels in the immediate neighbourhood – the channels open 'cooperatively'.

It seems likely that mammalian cells use this novel mechanism to selectively respond to certain input signals. "The cells function like a high-pass filter; fast signals are transmitted well, slow signals are suppressed", explains Naundorf. The large variability of the threshold potentials allows the cells to ignore stimuli with slow onsets. The fast activation of action potentials, on the other hand, helps to transmit fast changing signals with high precision.

Source: Naundorf, B. et al. (2006). Unique features of action potential initiation in cortical neurons. Nature 440, 1060–3.

Sound localization through experience

The ability to localize sound develops in gerbils in the first days after hearing onset

Our hearing is capable of localizing sounds with great accuracy – we don't need to look to work out whether a car is coming from the left or the right. Most animals also have good directional hearing, so that they can locate dangers, prey or mating calls. To localize a sound source, the brain compares the auditory information of the two ears. To this end, it uses two different mechanisms. Firstly, it detects differences in volume between the ears – a sound coming from the side will be blocked by the head, and will therefore be much quieter on the far side of it. Secondly, the brain processes the temporal delay between the sound reaching one ear and then the other. In this task, the brain achieves a temporal resolution in the range of a few microseconds. Benedikt Grothe of the Ludwig Maximilians University in Munich and his colleagues have investigated the neuronal mechanisms that underlie the high performance of the mammalian brain, and discovered how the acoustic experience of newborn gerbils leads to the acquisition of the ability to localize sound.

In 1948, Lloyd Jeffress presented a model according to which specific neurons in the brain are tuned to sounds from a certain direction through defined neuronal circuits. This model is based exclusively on excitatory neuronal signals. In 2002, Grothe's group found that in mammals, inhibitory neuronal connections, which suppress the activity of downstream neurons, also play a major role in localizing an acoustic source. Jeffress's model therefore did not apply for these animals.

Acoustic signals are processed in several stages in successive brain regions. On the lowest level of this hierarchy are the neurons that detect the temporal difference between the ears, located in the medial superior olive (MSO). Grothe and his colleagues have now investigated neurons in the next level in the dorsal nucleus of the lateral lemniscus (DNLL), and found that their response to simple acoustic signals of defined frequencies is exactly the same as that of neurons in the MSO. However, cells in the DNLL presumably acquire more specialized functions through neuronal interaction with other brain regions, such as suppressing echo signals or tracking moving sound sources.

Since neurons in the DNLL are far more easily accessible experimentally than those in the MSO, the scientists were for the first time able to collect enough data for comparative studies of development of directional hearing, thus enabling them to draw conclusions about the primary circuits of the MSO. The researchers were able to show that neurons processing signals from both ears are not, or only poorly, tuned to a specific direction in newborn gerbils. The ability to localize sound only develops through hearing experience – a process that is associated with structural changes in the inhibitory input signals to the MSO neurons. Sound localization only develops if the gerbils are exposed to localized sound sources within a certain time frame. If the researchers subjected the gerbils to constant unlocalized noise, directional hearing did not develop normally.

Source: Siveke, I. et al. (2006). Binaural Response Properties of Low Frequency Neurons in the Gerbil Dorsal Nucleus of the Lateral Lemniscus. J Neurophysiol., in press.
Seidl, A.H., Grothe, B. (2005). Development of sound localization mechanisms in the mongolian gerbil is shaped by early acoustic experience. J Neurophysiol, 94(2):1028–36

Meet the Scientist

Peter Jonas

Pioneer in the field of neuronal communication

"Understanding the brain is one of the major challenges in medicine. Even today, six years after the decade of the brain, there are still fundamental questions open in this field", says Peter Jonas, scientist at the Bernstein Center of Computational Neuroscience in Freiburg. After studying medicine in Gießen, Jonas decided that a career as medical practitioner was not his preferred option and chose a career in research instead. He did his doctoral degree in the laboratory of Werner Vogel, where he worked on the peripheral nervous system. "Studying neurosciences has taken hold of me ever since," says Jonas. In the group of Bert Sakmann at the Max-Planck Institute for Medical Research in Heidelberg, Jonas discovered the subject he is still working on today: the function of inhibitory interneurons in the brain. In December 2005 Jonas received the Gottfried Wilhelm Leibniz-Preis of the Deutsche Forschungsgemeinschaft. Valued at 1.55 million Euro, the Leibniz Prize is the highest honor awarded in German research.

In a manner of speaking, Jonas's career follows a "bottom-up approach": he started out working on single molecules of the synapse, the junction between two neurons, and later turned to increasingly more complex questions. How do molecules and synaptic interactions function in brain tissue, or even in the context of the whole brain? Jonas constantly searches for new challenges. Using sophisticated methods, he endeavors to uncover the secrets of neurons and neuronal communication. In doing so, he has done much pioneer work – "for ourselves," as he says, but also for others. Many methods that Jonas established are also used in other laboratories, while Jonas moves on to new tasks. "I always like to learn something new," says Jonas.

The extraordinary accomplishments of the brain require an exact coordination between different kinds of neurons. Sensory and motor neurons relay perceptional information to the brain and send signals to the muscles, respectively. So called interneurons, which make exclusively contact with other neurons, modulate these processes. Such interneurons are the subject of Jonas's research interests.

Most interneurons are inhibitory in nature; they act by repressing the activity of the downstream neurons and subtly modulate their activity. Inhibitory interneurons are therefore crucial for functions that depend on exact timing and precision – from accurate movement coordination to sound localization through comparison of the input signals between both ears. In addition, interneurons are responsible for the generation of so called gamma rhythms, fast and high-frequency brain waves that arise through synchronous activity of groups of neurons from different brain regions. Several findings suggest that such synchronization is crucial for higher cognitive functions that involve multiple brain regions.

For a long time, the notion that excitatory and inhibitory neurons are very similar prevailed in the field. Jonas has turned

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this idea on it's head. He showed that inhibitory neurons have unique properties on the molecular level that equip them for their special role in the brain and allow them to respond particularly fast and precisely.

In 1998 Jonas showed that interneurons in the spinal chord communicate using two different transmitters, GABA and Glycine. This observation was surprising, as it contradicted the then widely accepted idea that every neuron produces only one kind of transmitter. The difference in the effects of GABA and Glycine on the downstream neuron is that GABA produces a somewhat longer reaction. Presumably, the combination of the two transmitters that work at slightly different time scales is essential for precise motor coordination.

In a series of experiments, Jonas investigated the molecular basis for the ability of interneurons to produce neuronal impulses at extremely high frequency. He showed that this peculiar feature of interneurons is due to a unique set of ion channels with very fast reaction times. The electrical signal of a neuron arises through the regulated flow of ions through channels in the cell membrane. In interneurons, the channels for sodium and potassium ions are molecularly and functionally unique. Interneurons possess Kv3-channels, a form of potassium channels which deactivates particularly quickly. In technically sophisticated experiments, Jonas investigated the exact characteristics of these channels quantitatively. To this end, he developed a "fast dynamic clamp", which can be used to reproduce the exact properties of the channels by injecting a defined current into the cell.

A quantitative analysis is crucial for a detailed understanding of signal transmission processes between neurons in the context of larger neuronal networks. How fast must a process be in order to elicit a certain response? How much potassium has to leave the cell; how fast must certain channels close? "A rough qualitative idea of a process is often obtained quickly, but it frequently breaks down when tested quantitatively," says Jonas. Quantitative issues can only be addressed through research at the boundary between experiment and theory; quantitative mathematical models are becoming ever more important . Jonas's research is therefore moving into the field of "computational neuroscience" – a new challenge that Jonas willingly meets.

Florentin Wörgötter

Robots that learn playfully

Children learn by exploring their environment. They grab objects, thereby practicing their movement coordination, they observe, they conclude and thus learn to cope with the challenges of an ever-changing surrounding. Conventional industrial robots can't do that – at least not yet. As yet, a robot needs to be programmed with basically every behavior it is supposed to carry out – for every behavioral modification, the program needs to be adapted. As long as the robot sticks to stereotyped procedures or defined rules, this is not much of a problem. However, more complex behavioral skills or more flexible reactions can only be achieved if robots can autonomously adapt and optimize their behavior. In other words, robots need to acquire the ability to learn, like children. This is a central goal of many research groups world wide. Optimizing learning processes in computer based systems also is the research goal of the group of Florentin Wörgötter, professor at the Bernstein Center for Computational Neuroscience in Göttingen since July 2005.

„The human brain is presumably the best model for robot learning. There is nothing in nature that learns more effectively", says Wörgötter. But the human brain cannot be simply reconstructed in silicon – not only because it is of a different material, but also because it is far too complex. Instead, insights from brain research need to be put into mathematical algorithms used to control the robot. Wörgötter has the best prerequisites for conducting research at this boundary between biology and mathematics. He studied both subjects – a rare combination, especially since there was no clear career profile for this combination at the time of Wörgötter's studies. "I simply studied whatever I felt like," says Wörgötter – a wise decision, in retrospect.

To strengthen both aspects of his studies, Wörgötter followed both experimental and theoretical work during his early career – the former during his doctoral thesis (1985-1988) in the laboratory of Ulf Eysel in Essen and Bochum (Germany), the latter as a post doc at CALTECH (Pasadena, USA) with Christof Koch. In both positions, he studied visual perception. Wörgötter didn't engage with the topic of learning until much later, when he held a professorship at the Department of Psychology at the University of Stirling (Scotland) – triggered by a PhD student in his lab. "Bernd Porr wanted to work on learning. I told him: 'fine, do that, but I can't help you. I have to learn that myself first'," Wörgötter reports. The subject then became one of the two key research topics in Wörgötter's lab. Before coming to Gottingen, Wörgötter was director of the Institute of Neuronal Computational Intelligence and Technology in Stirling.

How are learning robots constructed? "The trick is in the abstraction," says Wörgötter. The principles of learning need to be recognized and put into mathematical formulas. For example, the fact that synapses are strengthened when two contacting neurons fire at the same time – the cellular basis of learning – can be described by a simple mathematical equation. This corresponds to the first level of abstraction. From here, further abstractions are formulated, algorithms that reflect neuronal circuits are developed, even complex learning models from the

field of psychology can be incorporated into robot technology. In some cases, abstraction is driven to such an extreme that any connection to nature is apparently lost. However, Wörgötter's goal is to transition smoothly through all the levels of abstraction: from biophysics to the functionality of the robot. Whenever a new level of abstraction is reached, he looks back – does the robot still perform the same as its model – a human being? "We hope that robots can still learn a lot from humans," says Wörgötter, "and at the same time, we can gain a lot of insight into human learning through the simulation of learning processes in robots".

Wörgötter's success shows that his research approach does prevail in practice. Many a robot has turned out to be an amazingly quick learner, when supplied with the correct algorithms. Together with his Ph.D. student Tao Geng, Wörgötter developed the fastest walking robot to this day – at least relative to its size, it measures only about 30 cm. Under the control of 20 „neurons" the robot has learned to walk with far more supple movements than many of its contemporaries.

Wörgötter's robots also prove very talented when learning to avoid obstacles or collect objects. In many laboratories all over the world, robots are put to such tasks. But Wörgötter employed different algorithms to program learning behavior than those commonly used. Whereas most robots search their environment for „rewards", Wörgötter's robots attempt to avoid disturbances. The same behavior can be achieved with both approaches, only the underlying mathematics differs. And this indeed has an effect – the robots learn more quickly. Admittedly, they still have difficulties in learning complex procedures comprising multiple actions. Optimal performance can probably be achieved by combining both technologies. Wörgötter is currently investigating how this can be achieved.

Wörgötter's long term objective is to construct robots which autonomously investigate their surrounding and so learn to assign meaning to certain objects. Like children, such robots would "play" with items and draw their conclusions. They would learn to understand that a cup can be used to contain liquid or a cylinder can roll if it is laid down sideways. These robots would understand through trial and error that they should use their whole hand to grab large objects, whereas small objects can be more easily picked up using thumb and index finger. In the framework of an EU-funded project of several years, Wörgötter and his colleagues from other European laboratories are attempting to program the humanoid robot „Armar" (University Karlsruhe, Rüdiger Dillmann) so that it will learn by playing with objects – like a child. If they succeed, robots will have made a great leap towards autonomy.

But there needs to be a limit to autonomy as well, as Wörgötter states. "What use is a service robot that decides it would prefer to relax than to vacuum-clean?" he asks. "Right now, these are questions mainly asked by philosophers," he says. In the future, maybe they will have more direct applications.

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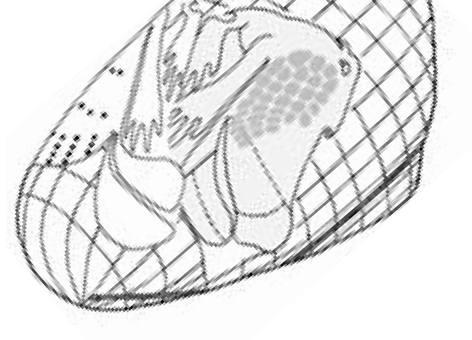

Michael Brecht

Single cells in the context of the brain

Thanks to tissue and cell culture experiments, we have a good understanding of how single neurons work. However, due to the enormous complexity of the brain, it has so far been extremely difficult to investigate the contribution of single cells to its overall function. Although it has long been possible to eavesdrop on neuronal activity with extracellular methods, in the intact brain there is no way to manipulate single cells or use intracellular methods to precisely describe their activity. “As yet, the analysis of cellular processes and the analysis of cellular activity in the living brain are worlds apart,” says Michael Brecht. Bridging the gap between these worlds is a central theme of his work. “We want to understand the function of single cells in the systemic context of the brain,” says Brecht. What is the role of a single cell, embedded into this complex network? What effect can it have? Brecht, currently at the Erasmus University Rotterdam, has accepted the professorship “Animal Physiology /Systems Neurobiology and Neural Computation” at the Bernstein Center for Computational Neuroscience in Berlin. He will join the Institute for Biology at the Humboldt University Berlin in fall 2006.

Brecht has been interested in the neuronal basis of behavior since researching his diploma thesis at the University of California. In his doctoral thesis in the lab of Wolf Singer at the Max Planck Institute for Brain Research in Frankfurt, Brecht investigated temporal coding in the midbrain of cats. From 1999 to 2004, he led an independent research group in the department of Bert Sakmann at the Max Planck Institute for Medical Research in Heidelberg. After completing his habilitation thesis in 2004, he moved to the Neuroscience Department of the Medical Center in the Erasmus University Rotterdam as an assistant professor.

In his diploma thesis, Brecht addressed questions concerning the tactile perception of the rat and returned to this field after his doctoral studies – because of the “elegance of the system,” as he says. In the regions of the cortex where tactile stimuli are processed and the movement of vibrissae is controlled, each vibrissa is represented through an easily identifiable group of cells. This makes tactile perception a very good system to investigate structure-function relationships. In addition, tactile movements of the rat vibrissae are very simple compared to the coordination of arm or finger movements. Vibrissae can only be moved forwards or backwards and these movements can be quantified very precisely. “Through a combination of cellular data and measurements in the intact brain, we are gradually approaching a quantitative description of the whole network, which cannot be said for other brain regions,” says Brecht.

In experiments on living animals, Brecht investigated the contribution of a single cell to the movement program of the vibrissae. “It used to be an implicit assumption that the activity of very large groups of cell is required to trigger any movement,” explains Brecht. However, the results of a number experiments strongly suggested to Brecht and his colleagues that the cells

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in the motor cortex, which control movement, exhibit far less activity than previously believed. This observation led them to suspect that the activity of single cells could be far more meaningful than assumed. They stimulated single cells in the motor cortex and found that it did indeed induce a movement program – the rats moved their vibrissae. “There are over a million cells in the vibrissae motor cortex – it is quite astonishing that the animal reacts with a clearly visible and complex movement to slight activity in just one cell,” says Brecht.

In order to target individual cells in the brain more precisely than previously possible, Brecht uses modern microscopy technologies and has contributed to their improvement. Classical neurophysiological experiments in living animals are “blind”– the scientists stimulate cells or measure their activity without knowing which cell type they are looking at. The cells can only be identified in retrospect, if at all, by marking them and subsequently analyzing them in slice. This procedure is tedious; furthermore, investigations of rare or very small cells are not possible. With the help of two-photon microscopy, fluorescently labeled cells can be identified in situ in the brain of the living animal. Brecht has combined this technology with neurophysiological methods and developed the method of „two-photon targeted patching“ (TPTP). Through TPTP, it is possible to target fluorescently labeled cells in the living brain and measure their activity. “Such experiments have been carried out in tissue slices on cells identified under the microscope for about a decade. The ability to specifically record the activity of defined cells revolutionized the field of cellular brain physiology. It opened the door for an entirely different type of experiment,” explains Brecht. “We hope that TPTP has a similar potential and will enable new experimental approaches for investigations of the intact brain.”

Elite Graduate Program “Neurosciences” in Munich

The Elite Graduate Program was established within the framework of the “Elite Network of Bavaria” at the Ludwig-Maximilians-University (LMU) in Munich. With 33 different study programs, the Elite Network of Bavaria provides the very best working conditions for the advancement of highly qualified students. Several scientists from the Bernstein Center for Computational Neuroscience in Munich were involved in the conception of the graduate program in neurosciences. The speaker of the program is Benedikt Grothe, Director of the Department of Neurobiology at the LMU Biocenter. The prospective beginning of the two-year graduate program is 2007.

Both the rapidly growing knowledge of the molecular and cellular bases of neuronal activity and the dramatic progress in imaging neural activity in the living human brain have revolutionized the neurosciences. However, there is a significant gap in our understanding when it comes to linking molecular and cellular mechanisms underlying information processing to higher brain functions. The M.Sc. program “Neurosciences” aims at preparing a new generation of neuroscientists to work on a systemic / organismic level in order to bridge this gap. The program will therefore focus on systemic issues like information processing in complex neural circuits and their plasticity, linking experimental and theoretical approaches. In addition, the program will cover the issue of social end ethical responsibility in this context.

This elite graduate program is a central component of an integrated teaching and research program in neurosciences, including several institutes in and around Munich. Their expertises range from molecular and cellular biology via systemic and theoretical neuroscience to behavioral neurobiology and neurophilosophy.

Source / further Information:
http://www.elitenetzwerk-bayern.de/en/esg_neuro.html

Bernstein Centers at the “Germany in Japan 2005 / 2006” initiative

The Bernstein Centers presented themselves at the “Germany in Japan Symposium on Computational Neuroscience”, which took place in Tokyo between February 1st and 4th within the framework of the “Germany in Japan 2005 / 2006” initiative. The workshop was organized by the four Bernstein Centers for Computational Neuroscience in Berlin, Freiburg, Göttingen and Munich, the RIKEN Brain Science Institute in Tokyo and three further Japanese research establishments. Scientists met at the workshop to identify the most important future challenges in the field of computational neuroscience and to initiate collaborations between German and Japanese laboratories.

The goal of the initiative “Germany in Japan 2005 / 2006” is to establish an image of Germany as a dynamic, progressive and creative partner through a number of cultural events and scientific symposia in Japan. The initiative was supported by the Federal Ministry of Education and Research.

Further information:
http://www.bernstein-centers.de/de/235.php

"Bernstein Award" 2006

Young Scientist's Research Award in Computational Neuroscience.

The German Federal Ministry of Education and Research (BMBF) has established the "National Network for Computational Neuroscience" with four high-performing "Bernstein Centers for Computational Neuroscience" as the major structural elements.

The "Bernstein Award" is equipped with up to 1.25 Mio EUR in the form of a grant over a period of five years. It will be awarded to a highly qualified young researcher, considering the candidate's verifiable research profile in the field of computational neuroscience and the scientific concept for a future young research group. Young researchers can apply for their own position and group. The group funded by the "Bernstein Award" will become an integral part of the National Network for Computational Neuroscience. Future announcements of the "Bernstein-Award" are in the scope of the Ministry's planning.

The grant is provided for a scientific project of a young research group headed by a postdoc regardless of nationality. The project will be conducted at a German university or research institution – within or outside the Bernstein Centers. It is a prerequisite for funding that the respective university or research institution employs the young researcher during the funding period and supports him/her with the basic equipment in terms of laboratory space and other infrastructure. A statement made to that effect by the receiving institution must be included with the project outline to be submitted.

Source: http://www.bernstein-centers.de/en/278.php
For further information, please view:
http://www.bernstein-centers.de/en/273.php

Upcoming events: BCCN Symposium 2006

The second Bernstein Symposium for Computational Neuroscience will take place in Berlin from October 1st to October 3rd 2006. There will be four sessions with scientific talks from groups of the Bernstein Centers, poster sessions, a Bernstein Lecture on Sunday evening and a museum tour through the Jewish Museum Berlin just before dinner on Monday evening. In addition, the BMBF will award the "Bernstein Award 2006". Within the framework of the program, there will also be a PhD satellite symposium for all interested Bernstein PhD students and postdocs and a press writing workshop for interested Bernstein postdocs and advanced PhD students.

For more information and registration, please see:
http://bccn.neuroinf.de/meetings/symposium-2006/

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GEFÖRDERT VOM

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und Forschung