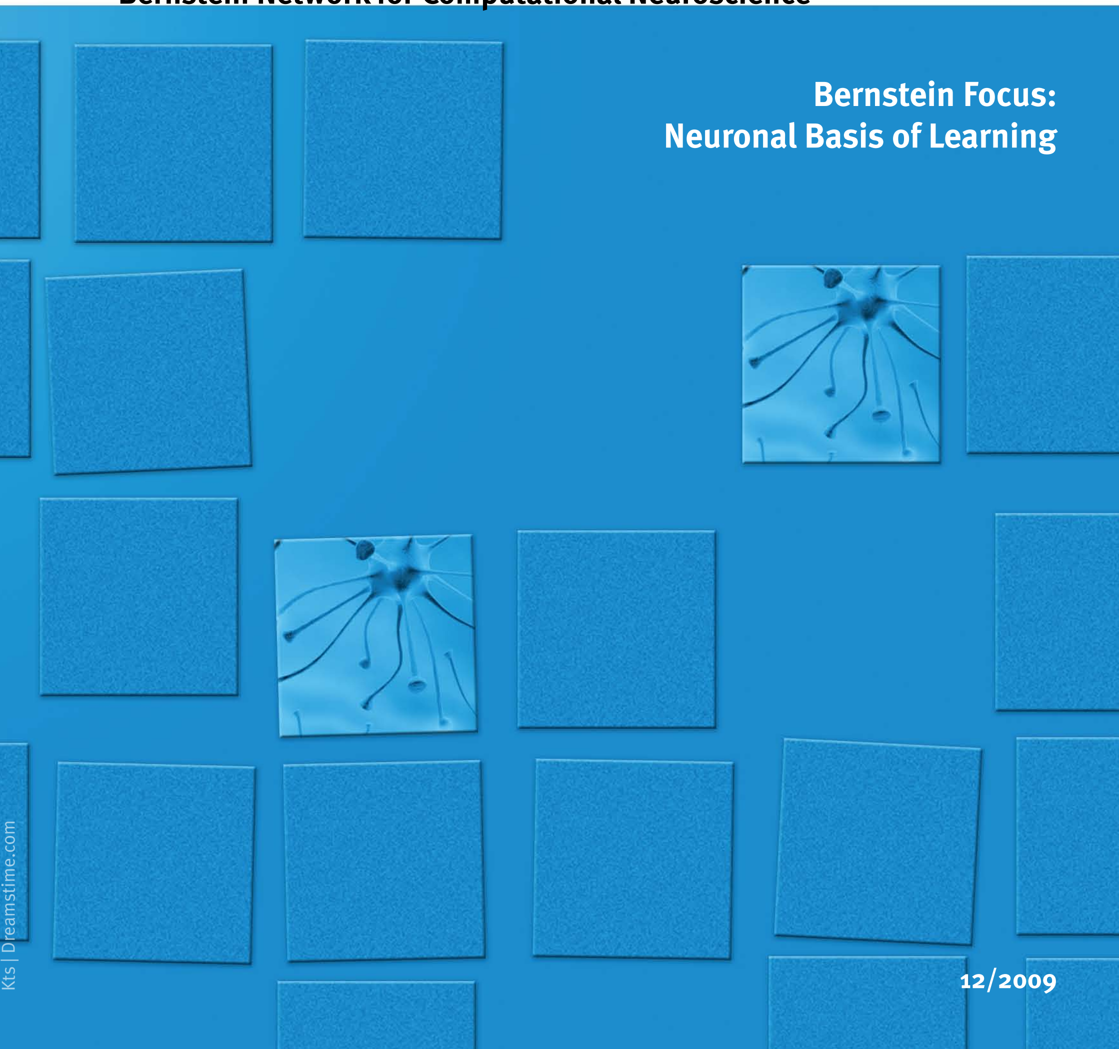
Bernstein Network for Computational Neuroscience

Bernstein Focus: Neuronal Basis of Learning



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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 and experienced throughout life.

With the new funding initiative „Bernstein Focus: Neuronal Basis of Learning“ the Bernstein Network 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. This booklet introduces the eight research projects.

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 projects however, have one common feature: a close cooperation between experimentalists and experts from theoretical neurobiology. The research results arising from the funding initiative will lead to new applications in the clinical field as well as in technology, as for example in the development of autonomous robots and driver assistance systems.

Complex Human Learning
(Coordinator: Christian Büchel)

Ephemeral Memory
(Coordinator: Hiromu Tanimoto)

Sequence Learning
(Coordinator: Onur Güntürkün)

Plasticity of Neuronal Dynamics
(Coordinator: Christian Leibold)

Memory in Decision Making
(Coordinator: Dorothea Eisenhardt)

State Dependencies of Learning
(Coordinators: Petra Ritter, Richard Kempter)

Learning Behavioral Models
(Coordinator: Gregor Schöner)

Visual Learning
(Coordinator: Siegrid Löwel)

How do we make decisions?

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Our life is a chain of decisions and every decision we make is based on what we have learned in the past. “The aim of our research project is to advance our understanding of decision processes by using computer models and the methods of neurophysiology,” says Christian Büchel, coordinator of the Bernstein Focus “Complex human learning” and researcher at the University Medical Center Eppendorf (UKE). How do we weigh alternative decisions? Why are we more likely to take an action leading to an immediate reward than an action leading to a positive result only in the far future? Moreover, the research of the Bernstein Focus shall help to better understand individual differences in decision making. Some people, for example, are more willing to take risks than others, and different persons show different degrees of flexibility when reacting to changes in the reward pattern. Which genetic factors influence the decision making behavior? How does decision making change with age? How is it influenced by medication?

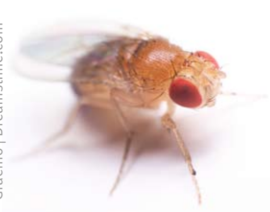
In order to answer these questions, experimentally and theoretically working neuroscientists closely collaborate within the Bernstein Focus. Using imaging techniques, brain activity is measured while subjects make decisions in behavioral experiments. Computer models help to quantitatively simulate and better understand the underlying neuronal processes. In the long run, the researchers hope to find new therapies for addictive disorders and age-related cognitive disorders. In addition, the investigation of decision processes plays an important role in economics. Stockmarket prices, for example, can better be predicted if the respective models take the decision behavior of the traders into account. In the joint research project, researchers of the UKE closely collaborate with researchers of the Technical University Berlin, Charité University Medicine Berlin, Max Planck Institute for Human Development and the Bernstein Center for Computational Neuroscience Berlin.

Coordinator: Christian Büchel (Universitätsklinikum Hamburg-Eppendorf), buechel@uke.de

Principal Investigators: Klaus Obermayer (Technische Universität Berlin), Tobias Sommer-Blöchl (Universitätsklinikum Hamburg-Eppendorf), Florian Schubert (Physikalisch-Technische Bundesanstalt Berlin), Shu-Chen Li, Ulman Lindenberger (Max-Planck-Institut für Bildungsforschung, Berlin), Hauke Haekeren (Freie Universität und Max-Planck-Institut für Bildungsforschung, Berlin), Andreas Heinz, Imke Puls, Jürgen Gallinat, Michail Plotkin, Jana Wrase, Michael Rapp (Charité Universitätsmedizin Berlin)

The short-term memory of the fly

During reading, our working memory enables us to keep the beginning of a sentence in our memory until we reach its end. Our working memory is responsible for storing information over short periods of time and helps us to orient ourselves in everyday life. Results from the research group of Hiromu Tanimoto, scientist at the Max Planck Institute for Neurobiology in Martinsried (near Munich) and coordinator of the Bernstein Focus “Ephemeral memory”, show that also flies have a very simple short term memory and can keep singular incidences in mind for a short time. In this joint research project, scientists investigate how sensory events can be stored in a brain over short periods of time, using the fruit fly *Drosophila melanogaster* as an example.



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If a fly is subjected to a particular scent for a short time and at the same time receives a small electrical impulse, it will learn to connect the scent to the negative event and henceforth avoid the scent. This form of learning is called classical conditioning. Classical conditioning, as Tanimoto showed, also works when the scent is followed by the electric impulse after a temporal delay, during which the fly has to hold the scent in its memory. Even if the electric impulse occurs only after the scent has already faded away, the fly will connect the scent with the event and avoid the scent from then on. The short term storage of sensory information that underlies this temporally delayed classical conditioning is referred to as “stimulus trace”.

Which nerve cells are involved in storing stimulus traces and how do they change during this process? How can these changes lead to a neuronal activity that keeps the scent alive in the brain? To answer these questions, the joint research project unites researchers from the experimental sciences and experts from the field of theoretical neuroscience, who will be engaged in data analysis and the development of computer models of the underlying network structures. Flies serve as a good model for investigating short-term memory due to their small and relatively simple brains. The basic mechanisms, though, are most likely applicable also to more complex forms of memory, like the short-term memory of higher animals and humans.

Coordinator: Hiromu Tanimoto (Max-Planck-Institut für Neurobiologie, Martinsried), hiromut@neuro.mpg.de

Principal Investigators: Andreas Herz (Ludwig-Maximilians-Universität München), Giovanni Galizia, Paul Szyszka (Universität Konstanz)

How do birds learn to sing?

Scientists of the Bernstein Focus "Sequence learning" address the question how complex tasks can be learned through repeated slight changes in the behavioral sequence. For this purpose, scientists investigate the development of the song system in songbirds, the navigation behavior of migrant birds and the learning of different motion sequences in birds and humans. The joint research project is coordinated by Onur Güntürkün, Ruhr-University of Bochum.

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Songbirds learn to sing in a similar way that people learn to speak – through a lot of practice and imitation. The neuronal circuits in the brain that underlie song learning are partly known already: Certain brain areas control the motor activity of singing. These brain areas are systematically influenced by other brain regions in order to slightly vary the singing each time. If this results in variants that are more similar to the singing of the tutor, the bird will be confirmed in its behavior and the underlying neuronal circuits will be consolidated.

Findings from the research on songbirds can probably also be applied to other learning procedures in animals and humans. Many behavioral patterns are based on an analogous neuronal system: a brain region that creates variability and a reinforcement system that strengthens the best of the possible variants. The scientists of the Bernstein Focus aim at a better understanding of the neuronal basis of such systems. Above all, there are two explanatory gaps to be closed: How can a simple feedback system that only distinguishes between "better" and "worse" form a neuronal system that creates such complex processes as the singing of a bird? How can the reward system influence an action that has long been completed when the reward is given? In order to be able to better interpret the data gained from the experiments and to transfer them into technical systems like robots, researchers from experimentally and theoretically working groups closely collaborate.

Coordinator: Onur Güntürkün (Ruhr-Universität Bochum)
onur.guentuerkuen@rub.de

Principal Investigators: Hubert Dinse, Martin Tegenthoff (Ruhr-Universität Bochum), Henrik Mouritsen (Universität Oldenburg), Klaus Pawelzik (Universität Bremen), Constance Scharff (Freie Universität Berlin)

Learning to hear without practicing

Humans are not born as "prefabricated" beings; we still have to acquire many skills. Also sensory perception must be learned; after birth our brain's ability to process sensory stimuli is not yet fully developed. It is only with time that we learn to tell different stimuli apart, which is essential for being able to cope with our environment. "Some studies, for example, reveal that, in children, the ability to distinguish sound stimuli and to learn to categorize them strongly correlates with their language development," says Christian Leibold, coordinator of the Bernstein Focus "Plasticity of neural dynamics" and researcher at Ludwig Maximilians University Munich.

Coordinator: Christian Leibold (Ludwig-Maximilians-Universität München) , leibold@bio.lmu.de

Principal Investigators: Felix Felmy, Benedikt Grothe (Ludwig-Maximilians-Universität München)

Every perception leaves traces in the brain – this is the basis for how we learn to hear and to see. The sensory organs translate light and sound into neuronal signals which are then transmitted from nerve cell to nerve cell within the brain. Thereby, the connections between the nerve cells changes – the perception is memorized in the brain. But how do such changes enable us to improve our hearing?

Using the acoustic perception of gerbils as an example, the scientists of the Bernstein Focus will examine how the animals learn to discriminate temporal stimulus properties of sounds. To this end, they examine the auditory midbrain – the brain structure that processes all acoustic information. How are the cells of the midbrain connected to each other, how does their activity change during the learning process? Every acoustic information we receive from our environment is represented in the spatio-temporal pattern of electrical impulses in groups of nerve cells. Which aspects of this pattern change when the gerbil learns to distinguish sounds? Within the Bernstein Focus, theoreticians and experimentalists collaborate. The results of the experiments are analyzed by means of computer-based methods. Computer models help to identify the parameters that are important for distinguishing sounds and to set up hypotheses about how this discrimination learning is achieved.

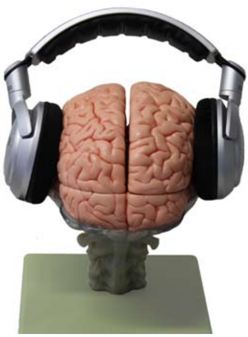

Foto: Kerstin Schwarzwälder

From bees to robots

"Every decision we make is based on our knowledge, i.e. on what we have learned in the past," explains Dorothea Eisenhardt, coordinator of the Bernstein Focus "Memory in decision making" and researcher at the Free University Berlin. The aim of the joint research project is to investigate the role of memory for decision making in insects and to then transfer the new insights to robotics. A bee or a fly, for example, learns to associate certain odors with a food reward and reacts correspondingly to the learned odors. How is learned information consolidated and stored in the brain, so that it can be retrieved in various decision making situations? How is different information, such as various odors, evaluated when the bee makes a decision?

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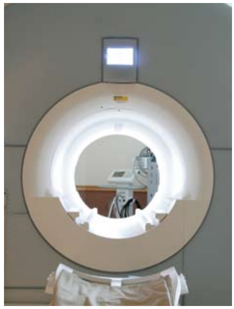
In a next step, findings from memory and decision making research are modeled and verified in computer simulations. "To date, computer simulation of neurobiological processes has mainly dealt with the problem of how information about the environment or behavioral instructions is represented in the nervous system. Constructing a network model that decides between various representations is new to the field" explains Martin Nawrot, who wil deal with these questions within the Bernstein Focus. In network models of this type, findings from behavioral biology are translated into a mathematical language that can then be implemented and tested in robots. In this way, robots are to gain the ability to modify their control structure through the interaction with their environment and to explore their surroundings spontaneously. But also basic biological research will profit from these research activities. "Results of these tests will lead to new hypotheses about the respective biological mechanisms and will stimulate new experiments," says Eisenhardt. The research fields of neurobiology, computer modeling, and neuroinformatics as well as artificial intelligence inspire each other and lead to a better understanding of the relationship between learning, memory, and the mechanisms of decision making.

Coordinator: Dorothea Eisenhardt (Freie Universität Berlin)
theodora@neurobiologie.fu-berlin.de

Principal Investigators: Randolf Menzel, Martin P. Nawrot, Raul Rojas (Freie Universität Berlin), Bertram Gerber (Universität Würzburg), Martin Riedmiller (Universität Freiburg)

Oscillations in the brain



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How and what we learn depends on the activity states of our brain. Depending on whether we sleep or are awake, whether we concentrate or doze, certain activity patterns predominate in the brain: Large groups of cells simultaneously send out impulses, which can be measured as oscillations in the electroencephalogram. It is a known fact that such oscillations play an important role in learning and memory. What we have experienced during the day, for example, is reactivated and consolidated during certain sleep phases – and this process is accompanied by oscillations. Moreover, throughout the day, various oscillations influence the way in which we recapitulate and memorize events. "Learning happens constantly and at different time scales," says Petra Ritter, researcher at the Charité University Medicine Berlin, who heads the Bernstein Focus "State dependencies of learning" together with Richard Kempter, Humboldt-Universität zu Berlin.

The long-term goal of this research is to develop improved learning strategies or rehabilitation procedures after a stroke or in brain disorders. It is known that in diseases like dementia or attention deficit/hyperactivity disorder (ADHD), oscillations in defined brain areas are altered. Possibly, learning abilities could be improved by interfering with oscillations. "Already today, there are private suppliers of devices that supposedly influence oscillations and by that facilitate learning. Scientifically, however, it has not been sufficiently clarified yet if such devices can really work and how far their potential will reach," says Ritter. The basis for this will be established by the Bernstein Focus.

In the joint research project, scientists of different disciplines collaborate in order to examine how oscillations and learning are connected. Different levels of complexity are covered: While some researchers deal with the question of how learning-related changes of nerve cells are associated with certain oscillations, others examine the connection between oscillations and the behavior of humans and animals.

Coordinators: Petra Ritter (Charité Universitätsmedizin Berlin) & Richard Kempter (Humboldt-Universität Berlin)
petra.ritter@charite.de, r.kempter@biologie.hu-berlin.de

Principal Investigators: Susanne Schreiber, Michael Brecht (Humboldt-Universität Berlin), Uwe Heinemann (Charité Universitätsmedizin Berlin), Hubert Dinse (Ruhr-Universität Bochum), Jan Born, Burkhard Pleger (Universität Lübeck)

Learning at different time scales

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The Bernstein Focus "Learning behavioral models" is coordinated by Gregor Schöner at the Institute for Neuroinformatics of the Ruhr-University Bochum and deals with complex human learning processes and their implications for robotics. The aim of the joint research project is to better understand how humans learn to generate goal-directed actions in naturalistic scenarios. Insights from these studies are then applied to robotics. How does acting in an environment change the brain? And how then, in turn, is perception influenced by what the person has learned in the past? Using behavioral experiments with humans as well as theoretical approaches, the scientists of the Bochum Bernstein Focus examine learning processes at very different time scales. They investigate learning from single events, as well as the question of how sequences and actions can be learned and consolidated in the brain during the course of development. The resulting learning models are then tested in robots that carry out specific tasks in a natural environment.

A group of scientists within the joint research project addresses the question of how people can memorize scenes and objects that they see only once. Another group deals with how movement patterns are learned from examples and how movement primitives can be put together into goal-directed behavior. Amongst other questions this subproject investigates human driving behavior – with the aim of developing driver assistance systems. A third project group addresses learning from the experience made during the lifespan. How is information selected in such a way that we can store movement sequences and predict the result of movement control? Apart from the scientists of Ruhr-University Bochum, industry partners of the NISYS GmbH (Bochum) and Schunck GmbH & Co. KG (Lauffen / Neckar) take part in the Bochum Bernstein Focus.

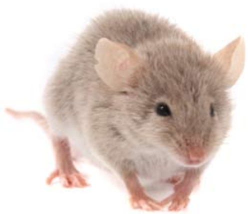
Coordinator: Gregor Schöner (Ruhr-Universität Bochum), Gregor.Schoener@rub.de

Principal Investigators: Ioannis Iossifidis, Christian Igel, Laurenz Wiskott (Ruhr-Universität Bochum)

Industry Partners: Hannes Edelbrunner (NISYS GmbH , Bochum), Andreas Hoch (Schunk AG, Lauffen/Neckar)

Learning after stroke

In Germany alone, every year approximately 200,000 people undergo a stroke. Fast intensive care saves the lives of many persons affected. But more than two thirds of the patients suffer from permanent damages. Scientists of the Bernstein Focus "Visual learning" investigate why learning is so arduous and often futile after a stroke. "We do not only aim at exploring the reasons for the brain's restricted ability to learn after stroke," says Siegrid Löwel from the University of Jena, who coordinates the research project. "In the long run, we wish to develop new therapies that help to recover the learning ability of the brain."



After oxygen shortage, not only the brain cells in the immediate vicinity of the stroke area are damaged. "From our own studies we know that also regions of the brain that are not immediately affected by the stroke suffer from a loss of plasticity," states Löwel. Plasticity in a neurobiological sense means the ability of brain cells to form new synapses with other neurons. This is the basis of every learning process.

With the help of experiments on mice, the researchers try to find out which non-local control mechanisms are responsible for the interaction of two distant areas of the brain. "The use of mouse models is particularly useful to study learning processes, for example visual learning," emphasizes Prof. Löwel. On the one hand, the visual system of mice is a well characterized animal model for the plasticity of the brain. On the other hand, within the framework of the project, the Jena researchers will for the first time combine two special imaging techniques that are available only at a handful of institutions worldwide: Firstly, optical imaging of nerve cell activity that allows to visualize activity patterns of the brain at a much higher spatial resolution than e.g. an MRI scanner, and secondly, in vivo 2-photon microscopy, which is able to additionally visualize the activity of single nerve cells.

Coordinator: Siegrid Löwel (Friedrich-Schiller-Universität Jena)
siegrid.loewel@uni-jena.de

Principal Investigators: Knut Holthoff, Christian Hübner, Otto W. Witte (Friedrich-Schiller-Universität Jena), Fred Wolf (Max-Planck-Institut für Dynamik und Selbstorganisation, Göttingen)

The Bernstein Network

Bernstein Centers for Computational Neuroscience (BCCN)
Berlin – Coordinator: Prof. Dr. Michael Brecht
Freiburg – Coordinator: Prof. Dr. Ad Aertsen
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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 – Coordinators: Dr. Petra Ritter, Prof. Dr. Richard Kempter
Learning Behavioral Models – Coordinator: Prof. Dr. Gregor Schöner

Bernstein Groups for Computational Neuroscience (BGCN)
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Dr. Matthias Bethge (Tübingen), Dr. Jan Benda (Munich), Dr. Susanne Schreiber (Berlin), Dr. Jan Gläscher (Hamburg)

Project Committee
Vorsitzender des Bernstein Projektkomitees / Chairman of the Bernstein Project Committee: Prof. Dr. Ad Aertsen
Stellvertretender Vorsitzender des Bernstein Projektkomitees / Deputy Chairman of the Project Committee: Prof. Dr. Theo Geisel

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Translation, English Language Editing: Meike Höpfner, Simone Cardoso de Oliveira, Katrin Weigmann

Coordination: Simone Cardoso de Oliveira: info@bcos.uni-freiburg.de, Kerstin Schwarzwäler

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