



Bernstein Centers for Computational Neuroscience

BCCN Newsletter



Recent Publications

Regeneration – Network
Structures – 15 Publications



Meet the Scientist

Leo van Hemmen



News and Events

Coordination Office for the
Bernstein Network

08/2007





RECENT PUBLICATIONS

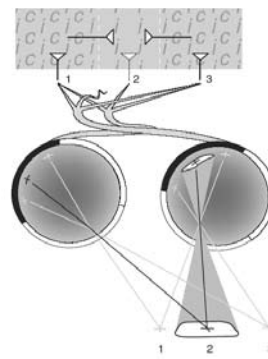
How does the brain create its structure?

Scientists investigate the principles of regeneration

The cognitive abilities of an individual depend on the connections that are formed between the neurons of the brain. Not only during development, but throughout adult life, new neuronal connections are formed and others are lost. As part of an international collaboration, researchers at the Bernstein Center for Computational Neuroscience Berlin have elucidated an important principle underlying these changes in neuronal connectivity. The work, which was conducted by Joshua Young and Klaus Obermayer from the Berlin University of Technology together with colleagues from Australia and Poland, has implications for understanding fundamental processes underlying development, as well as how the brain reorganizes in response to injuries.

The brain is a complex network of neurons that communicate with each other via electro-chemical signals. Every neuron receives signals from a multitude of upstream neurons and integrates this input in order to decide whether to send out its own signal. When neuron A sends an impulse which elicits a response in neuron B, the contact from A to B is strengthened. This increase in the strength of the connection leads to an increased responsiveness of neuron B to input from neuron A. Through this process cell B begins to adopt cell A's pattern of activity. Because this transfer of activity pattern is asymmetric the researchers have labelled the phenomenon as 'didactic reorganization'.

A brain lesion induces a fundamental reorganization of the connections in the surrounding area. A reorganisation of connectivity is also observed within brain tissue that has undergone a partial loss of input. By analyzing the responses



Schematic representation of the experimental setup. After lesion of the retina in region 2, the visual cortex lacks the respective input signal, leading to a neuronal reorganization.

of the neurons to visual stimuli the scientists have investigated how neurons of the visual cortex reorganize their connections in response to the inactivation of a small area of the retina. By comparing these experimental results with those of computational models clear evidence was produced indicating that this connectivity was a consequence of didactic reorganization.

The visual cortex is the primary brain region for analyzing visual signals. Due to the retinal inactivation, neurons in a small circumscribed zone of the visual cortex lose their 'direct' input from the retina. As a consequence of this loss of input, the ability of these neurons to propagate signals originating from those that still receive direct input from the retina is greatly increased. It is this enhancement that allows the effects of didactic reorganization to be clearly demonstrated, as in the case of this study. However, the scientists suspect that didactic reorganization occurs during the modification of neuronal connections in the intact brain as well.

As a fundamental process, this discovery is likely to be very important for understanding how basic neuronal circuits emerge during development. The processes that are active during development seem to re-emerge during adult repair and recovery, thus it is possible that didactic reorganization occurs any time cortical neurons begin to reorganise their connectivity. If so, understanding this phenomenon will be essential for developing better treatments for people who suffer from problems like a cerebral stroke or retinal degeneration.

Source: Young, Waleszczyk, Wang, Calford, Dreher & Obermayer (2007): Cortical reorganization consistent with spike timing- but not correlation-dependent plasticity. *Nature Neuroscience* 10(7):887-895.



Who's with whom?

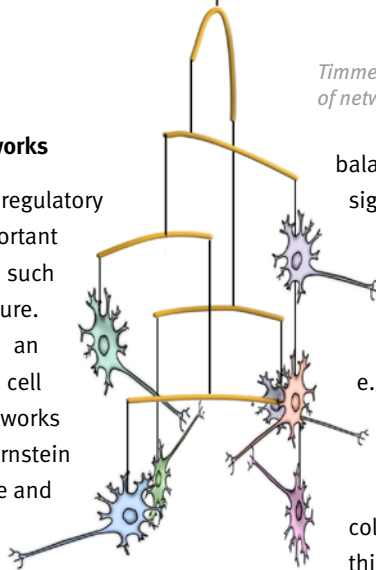
Identifying circuitry structures of networks

The mathematical analysis of regulatory networks is becoming increasingly important in different fields of biology, because such networks exist everywhere in nature. Species of animals and plants in an ecosystem, genes and proteins in a cell or neurons in the brain constitute networks of interacting units. Marc Timme, Bernstein Center for Computational Neuroscience and Max Planck Institute for Dynamics and Self-Organization in Göttingen, has now developed a mathematical method to infer the circuitry structure of a regulatory network from its dynamical response properties. The implementation of this theoretical method can make it possible to determine the exact connections between the units of a network – for example, the interaction between the molecules of a cell or the synaptic connections in a neuronal network.

As a precondition, Timme's method requires that the network is in a stable, balanced equilibrium, similar to that of a mobile toy in a balanced state. If a small weight is carefully attached to a figure of the mobile, the other figures will consequently move upwards or downwards. Timme has shown how the structure of a network can be determined by studying these alterations – not necessarily for mobiles, but for regulatory networks in general.

In nature, we find many regulatory network systems, for example, for generating the recurring pattern of activity when breathing or when the heart beats. If a neuronal network is fed somewhere with an external signal, a new, slightly shifted

Timme has developed a method to determine the connectivity structures of networks that are in stable equilibrium - just as a balanced mobile toy.



balance is restored – that is, some neurons now transmit signals later, some earlier. Timme showed how every single connection of the network's structure can be determined by studying its responses in a number of similar experiments. Up to now mathematical analysis methods have mainly allowed for statistical assertions, e.g. about the percentage of connected units or the expected strengths of the connections.

“To reconstruct the entire network we need to collect sufficient information”, Timme explains, “in general this means that the number of different experiments needs to equal the number of all components of a network.” In reality, regulatory networks consist of thousands or millions of components, making a recording of the responses of a network to a large number of signals practically impossible. A further significant step in Timme's method nonetheless allows to determine the structure of even very large networks with just a moderate number of experiments. Nature normally arranges its network units very efficiently such that a desired function can be accomplished with a minimal number of connections. Timme shows how to reconstruct the structure of a sparsely connected network with a number of experiments far fewer than the number of components in a network. The novel method provides researchers with the basic principles for a potential future tool to systematically investigate the interdependences between structure and function of regulatory networks.

[Timme, M. \(2006\). Does dynamics reflect topology in directed networks? *Europhysics Letters* 76 \(3\), 367–373](#)

[Timme, M. \(2007\). Revealing Network Connectivity From Response Dynamics. *Physical Review Letters*, 98:224101](#)

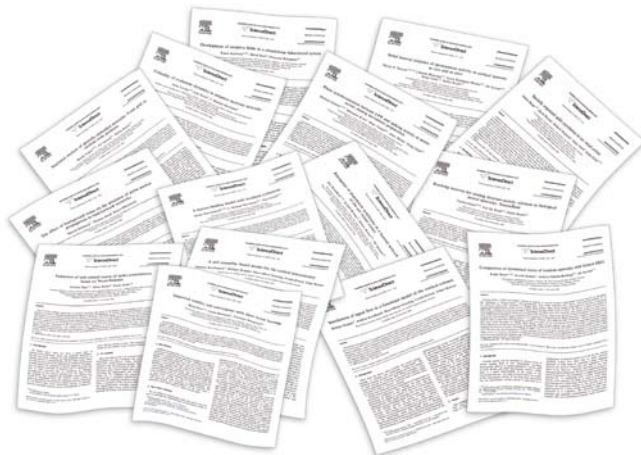


15 In One Fell Swoop

15 Reports from BCCN Scientists have been published in a special edition of 'Neurocomputing'

For over 15 years the 'Computational Neuroscience Meeting' has been an international forum for exchanging scientific results in this interdisciplinary area of research. Around 400 scientists met at last year's meeting in Edinburgh (Scotland). Their articles were submitted for publication in the magazine 'Neurocomputing'. Following a review process the magazine has published 100 articles in a special edition in June 2007 under the title 'Computational Neuroscience: Trends in Research 2007'. From all these articles, a total of 15 are authored by scientists from the Bernstein Centers for Computational Neuroscience. How does the brain encode information? How are the structure and function of neuronal networks linked? These are amongst some of the questions which are discussed in the publications.

Neurons send information by firing electrical impulses. The brain enciphers the information in the spatiotemporal patterns



of their discharges. By using a network model Stimberg et al. (1) have investigated how this information can be reliably transferred in the face of constant background noise.

How information in the spatiotemporal patterns of neuronal discharges is encoded remains a big puzzle. Equally important is the question of how the observed neuronal activity patterns come about. How, for example, does the readiness of a neuron to fire depend on the dynamic of the last impulses (2)? This question was experimentally researched by Nawrot et al. (2) at the level of individual cells. How is the structure of the brain related to the activity which it produces? Gürel et al. (3) have developed a method to show how the features of a simulated network can be used to derive a prognosis about its activity. Short outbursts of such neuronal discharges, called 'neuronal avalanches', could be observed through multi-electrode recordings in neuronal cultures. Levina et al. (4) have investigated how such discharges can come about in a network model with feedback connections.

In two articles scientists have examined the link between structure and function in the sensory and motor areas of the cerebral cortex using the example of the neocortex. In simulations using a formal model they show how the cortex affects saccades in order to direct attention to new object parts. With this model they can explain how the structure of the neocortex can generate object recognition or classification (Kupper et al., 5; Knoblauch et al., 6).

Synchronous waves often occur in the brain when groups of neurons fire simultaneously. With the aid of an improved analysis technique Pipa et al. (7) were able to confirm that during the planning of movement, synchronous discharges take place mainly in phases which are relevant for behavior. In comparable data Denker et al. (8) could demonstrate that the firing of individual



RECENT PUBLICATIONS

cells shows an increased synchronization in correlation with the field potential, the summed potential generated by several cells. Different features of an object, for example visual und acoustic, are analyzed in different areas of the brain. Synchronous waves are also responsible for putting together these pieces of information. The phenomenon, known as ‘feature binding’ was studied by Schrobsdorff et al. (9).

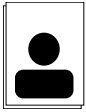
The subject of how synchronous waves originate has been researched by more BCCN scientists. Are experimentally observed synchronous neurons arranged in a certain spatial pattern (Berger et al., 10)? So-called ‘hubs’ in the network model – neuronal connections with many recurrent connections – could be the source of network wide synchronization waves (Kremkow et al., 11). The way in which these hubs are dispersed in the network has a strong influence on its dynamics (Voges et al., 12).

Needless to say, a better understanding for the basics of the network structure and its dynamics also has its uses. Scientists from Freiburg studied how more information can be extracted from electroencephalograms when aspects such as the synchronicity or irregularity of the activity patterns are taken into account (Meier et al., 13).

Last but not least, scientists from the Göttingen BCCN have also explored various learning models and tested them with robots. So-called receptive fields in the visual system can develop through learning rules, in other words, neurons which only react to stimuli from a specific part of the visual field. This was demonstrated with a robot which learnt to follow a line (Kulvicius et al., 14). The scientists illustrated the relevance of a ‘neuromodulator’ with another learning robot which could mirror the activity of a so-called dopaminergic neuron and influence the learning aptitude of an individual neuron (Porr et al., 15).

Source: *Neurocomputing* 70 (10-12), 1595-2138 (June 2007)

1. *Stimberg, M., Hoch, T. & Obermayer, K. The effect of background noise on the precision of pulse packet propagation in feed-forward networks. 1824-1828*
2. *Nawrot, M.P., Boucsein, C., Rodriguez-Molina, V., Aertsen, A., Grün, S. & Rotter, S. Serial interval statistics of spontaneous activity in cortical neurons in vivo and in vitro. 1717-1722*
3. *Gürel, T., De Raedt, L. & Rotter, S. Ranking neurons for mining structure-activity relations in biological neural networks: NeuronRank. 1897-1901*
4. *Levina, A., Ernst, U. & Herrmann, M.J. Criticality of avalanche dynamics in adaptive recurrent networks. 1877-1881*
5. *Kupper, R., Knoblauch, A., Gewaltig, M., Körner, U. & Körner, E. Simulations of signal flow in a functional model of the cortical column. 1711-1716*
6. *Knoblauch, A., Kupper, R., Gewaltig, M., Körner, U. & Körner, E. A cell assembly based model for the cortical microcircuitry. 1838-1842*
7. *Pipa, G., Riehle, A. & Grün, S. Validation of task-related excess of spike coincidences based on NeuroXidence. 2064-2068*
8. *Denker, M., Roux, S., Timme, M., Riehle, A. & Grün, S. Phase synchronization between LFP and spiking activity in motor cortex during movement preparation. 2096-2101*
9. *Schrobsdorff, H., Herrmann, M.J. & Geisel, T. A feature-binding model with localized excitations. 1706-1710*
10. *Berger, D., Warren, D., Normann, R., Arieli, A. & Grün, S. Spatially organized spike correlation in cat visual cortex. 2112-2116*
11. *Kremkow, J., Kumar, A., Rotter, S. & Aertsen, A. Emergence of population synchrony in a layered network of the cat visual cortex. 2069-2073*
12. *Voges, N., Aertsen, A. & Rotter, S. Statistical analysis of spatially embedded networks: From grid to random node positions. 1833-1837*
13. *Meier, R., Kumar, A., Schulze-Bonhage, A. & Aertsen, A. Comparison of dynamical states of random networks with human EEG. 1843-1847*
14. *Kulvicius, T., Porr, B. & Wörgötter, F. Development of receptive fields in a closed-loop behavioural system. 2046-2049*
15. *Porr, B., Kulvicius, T. & Wörgötter, F. Improved stability and convergence with three factor learning. 2005-2008*



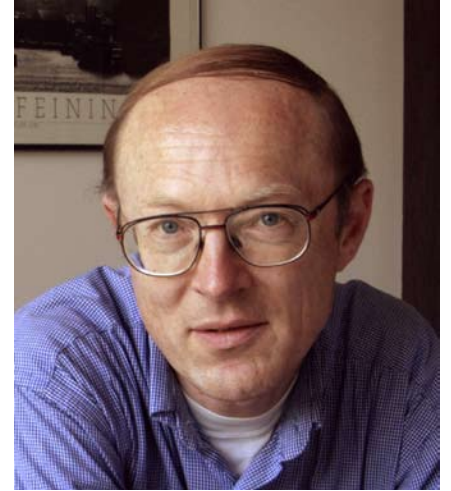
MEET THE SCIENTIST

Leo van Hemmen

Discovering universal laws of biology

From the sense of hearing of birds to the lateral line organ in fish and on to the infrared vision of snakes, there is an almost infinite number of strategies by which different animal species obtain information about their surrounding. Nonetheless, the function of the sense organs is based on the same general principles. “There is a universality in the mathematical laws which underlie biology,” says Leo van Hemmen. Discovering these universal principles is the goal of his research. He likes to refer to his field of studies as “theoretical neurosciences”, in accordance with the term of “theoretical physics”. “While in physics basic mathematical laws have already essentially been formulated, these are still to be discovered in biology,” says van Hemmen, “it is in large parts still virgin territory.”

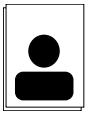
The mathematical description of a learning rule for neurons, which van Hemmen and his colleagues formulated in a seminal publication in 1996 in the scientific journal *Nature*, today forms the basis of our understanding of the processes underlying learning at the cellular level. The connection between two neurons can be strengthened by their activity, thus nerve tracts are consolidated, when frequently used. The learning rule states that the crucial factor in this process is the exact timing of the impulses sent out by the two neurons relative to each other. Computational Neuroscience today would be unthinkable without this principle of “spike-time-dependent-plasticity” (STDP), as it was later called. “The basic idea of STDP occurred to us after the PhD work of Andreas Herz in summer 1990; it was then formulated in the dissertation of Wulfram Gerstner,” says van Hemmen. The idea then matured with the question, how sound localization develops in the barn owl. Van Hemmen and his



colleagues could show how the “correct” synapses form through STDP to enable sound localization.

Today, the group of van Hemmen explores the sensory systems of frogs, fish, snakes and scorpions. “We investigate systems that are simple enough to understand and complex enough to generate a fascinating behavior,” says van Hemmen outlining his research interests. The visual, the auditory and many other sensory systems map the animals surroundings onto its brain so it can locate prey and enemies. The process results in a topographically ordered neural representation – objects that are next to each other in nature will also be found in adjacent locations of the neuronal map. How neuronal circuitry leads to an internal map of the acoustic perception of the barn owl is well established – thanks to, amongst others, research done in the department of van Hemmen.

In contrast to what is generally believed, snakes are not deaf, though they do have a fundamentally different way of hearing. Instead of using their ears to perceive sound waves in the air, they detect vibrations in the sand that indicate the approach of potential prey. When snakes lay their head down on the sand, their two loosely connected lower jaws swing on these vibration waves like two boats on the sea. Each of the lower jaws is connected to an ear, where sensory cells are stimulated by the small movements of the jaws. Scientists in van Hemmen’s



MEET THE SCIENTIST

group have for the first time shown that this stimulation not only enables the snake to hear, but also to locate sound.

When the clawed frog on its nightly hunt lurks in the water, it detects its prey with its lateral line organ. A fly dropping onto the water surface triggers small waves, which run over the 180 sensors of the frog's lateral line organ. These sensors topographically map to the frog's brain. In this way, although the frog cannot see in the dark, it is able to locate its prey. Nonetheless, the visual sense is important; every interference with the development of vision also has an impact on the lateral line organ. "Perhaps, the major function of vision is to instruct the development of the lateral line organ," says van Hemmen. How precisely the frog can locate its prey and whether it takes its distance into account is as yet unknown. "It does have a very wide mouth. So maybe there is quite a lot room for error," van Hemmen says jokingly.

With their pit organ some snake species can perceive infrared radiation and detect their prey in darkness based on its body temperature. The function of the pit organ is another topic of interest in the department of van Hemmen. It consists of a freely suspended membrane in a cavity, isolated by air, which detects

infrared radiation. As it needs to be able to detect very weak signals, the opening of the pit organ is relatively wide. Just as taking a picture with a camera with the aperture wide open will result in a blurred image, the same holds true for the image that falls onto the pit membrane. Scientists at van Hemmen's institute have developed a mathematical model to explain how the snake can nonetheless reconstruct a sharp image from the information received by the pit organ.

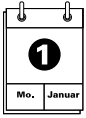
Not only is van Hemmen's research triggered by fascination with the creations of nature, he also aims to translate results into technical applications. Robots that can see or hear are a promising field of development. But other sense organs can also greatly benefit the world of technical systems. The pit organ of the snake still out-competes every current technical system by a factor of 10 at room temperature. If cars could, for example, detect pedestrians crossing the street at night using a similar system, this would greatly contribute to road safety.

"When scientists leave my research group, they often take the topic they were working on with them," says van Hemmen, "I do not want to be in competition with them." Van Hemmen then continues to avail himself of the inexhaustible repertoire of sensory systems provided by nature. This is the reason why the first basic insights into numerous sensory systems have been gained in his group. In this way, van Hemmen is constantly collecting new examples, whose mathematical foundations he determines. "Universal principles are revealed on the basis of examples," he says.



With the help of its lateral line system, the clawed frog (Xenopus) registers water movements. Photo: Peter Halasz

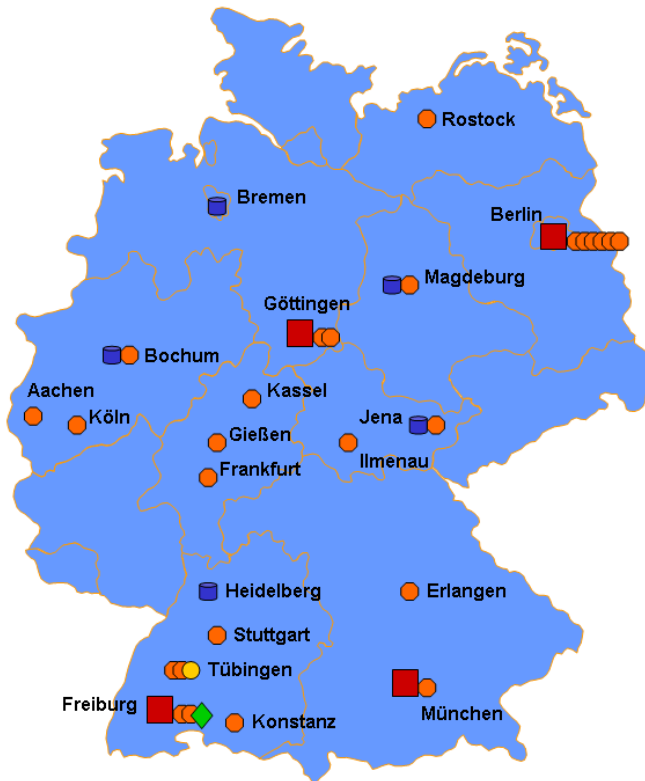
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Coordination Office for the Bernstein Network

A new Coordination Office for the National Network Computational Neuroscience (NNCN) will be instantiated at the Bernstein Center for Computational Neuroscience in Freiburg as of September 1st 2007. The National Network, which is funded by the Federal Ministry of Education and Research, has grown rapidly over the last years. Meanwhile, it consists of the four Bernstein Centers, five Bernstein Groups, eleven Bernstein-Partner-Projects and one Bernstein Junior Group. In the future, the NNCN will expand further, most notably through the envisioned establishment of up to five Bernstein Centers for Neurotechnology in Germany.

One of the main tasks of the NNCN is to support the collaboration between its members and to contribute to their visibility. Beyond that, the Coordination Office will serve as a liaison body between the Federal Ministry of Education and Research, the Project Management Agency in the German Aerospace Center and the NNCN.



- Bernstein Zentrum / Bernstein Center
- Bernstein Gruppe / Bernstein Group
- Bernstein Kooperationen / Bernstein Collaboration
- Bernstein Preis / Bernstein Prize
- ◆ Bernstein Koordinationsstelle / Bernstein Coordination Office

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Title Image: Tempel Viper. Directly in front of the eye and behind the nostril lies the pit organ, which enables the snake to detect infrared radiation (see page 11). Photo: Guido Westhoff

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