Bernstein Network for Computational Neuroscience

Bernstein Newsletter

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Nerve Cells Pay Attention to their Neighbors – No Chinese Whispers – Precise Signal Transmission in the Brain

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07/2010

Nerve cells pay attention to their neighbors

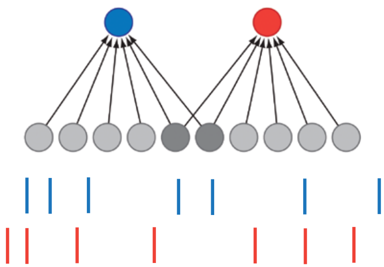
In an orchestra, the entries of the individual instruments must be very precisely coordinated. Also in the brain, the activity of billions of nerve cells (neurons) is “correlated”, as it is called in neuroscience. Only in this way, the brain can accomplish such amazing achievements as reading or listening to music. Despite the central importance of neural correlations, it has not been clarified yet how and under which conditions they occur. Scientists around Fred Wolf from the Bernstein Center for Computational Neuroscience and the Max Planck Institute for Dynamics and Self-Organization in Göttingen have developed a mathematical formula to precisely predict how and when neurons synchronize.

Each neuron in the cerebral cortex receives information from approx. 30 000 other cortical neurons and – in response to this – sends individual neural impulses. At least theoretically, a simple relation between input signals and neural response is conceivable: If, for example, two neurons share 1/10 of the input signals, 1/10 of their response signals would be the same as well. But neurons do not calculate that simply. Neurons receive a large number of electrical input signals which result in random membrane voltage fluctuations. When the membrane voltage reaches a threshold value the neuron sends out a signal. The Göttingen scientists investigated how the statistics of input and output signals are actually related, taking into account this mode of neuronal operation. They managed to summarize the neural conversion from input signals into output signals in a relatively simple mathematical formula.

As the researchers were able to show, the correlation of the response signals of two nerve cells depends not only on how similar the respective input signals are, but also on how active the cells are. If neurons send out many signals in rapid succession (their activity, the so-called firing rate, is high) also the response signals are more strongly correlated. However, this only applies if the neurons share just a fraction of their input signals. The rules change drastically if neurons are largely stimulated by common input signals and correspondingly produce similar response signals. In this case, the firing rate is no longer important. The scientists were able to directly experimentally confirm these theoretical predictions by stimulating cells with computer-simulated brain currents and measuring their response signals.

Moreover, this novel theoretical concept introduced by the Göttingen scientists offers a glimpse at how the cognitive information processing in the brain might work. For a long time, neuroscientists have been discussing the question of how the brain encodes information in the electrical activity of neural signals. In some cases, the firing rate seems to be crucial, in other cases it is the exact timing of a neural impulse in relation to other signals. In their work, the Göttingen scientists and their colleagues now demonstrated how closely these two concepts of neural coding are connected and which theoretical description can capture the sensory processing.

Tchumatchenko, T., Malyshev, A., Geisel, T., Volgushev, M. & Wolf, F. Physical Review Letters, Vol.104, No.5

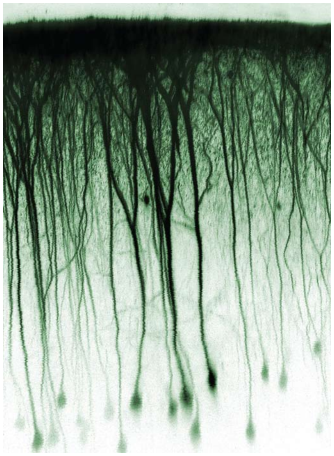


Two neurons (red, blue) receive partially overlapping information from upstream cells. The response signals of the neurons, depicted as a sequence of bars, are correspondingly also partly synchronous.

No chinese whispers in the brain

You hear squealing tires, see a car coming closer from the corner of your eyes and quickly jump back onto the sidewalk. The brain is able to process large amounts of information in a blink of the eye. Scientists around Matthias Bethge, Max Planck Institute for Biological Cybernetics and Centre of Integrative Neuroscience in Tügingen, and Andreas Tolias, Baylor College of Medicine (USA), have shown that adjacent cells in the brain work more independently than previously assumed. This could imply that information processing in the brain is by far more efficient than previously thought.

Every image that reaches the retina is processed successively at different hierarchical levels of the brain. Nerve cells forward information in the form of electrical signals, so called action potentials – they are said to "fire". However, if a subject is shown the same image a number of times, the neurons will fire differently each time. Therefore, part of the neural activity is independent of the visual stimulus. Until now, it has been assumed that those stimulus-independent action potentials often occur simultaneously in adjacent cells, since they are tightly coupled within the neural network. This would be problematic, though: the more strongly the cells are correlated, the stronger the stimulus-independent fluctuations become and the more difficult it is for the brain to differentiate between relevant and irrelevant information.



Ecker, Reimer, Tolias / MPI f. Biol. Kybernetik

Neurons connect to each other via long extensions.

"We have developed a method to measure action potentials more precisely," said Alexander Ecker, doctoral student at the Max Planck Institute for Biological Cybernetics and the study's first author. The researchers showed different images to trained rhesus monkeys while they measured the activity of several neighboring neurons. By utilizing a new combination of measuring technique and test design, the German-American team of scientists succeeded in demonstrating that closely located neurons react much more independently than previously assumed.

"Our findings suggest that the relay of neurons in the brain is organized such that their activities become decorrelated," says Ecker. That means that, although all neurons receive similar information, each cell processes and transfers it differently. This mechanism possibly serves to simplify and improve the interaction among the neurons when processing signals. "Information processing in the brain is a lot simpler when the neural activity is not correlated. If one hierarchical level wants to know what the other one is doing, it does not have to subtract out the correlations," said Andreas Tolias.

"Our insights shed new light on previous models of the cortex's structure. If we know how a healthy brain works, this might help us to better understand the brains of epileptics or autists in the future," hopes neuroscientist Ecker.

Source: Ecker, A. S., Berens, P., Keliris, G. A., Bethge, M., Logothetis, N.K., Tolias, A.S. Decorrelated Neuronal Firing in Cortical Microciruits. Science. 2010 Jan 29;327(5965):584-7

Precise signal transmission in the brain

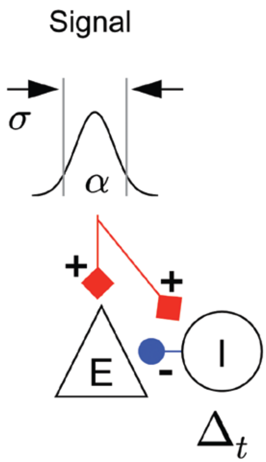
In sensory perception, the brain processes information step by step in successive layers. Neurons in a given layer send signals – in the form of electrical impulses – to the next layer. There are two types of signals: those that activate downstream cells (excitatory signals), and those that suppress their activity (inhibitory signals). The latter may sound paradoxical at first: why should the brain invest energy to inhibit its own activity? Jens Kremkow and Ad Aertsen of the Bernstein Center Freiburg and the Faculty of Biology at the University of Freiburg, together with colleagues from Marseille (France), have used computer models to systematically investigate the role of inhibitory connections in the information processing by the brain. They show that inhibitory connections strongly promote precise signal transmission.

A nerve cell often receives excitatory as well as inhibitory signals from the same upstream structure, with the inhibitory signal lagging a few milliseconds behind the excitatory one. This is caused by a defined circuitry scheme, the so-called "Feed Forward Inhibition" (FFI). In their study, the researchers investigated the influence of FFI on signal transmission within the brain – both at the level of single cells and in more complex networks.

FFI causes individual nerve cells to work like filters for simultaneous signals. This effect has a straightforward explanation and can be understood without computer modeling. Each nerve cell receives input signals from thousands of upstream cells, and "adds them up". Only if a certain threshold value is reached, it sends out a signal itself – one says, the neuron "fires". If each excitatory signal is followed by an inhibitory one, the threshold is hardly ever reached. The cell only has a chance to fire if a large number of excitatory signals comes in simultaneously, such that the threshold is reached before the inhibitory signals arrive. For the transmission of information within the brain, such a filter for simultaneity can be quite valuable, since sensory inputs may lead to synchronous – i.e. simultaneous – activity of nerve cells in the brain; these are then preferentially transmitted.

In the nervous system, signals are transmitted by groups of nerve cells in recurrent networks, from layer to layer. In computer simulations, the Freiburg scientists investigated how FFI influences signal transmission in such structures. They found that, also in this context, FFI leads to a selective transmission of synchronous signals – asynchronous signals are filtered out. In addition, the investigators showed that inhibitory signals keep the background activity of the network into which the neural connectivity scheme is embedded in a state that is favorable for signal transmission. Thus, taken together, inhibition in the form of FFI allows synchronous signals to be more effectively and selectively transmitted in the brain.

Kremkow, J. Perrinet, L.U., Masson, G.S. & Aertsen, A. J Comput Neurosci. 2010 Jun;28(3):579-94



The signal reaches the downstream cell (E) once through a direct, excitatory connection and once, indirectly, through an inhibitory interneuron (I). This short detour via (I) is responsible for the time lag. α: signal strength; σ synchrony of the signal.

Meet the Scientist

Stefan Treue

Pioneer of attention research

It very rarely occurs in science that new insights abandon previous common beliefs and start a whole new school of thought. Such an insight announced itself to Stefan Treue, today Director of the German Primate Center in Göttingen, as a crackling noise. When scientists carry out electrophysiological experiments, they usually monitor the neuronal impulses produced by the nerve cell under investigation through loud speakers. In the 1990s, as a postdoc in the laboratory of John H.R. Maunsell at Baylor College of Medicine (Houston, USA), Treue investigated the neuronal basis of visual attention and measured the brain activity of macaque monkeys in the region "MT". Nobody would have expected that cells in this area would be influenced by non-sensory processes like attention. It was commonly accepted that attention is a process that would exclusively affect higher brain areas – and MT is part of the earlier steps in the processing chain of visual information. The crackling noise, though, spoke a different language. "The first thought, of cause, is: what is going wrong?" Treue remembers today. "But the acoustic signal is pretty unambiguous – there is not much room for interpretation".

In his experiment, Treue investigated the effect of attention in two brain areas that process motion information – MT and MST. The latter was the main object of analysis – MT was merely intended as a reference measure, since no effect was expected here. The activity of single neurons was investigated in the brain of macaques, while they were looking at the center of a screen and at the same time paying attention to moving dots in the periphery of the screen. Neurons in MT that processed visual information in the attended region reacted far more strongly than cells that were in charge of a other parts of the visual field, indicating that the cells were influenced by higher cognitive processes like attention. Further studies confirmed these new findings and eventually a clearer picture of visual information processing emerged: Already in the first steps of visual processing, our brain neglects information that is irrelevant to us. We therefore see better in the parts of the visual field that we pay attention to.

Treue did his PhD at the Massachusetts Institute of Technology in Cambridge, USA, followed by a postdoc in the group of John Maunsell, where he began to study attention. Subsequently, he set up a research group in Tübingen (Germany) and finally, in 2001, became Director of the German Primate Center and Professor for Cognitive Neuroscience at the Georg August University in Göttingen. Also here, Treue continues to work on attention processes. Spatial attention – the process Treue initially addressed – has a lot to do with the control of eye movements. Generally, when something in the periphery of our visual field catches our attention, we will turn our eyes towards it. Treue's current scientific interests also include other forms of attention. We can pay attention not only to a defined region of the visual field, but also to certain features, like color, form or direction of movement. Searching a book shelf for a small yellow book or a large red book will lead to the same image on the retina. But, as newer studies of Treue and colleagues suggest, the visual processing in the brain will depend on which features one is looking for.

Not only can one distinguish between spatial and feature-based attention, but also between voluntary and reflexive shifts in attention. Attention can be controlled consciously. In addition, certain visual stimuli – a sudden flash of light or a swift movement in the corner of the eye – can attract reflexive attention. Studies by Treue and colleagues show that these two forms of attention are based on different neuronal circuits: reflexive shifts in attention are significantly faster than voluntary ones.

Are these different forms of attention based on different neuronal mechanisms? “I only believe that in my most pessimistic moods,” says Treue. “As a reductionist, I rather think that attention is such a fundamental process and the different forms of attention need to be so well-orchestrated that they should be based on the same underlying mechanism”. How attention arises and how it controls visual processing is a question that Treue and his colleagues will address in future. Voluntary decisions are made in the frontal parts of the brain – and Treue’s research focus is now moving towards these regions.

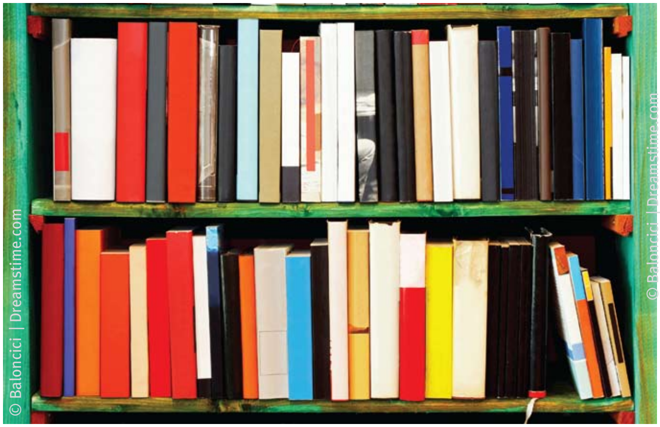


Image processing in the brain depends on which features we focus our attention on: e.g. whether we search a shelf for a small yellow or a tall red book.

Many children suffer from Attention Deficit Hyperactivity Disorder (ADHD). The exact cause of this disorder is still unknown. One goal of Treue’s work is to shed some light onto this issue. Together with Aribert Rothenberger, scientist at the Medical School of the Göttingen University, he could show that problems in the processing of visual information are at least one aspect of this disorder. The scientists are now developing simple visual tasks that pose more difficulties to children with ADHD than to their age mates. Such tests will serve to confine the problems of ADHD children more precisely and to develop therapeutic exercises for them to specifically practice the control of their attention.

Only 15 - 20 years ago – when Treue started studying attention – hardly anyone would have believed that such higher, ill defined cognitive functions can be investigated by means of neuroscientific methods at all. Treue is one of the pioneers in this field. What has paved his way into this exciting research area is probably first and foremost one skill: asking the right questions and planning experiments such that they produce clear, quantitative results. Besides various awards for his contributions to the field of attention research, Treue received the Gottfried Wilhelm Leibniz Prize of the German Research Foundation (DFG) in March 2010.

Even if Treue’s work falls within the scope of basic research, it is nonetheless relevant for applications. Attention is a fundamental ability that accompanies us throughout our daily life. When attention is impaired, this will affect every aspect of life. A better treatment of such disorders requires a better understanding of the underlying processes. Treue has made a significant contribution towards achieving this goal.

Personalia

Abigail Morrison, Junior Professor at the Bernstein Center and the University Freiburg, receives 141 000 Euro over the next three years from the Baden-Württemberg Junior Professorship Program for her research work on the neuronal basis of movement control.
Source:http://www.pr.uni-freiburg.de/pm/2010/pm.2010-04-21.79/ (in German)

Sonja Karg, scientist in the group of Werner Hemmert at the Bernstein Center and the Technical University Munich, was awarded by the German Society for Audiology (DGA) with the prize for the best scientific talk during the DGA Junior Symposium. The title of her presentation was “Temporal pulse interaction due to neuronal dynamics in cochlear implants”.

Book publication: “Analysis of Parallel Spike Trains”

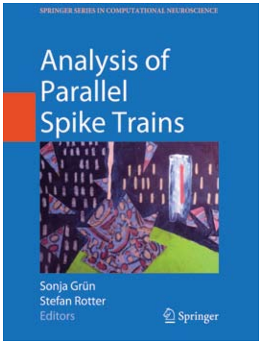
Sonja Grün (RIKEN Brain Science Institute, Japan and Bernstein Center Berlin) and Stefan Rotter (Bernstein Center Freiburg) edited the book “Analysis of Parallel Spike Trains”. With 20 individual contributions, written by leading experts in the field, the book offers a comprehensive overview over state-of-the-art methods for the analysis of coordinated neuronal activity in the brain. It is directed at scientists and advanced students from the fields of Systems Neurobiology and Computational Neuroscience. The book will be published in August 2010.

Grün S., Rotter S. (eds.): “Analysis of Parallel Spike Trains”, Springer Series in Computational Neuroscience, 2010.
ISBN 978-1-4419-5674-3

Hannah Monyer receives prestigious research grant

Hannah Monyer

Hannah Monyer (University Hospital Heidelberg, Bernstein Group Heidelberg) will be supported over the next five years by an “Advanced Investigator Researcher Grant” of the “European Research Councils” (ERC), amounting to 1.87 million Euros. Hannah Monyer investigates the molecular characteristics of so-called inhibitory interneurons – nerve cells that do not excite but rather inhibit other neurons. Interneurons are responsible for the synchronisation of entire neuronal networks, thereby playing a crucial role in fundamental brain functions such as consciousness and memory. Her ERC project was selected from more than 1.500 proposals within the natural sciences, engineering, social sciences, humanities, and life sciences. Scientists from 18 European countries had applied, and a total of 236 projects were successful.
Source:http://idw-online.de/pages/de/news363456



Bernstein Network at the 2nd Ecumenical Kirchentag

At the 2nd Ecumenical Kirchentag (church day), which took place from May 12 till May 16, 2010 in Munich, the Bernstein Network presented current topics and application perspectives of Computational Neuroscience at a 30 m² booth. Posters, exhibits and interactive computer terminals explained the enormous achievements of the brain when coping with everyday tasks like seeing, hearing or the coordination of movements. Scientists from the Bernstein Network were available for questions about the exhibits, the Bernstein Network, brain related diseases, and basic principles of brain function.

The 2nd Ecumenical Kirchentag was visited by approximately 130.000 permanent visitors and 11.000 daily visitors. The information booth of the Bernstein Network was located at the "Centre for Dialogue with the Natural, Social and Life Sciences", which provided – with information booths, talks and panel discussions – a forum for the discussion of scientific topics relevant to society .

Booth of the Bernstein Network at the 2nd Ecumenical Kirchentag.

G-Node Inaugural Symposium

On June 17, 2010, the G-Node Inaugural Symposium "Neuroinformatics: Linking Brain Research from Physiology to Models" took place at the Biozentrum of the Ludwig-Maximilians-Universität München (www.g-node.org/symposium2010). With talks by Piotr Durka (Warsaw), Gaute Einevoll (Aas), Sten Grillner (Stockholm), Colin Ingram (Newcastle) and Mayank Mehta (Los Angeles), as well as discussions and poster presentations, the symposium explored the relevance of neuroinformatics for modern neurosciences.

G-Node Symposium. Top row: A. Herz, S. Grillner, G. Einevoll. Bottom: C. Ingram (left), audience (right)

G-Node is the German National Node of the "International Neuroinformatics Coordinating Facility" (INCF) and integral part of the Bernstein Network. G-Node aims at advancing the sharing of data and methods in the neurosciences by providing tools for data management and data analysis. G-Node Scientific Director is Thomas Wachtler.

Upcoming Events

Date	Title	Organization	URL
July 3-7, Amsterdam, The Netherlands	Bernstein Network Booth (#634) at FENS	7th FENS Forum of European Neuroscience	http://nncn.de/termine-en/fens2010/
August 2-27, Freiburg	15th Advanced Course in Computational Neuroscience	J. Rinzel (NYU,USA), P. Latham (UCL,UK), Y. Prut (HU,Israel), C. van Vreeswijk (CNRS,France) / F. Dancoisne and G. Grah (BCCN Freiburg, Admin. Directors)	http://neuroinf.org/courses/EUCOURSE/F10/index.shtml
August 30 -September 1, Kobe, Japan	3rd INCF Congress of Neuroinformatics	Shiro Usui (RIKEN, Japan)	http://neuroinformatics2010.org/
September 20-24, Göttingen	8th Fall Course on Computational Neuroscience	H. Schrobsdorff (BCCN Göttingen)	http://bccn-goettingen.de/events-1/cns-course/cns-course
September 27-October 1, Berlin	Bernstein Conference on Computational Neuroscience	K.R. Müller, M.L. Jugel, I. Weitkamp (BFNT Berlin)	http://bccn2010.de/
October 10-15, Freiburg	BCCN/NWG Course: Analysis and Models in Neurophysiology	S. Rotter (BCCN Freiburg / BFNT Freiburg-Tübingen), S. Grün (RIKEN, Japan and BCCN Berlin), U. Egert, A. Aertsen / J. Kirsch (BCCN Freiburg / BFNT Freiburg-Tübingen)	http://www.bcf.uni-freiburg.de/events/conferences/101010-nwgcourse
October 26-27, Dresden	Workshop:Spike-Frequency Adaptation in Neural Systems	J. Benda (BPCN and BCCN München), B. Lindner, M. Lochar (MPIPKS, Dresden)	www.mpipks-dresden.mpg.de/~spaneu10/

Das Bernstein Netzwerk / The Bernstein Network

Bernstein Centers for Computational Neuroscience (BCCN)
Berlin – Coordinators: 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 Basis 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 – Coordinators: PD Dr. Petra Ritter, Prof. Dr. Richard Kempter
Learning Behavioral Models – Coordinator: Dr. Ioannis Iossifidis

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

Bernstein Award for Computational Neuroscience (BPCN)
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. Andreas Herz
Stellvertretender Vorsitzender des Bernstein Projektkomitees / Deputy Chairman of the Project Committee: Prof. Dr. Theo Geisel

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Title Image: Image processing in the brain depends e.g. whether we search a shelf for a small yellow or a tall red book. (See article about Stefan Treue, p. 9).

GEFÖRDERT VOM

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für Bildung
und Forschung