



Bernstein Centers for Computational Neuroscience

BCCN Newsletter



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01/2007



The mind's magnifying glass

How attention sharpens the senses

When being addressed by someone we turn and look at him or her. We want to take a closer look at the person who attracted our attention. But even before we change our direction of gaze, mechanisms directing our attention enhance vision within the current region of interest in the visual field. This was shown by scientists from the group of Stefan Treue, head of the department of Cognitive Neurosciences at the German Primate Center and researcher at the BCCN in Göttingen, in experiments with macaque monkeys. 'Improving the visual acuity within the area of interest—even without an immediate eye movement—is of great importance for visual information processing within a natural environment,' as Treue explains. This ability enables us to recognize signposts at the roadside without having to take our gaze from the road.

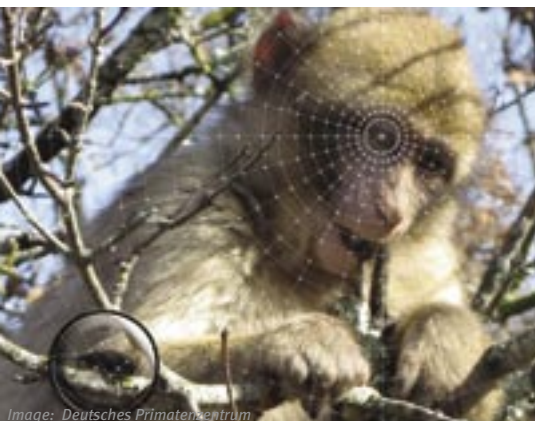
Visual information captured by the retina is analyzed within the brain at different levels of information processing. Only a

fraction of the visual information reaching the retina enters human consciousness. For a long time it was believed that a conscious decision about which object received attention was only made by higher processing levels. Such a filter would only allow relevant information to enter consciousness. Treue and his team were now for the first time able to convincingly show with a plenitude of data that attention already works on lower visual processing levels, literally sharpening the senses.

For their experiments the researchers trained monkeys to solve a complex task. The monkeys directed their gaze at a particular point while their attention was focused on a different stimulus in the periphery of their visual field. Simultaneously, the activity of neurons in the area MT of the visual cortex was recorded. Area MT is a well analyzed brain region whose neurons are specialized for the analysis of visual motion. The neurons responded more strongly to movements within the focus of attention than to movements in other areas. Thus, the scientists were able to show that conscious processes modulate neuronal activity within the visual cortex and control dynamically which visual areas are to be analyzed in more detail.

In the future Treue and his colleagues want to analyze the influence of attention on the neuronal activity in other levels of visual processing. A better insight into the exact mechanisms of how the senses are sharpened through attention could in the long run help to develop therapies for attention deficit disorders. Furthermore, it could help to advance the development of artificial visual systems.

Source: Womelsdorf, T., Anton-Erxleben, K., Pieper, F. & Treue, S. (2006). Dynamic shifts of visual receptive fields in cortical area MT by spatial attention. *Nat Neurosci.* 9(9):1156-60.



Depiction of a visual scene from an observer's perspective. The observer's gaze is directed to the face of the monkey. Simultaneously, the attention is focused on the beetle to the left; the mind's magnifying glass enlarges this visual area.



RECENT PUBLICATIONS

Simplicity in the fly's brain

How the fly analyzes motion

As the fly flies, its surroundings pass by its eyes. When it moves upwards, its environment, viewed from the perspective of the fly's eye, moves down. When it turns left, objects around it will move past it to the right. The fly uses such visual stimuli to coordinate its own flight. Neurons that process such visual information are wired up in such a way that information about the fly's motion becomes most easily accessible for flight control. At the end of a chain of neuronal interconnections, cells are specialized to react to specific movements of the fly, e.g. to horizontal turns or vertical translocations. Alexander Borst and his research group at the Max Planck Institute for Neurobiology investigate how neuronal interactions can produce such selectivity. They discovered that a specific kind of neuronal contact is responsible for increasing selectivity in the neuron 'H2' of the fly's visual system in a very simple manner.

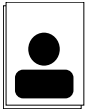
An H2 cell is present in each hemisphere of the fly's brain and reacts to back-to-front movements in front of the same (ipsilateral) eye. This reaction is enhanced by front-to-back movements in front of the eye on the other side (contralateral). This combination of stimuli arises when the fly performs a horizontal turn. The H2 cell thereby reacts in a 'non-linear' manner. 'The reaction to both stimuli together is not equal to the sum of the reactions to each stimulus alone', as Borst explains. Although H2 preferentially reacts to a combination of stimuli in front of both eyes, it shows no reaction at all to movements in front of the contralateral eye presented alone. In a series of technically challenging experiments, Borst and his co-workers could show that the non-linearity of H2 arises through one single neuronal connection with a cell called HSE on the contralateral side.



Motion sensitive neurons in the fly brain.

Neurons usually transmit information in the form of electrical impulses. When a cell receives enough impulses from upstream neurons, the voltage across its membrane will change up to a certain threshold value, and the cell will send an impulse itself. The connection between H2 and HSE effectively represents a 'shortcut' to this procedure. HSE does not react to movements by sending impulses, but rather just by changing the voltage across its membrane. It directly transmits this alteration in membrane potential to the H2 cell via so called 'electrical coupling'. The change in membrane potential alone never reaches the threshold required to activate H2. But it causes the H2 cell to be more susceptible to signals in front of the ipsilateral eye. The connection between HSE and H2 accomplishes the non-linear reaction of H2 and an increase in its selectivity—the cell reacts to horizontal turns much more strongly than to translocational movements. 'Movement selectivity is established in several steps', says Borst. 'With these experiments, we have understood how the specificity for horizontal turns is increased in neuron H2'.

Source: Farrow, K., Haag, J., & Borst, A. (2006) Nonlinear, binocular interactions underlying flow field selectivity of a motion-sensitive neuron. *Nature Neuroscience* 9(10), 1312-20.



MEET THE SCIENTIST

John-Dylan Haynes

In search for consciousness

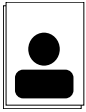
With imaging methods like nuclear magnetic resonance (NMR) tomography, scientists can observe which areas of the brain are active when processing visual stimuli, planning movements or even experiencing fear, joy or rage. Presumably, however, there is much more information in the NMR-images than what up until now has been elicited. It is this additional information that John-Dylan Haynes, professor for 'Theory and Analysis of Large-Scale Brain Signals' at the Bernstein Center for Computational Neuroscience Berlin since November 2006, intends to retrieve with improved data analysis methods. 'We are still far from building a machine that can read your mind', says Haynes. However, he is convinced that in the next few years, scientists will make substantial progress in decoding mental states such as consciousness or intention.

Today, NMR tomography is used to analyze changes in the brain that are related to certain tasks, like processing a visual stimulus or planning and executing a motor activity. If the activity in a certain area of the brain strongly increases, scientists can conclude that this brain area is involved in the respective task. Conventional methods consider the changes in different areas of the brain independently. In practice, however, it is often not possible to attribute complex reactions of the brain to clearly defined areas. The isolated analysis of single sample points therefore misses a lot of information. Haynes seeks to overcome this problem by using 'multivariate pattern recognition'—an advanced method to which he strongly contributed. 'We do not go through the data point by point. Rather, we look for spatially distributed activation patterns that are characteristic for certain mental conditions,' states Haynes as he describes his concept. 'If you compare, for



example, a photo of a man and a woman point by point, you will find that individual pixels are brighter in one or the other picture. But only the conjunction of all points carries information about whether it is a picture a man or a woman. Once we have captured the activation patterns in the brain, we will be able to derive the behavior and experience of a person, only by looking at their brain activity'.

What happens in the brain when we consciously perceive a visual stimulus? This question is one of Haynes' main research focuses. 'Current research tells us that the brain detects a lot of details that do not enter consciousness,' Haynes explains. By using multivariate pattern recognition, Haynes could show, for example, that the brain processes visual information to a certain degree, even if we see it only for a fraction of a second and therefore do not notice it consciously. What does the brain do with this information? 'The idea that human behavior can be manipulated by such subliminal stimuli has been picked up by the popular scientific press for decades—simply because it fascinates people,' says Haynes. In this way, rumors developed that commercial strategists or political campaigns manipulated people through subliminal messages. If anything, they were certainly not very successful in this attempt. According to Haynes, 'such information does not have any effect on complex human behaviors'.



MEET THE SCIENTIST

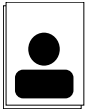
Visual information is processed in the brain in different stages. Only a fraction of the information reaching our retina enters consciousness. Does this imply that it has to have a certain structure and that it needs to be processed in a certain way? How does the brain encode consciousness? Haynes sought to answer these questions by an intricately designed experiment, in which subjects were presented with a red stimulus in one eye, and a blue stimulus in the other. Under these conditions, subjects do not perceive a mixed color, but rather, their conscious experience is dominated by the information in either eye in turn – they alternately see red or blue. Since the visual stimulus in this experimental setup did not change, Haynes could be sure that any change in brain activity exclusively reflected a change in consciousness. The experiment showed that only higher processing levels in the brain show an activity structure reflecting conscious perception.

‘Brain areas, in which conscious perception takes place, are strongly interconnected with other areas of the brain’ explains Haynes. ‘The perception of color, brightness and movement perception must be integrated so that a visual perception can enter our consciousness’. The recognition or interpretation of what we see is another independent step. ‘If we look at a painting by Wassily Kandinsky, we can experience that indeed we are able to perceive images consciously without being able to interpret them’, says Haynes.

The question about the neural code of consciousness is not the only research interest of Haynes. The advancement of methods for the analysis of brain activity also allows investigating of other mental states, such as intentions or attention. Can one, for example, predict which actions a person is planning from the neural activity—even before he or she is aware of it? How do we control our attention? How can the thoughts of a person be read from his or her brain activity? Answering such questions is not only of academic interest, but suggests various applications in man-machine interactions, such as the control of artificial prostheses or computers by means of patients’ brain activities.

*The brain can consciously perceive images without
being able to interpret them.
Kasimir Sewerinowitsch Malewitsch (1878 - 1935):
„Suprematism“.*





MEET THE SCIENTIST

Matthias Bethge

The language of the brain

Matthias Bethge is the first recipient of the Bernstein Prize from the Federal Ministry of Education and Research. The Bernstein Prize, valued at 1.25 million Euros, is awarded annually to young scientists in the field of Computational Neuroscience to enable them to establish their own research group. It is part of the 'National Network for Computational Neuroscience', the core of which is formed by the four Bernstein Centers. Bethge studied physics in Göttingen. After his dissertation in Bremen, he did a post doc in the laboratory of Bruno Olshausen at the Redwood Neuroscience Institute in California. Since November 2005 Bethge has worked at the Max Planck Institute for Biological Cybernetics in the group of Bernhard Schölkopf.

Neurons transmit signals in the form of short electrical impulses—they 'fire'. Every sensation, from the scent of a rose to the play of colors in an evening sky, is converted into such a neuronal 'morse code' in the brain. Since his Diploma Thesis, Bethge has been interested in the question of neuronal information coding. Is a neuron's firing rate critical to information coding; does the combined activity pattern of several neurons play a role? Information coding in the brain must be extremely fast. Bethge's calculations show that a maximal information rate can be reached, when neurons act according to an all-or-nothing law and either fire salvos of impulses or show only minimal activity. 'Minor differences in the frequency of impulses can not be resolved in such a short time', Bethge explains. In addition, the system can only function, if populations of neurons collectively code information. 'It is a great challenge to analyze and understand such a system,' says Bethge.

Not every piece of information that reaches the brain through the sense organs is processed. Rather, the brain can distinguish relevant from irrelevant information and filter the latter one out. But not only that, it can also interpret visual information. For example, the brain has the ability to deduce the three dimensional structure of objects from the two dimensional image that is projected onto our retina. Using different methodological approaches, Bethge addresses how the visual system can infer viable information from the enormous amount of sensory input.

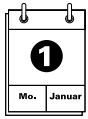
A 'top-down approach', as Bethge calls it, is the abstract reflection, which principles the brain could use to optimally process visual information. 'What would we do, if we wanted to build a machine which can recognize three-dimensional structures?' asks Bethge. This may not only lead to a better understanding of biological vision, it can also advance applications in the area of artificial intelligence. 'Research in the field of computer vision usually attempts to find solutions for very specific applications', says Bethge. Only very narrow classes of objects can be recognized by computers. In order to do so, they resort to previous knowledge, which cannot be extrapolated to other object classes. The brain, in contrast, is capable of understanding the features of an abstract sculpture of which it has no previous knowledge, based only on the distribution of shadows and edges. 'We try to understand the principles of such an analysis of shapes, so that a computer will at some point be able to interpret images with diverse contents.'

In a 'bottom-up approach' Bethge sets out from measurements of neuronal activity. From the way in which neurons react



Matthias Bethge

foto: Max-Planck-Institut für Biologische Kybernetik



to visual stimuli, he draws conclusions about image recognition. Current models of how the brain analyzes images generally assume a linear mode of information processing in several successive layers. Such models, however, reflect reality only in a limited way; they are not very good at predicting neuronal activity in the retina or the subsequent processing areas of the brain. Bethge is developing methods that go beyond such conventional models and also take the interaction of neurons within each layer into account.

Comparable to a computer program for image compression, the brain strives to dispose of redundant information. Not every pixel of a uniformly blue surface needs to be independently processed—missing regions can be easily filled in. So called ‘simple cells’ in the primary visual cortex preferentially react to edges and contours. Statistical models for image processing predict that edges are particularly independent image components. Through quantitative analysis, Bethge could show that other aspects of an image can similarly serve as independent image components. Together with Felix Wichman, also at the Max Planck Institute for Biological Cybernetics, Bethge tests his theoretical results using psychophysical methods. ‘Test persons can predict edges and contours very well, meaning that they are no less redundant than other aspects of an image’, explains Bethge. Given the enormous complexity of the brain, mathematical models and computer analyses are essential tools to unravel its function. But in the end, these models have to be measured against reality.

Bernstein Symposium 2006 in Berlin

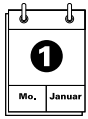
From October 1st to 3rd, scientists from the four Bernstein Centers met at their second joint symposium in Berlin to discuss their results with each other and with invited international experts. The framework of the symposium also included a satellite workshop for communication with the public and a seminar for PhD students and young post-docs to exchange ideas and discuss several topics.

„Variability and Reliability“, „Dynamics“, „Adaptivity“ and „Space-Time“ were the four session topics of this year’s symposium. The science behind the themes is more concrete than the titles might suggest. Research at the Bernstein Centers addresses questions that affect mankind in everyday life—like the processing of visual and acoustic information, the planning of movements and the development of a sense of time and its use for orientation in space. In addition, approaches to technological and clinical applications, for example in the field of automatic speech recognition or prediction of epileptic seizures, were presented at the symposium.

A highlight of the symposium was the award of the Bernstein Prize to Matthias Bethge (see page 12). The prize was presented by Ministerialdirigent Dr. Peter Lange.

Participants of the BCCN Symposium 2006





Funding for neuroprosthetics

To develop a computer-based prosthesis that helps paralyzed patients regain their ability to move – this is the goal of an interdisciplinary research team around Carsten Mehring, Jörn Rickert and Tonio Ball from the BCCN and the University of Freiburg. The project will now be supported with nearly 2 million Euros by the funding initiative ‘GO-Bio’ of the Federal Ministry of Education and Research. ‘GO-Bio’ supports scientists in the field of biotechnology who are developing new technologies and are preparing them for commercial use. The research project of Mehring and his colleagues is among the twelve winners of the first round of funding.

In healthy people, movements are controlled by the motor cortex. From there, neuronal impulses are sent to the muscles via the spinal cord. Severing this pathway, for example, as a consequence of a stroke, leads to palsy, even though the brain is still capable of sending the right signals. In the technology of ‘brain machine interface’, electrodes will be implanted onto the surface of the brain where they measure the neuronal activity. A complex system composed of amplifier, computer and software will then convert this activity into signals that can be used to control artificial limbs. It is also possible to stimulate the muscles of the affected body parts directly. The approach of the Freiburg scientists especially seeks to avoid any damage to the intact neuronal tissue by the neural prosthesis.

Further information: <http://www.bmbf.de/de/6868.php>
<http://www.bccn.uni-freiburg.de/news/eventsmat/gobio/press-aluf/press-aluf.php.htm>
(Both in German only)

Personalia in brief

Matthias Bethge is the first recipient of the Bernstein-Prize of the BMBF. The Prize, valued at 1.25 million Euros, enables young scientists to start their own research group. (See page 12).

John-Dylan Haynes has been appointed to the BCCN professorship ‘Theory and Analysis of Large-Scale Brain Signals’ in Berlin. (See page 7).

Christian Leibold has been appointed as professor at the BCCN in Munich. (See article in upcoming newsletter).

Christian Machens will join the BCCN in Munich, funded by the Emmy Noether Program, an initiative of the DFG. The goal of the program is to bring back excellent young scientists from abroad and to provide them with the possibility to start their own research group.

Fabian Theis is ‘Bernstein Fellow’ at the BCCN Göttingen. Theis has been awarded the Heinz Maier-Leibnitz Prize of the DFG this year. He works on the development of mathematical algorithms for biomedical data analysis and for modeling of neuroscientific problems.

BCCN member **Marc Timme** from Göttingen has started his own research group at the Max Planck Institute for Dynamics and Self-Organization. Timme uses methods of applied mathematics and statistical physics to study the dynamics of networks of complex structures.

Felix Wichmann has been appointed to the BCCN professorship ‘Modeling of Cognitive Processes’ in Berlin. (See article in upcoming newsletter).

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Impress

Published by:
Bernstein Centers for Computational Neuroscience
Berlin – Freiburg – Göttingen – Munich
<http://www.bernstein-centers.de>

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Translation, English Language Editing: Katrin Weigmann, Simone Cardoso de Oliveira, Daniela Pelz, Katie Ogston

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Layout:
newmediamen, Berlin / Katrin Weigmann

Print: Elch Graphics, Berlin

The Bernstein Centers for Computational Neuroscience are funded by the Federal Ministry of Education and Research (BMBF) and are a central element of the “National Network Computational Neuroscience”. The aim of the funding measure is to concentrate scientific expertise in Germany and to promote the clinical and technological applications of theoretical insights in the field of neuroscience.

*Cover image: The brain can understand the structure of an abstract sculpture based on the distribution of shadows and edges.
Matthias Bethge investigates the principles of shape analysis*

GEFÖRDERT VOM



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