



Bernstein Network for Computational Neuroscience

Bernstein Newsletter



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07/2009

Small brain, optimal wiring

With its spherical compound eyes, the fly has an almost complete all-round view of its surrounding. It uses its visual sense to coordinate its flight. From what it sees, it can infer its own movement – whether it is, for example, heading forwards or drifting off sideways. Alexander Borst from the Max Planck Institute for Neurobiology and Bernstein Center in Munich and his colleagues Yishai Elyada und Jürgen Haag have investigated, which neuronal circuits underlie these calculations. In a recent study the scientists show that a previously unknown mechanism plays a crucial role in this context: Different parts of a single cell take on different tasks in the processing of visual motion information. The cell's input region – the part with which it receives information – only processes a very narrow part of the fly's visual field. Near the cells output, this information is set off against information coming from neighboring cells. Computer models showed that this division of labor within a single cell is especially effective for calculating the fly's movement.

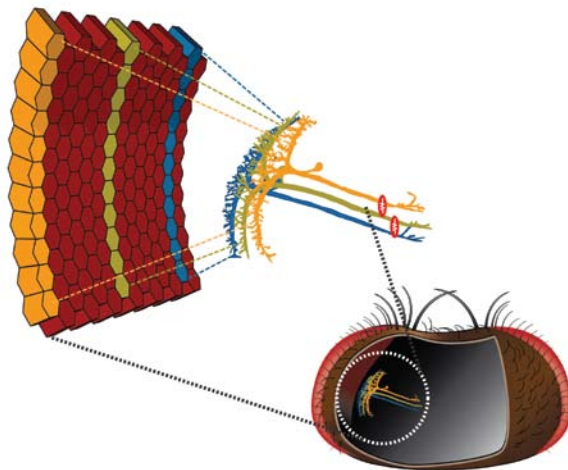
When observing the acrobatic flight of a fly it becomes evident that its small brain works extremely fast. Its efficiency is based on a sophisticated wiring scheme of the neurons that deduce the fly's flight based on its visual input. If the fly heads straight ahead, it sees its surrounding pass by horizontally. When it turns around its own body axis, its visual surrounding will drift off vertically. Defined motion sensitive neurons are specialized for computing of each of these movements, respectively. So called VS cells, for example, are specialized in computing vertical movements. Each VS-cell receives input from a narrow vertical stripe of the fly's visual field.

But this is, as the scientists have now discovered, only half the truth. They used sophisticated microscopy technologies to observe the distribution of calcium within the cell – an indication of the cell's activity – while they played patterns of moving stripes to the fly. The researchers showed that, although the cell can „see“ only a narrow stripe with its input regions, it gains additional information about neighboring regions through cell coupling at its output region. Computer models simulating the processing of visual information show that this division of labor between different regions within a single cell is very useful for the fly. Like this, it can calculate motion information faster and more precisely.

Source: Press release of the MPI f. Neurobiologie

Elyada, Y.M., Haag, J. & Borst, A. *Nat Neurosci.* 2009 Mar;12(3):327-32.

Each VS nerve cell receives visual information in its input region (broad cell end) from only a narrow strip of the fly's eye. In the output region at the rear end of the cell, electrical connections (red) enable the cells to communicate with neighbouring cells.



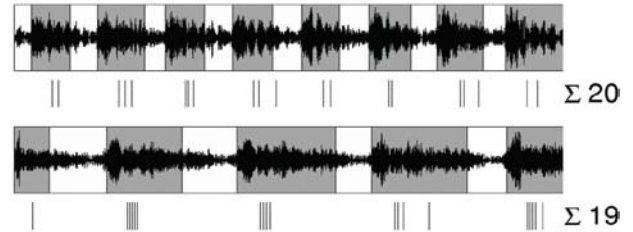


The math trick of neuron nr. 12

When watching soccer, it doesn't matter whether you shout "Goal!" or "Goooooaaaaa!"; in either case, our brains will quickly figure out that someone has scored. It's a similar case with certain animals that will also stretch or compress their acoustic signals. Grasshoppers, for example, produce their mating calls by rubbing their hind leg against the veins of the forewing. As they cannot regulate their own body temperature, their biochemical processes slow down in the shade or on colder days – which means the grasshoppers' call, too, becomes longer and more drawn out. It is the female's task to distinguish the mating calls of their own species from those of other species irrespective of the temperature. A research team led by Andreas Herz, Ludwig Maximilians University and Bernstein Center Munich, has now shown that, contrary to expectation, this requires no complex computation by the brain. 'A single neuron takes care of this task,' says Herz.

Grasshoppers mating calls have a fixed sequence of 'syllables' and 'pauses'. The absolute length of syllables and pauses will change with temperature and can therefore hardly be a criteria for distinguishing between species. It is rather the pause-to-syllable ratio that counts. It is the female's task to decode this ratio, in order to recognize an admirer of its own species.

One would be forgiven for assuming that it would take a number of complex operations to calculate this ratio. The temporal lengths of the syllable and pause would first have to be measured and then the former would have to be divided by the latter. Since syllables and pauses are offset in time, the result of the first time measurement would also have to be kept in memory until the second time measurement is complete. Altogether, this is a demanding task, which would appear to require at least a small neural network to solve.



Grasshopper song at different temperatures. The number of spikes of the neuron nr. 12 in a given period of time remains unchanged.

'We were able to demonstrate, however, that this computational problem can be solved by a single nerve cell,' reports Herz. 'In grasshoppers, we can even identify the responsible neuron: It is "ascending neuron No. 12"'. This neuron responds to the onset of a call syllable with a burst-like discharge pattern, where the number of spikes within the burst increases linearly with the length of the preceding pause. Fast calls therefore lead to many bursts, each with few spikes, while slower calls lead to fewer bursts, each with many spikes. If you then sum up the number of spikes over a fixed time window, you obtain an astonishing result: The total number remains the same and accordingly identifies the species of the male grasshopper – irrespective of the pace of the song.

'It is certainly a fascinating angle to our work to have discovered a simple trick that makes complex calculation completely unnecessary, and which might also be exploited by other animals,' states Herz. 'The project undertaken with colleagues from Berlin and Göttingen is concluded, yet the name "Neuron No. 12" alone implies there are at least eleven other similar neurons. And we would really like to know what computational problems those neurons solve.'

Source: Press release of the LMU

[Creutzig, F., Wohlgemuth, S., Stumpner, A., Benda, J., Ronacher, B. & Herz, A.V.M. J. Neurosci., 29\(8\), 2575-2580, 2009](#)

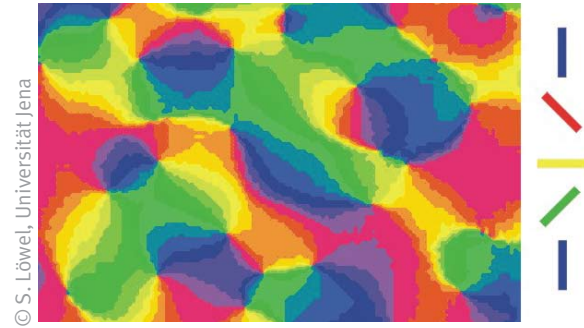


RECENT PUBLICATIONS

The script for brain development

Each of the two hemispheres of fish brains only processes information arriving from the opposing eye. Similar observations can be made in newborn mammals: Almost all neuronal inputs into the visual cortex originate from the opposing eye, it is only later in development that this task is reorganized until the two hemispheres finally process information from both eyes. Up to now there was no explanation for this phenomenon. Is this merely an evolutionary relic – similar to gills found in the embryonic development of humans? What is the purpose of this development? Lars Reichl and Fred Wolf (Bernstein Center and Max Planck Institute for Dynamics and Self-Organization Göttingen), together with Siegrid Löwel (University of Jena), were now able to answer these questions. ‘It is essential for the correct development of the visual center in the human brain,’ says Wolf.

Cells in the visual cortex respond to selected optical elements, such as edges and contours. Every cell has an ‘orientation preference’, it responds best to edges with a certain direction. Assigning the same color to cells with the same orientation, one obtains a so called ‘orientation preference map’. Usually, nearby cells have similar orientation preferences. But there are exceptions to this rule, so-called ‘pinwheels’: regions in which cells with different preferences meet, like in the center of a windmill. This alignment allows correct analysis of visual data while keeping processing distances minimal. Furthermore, cells in the visual cortex respond to stimuli that reach only one of the two eyes. The corresponding ‘ocular dominance map’ changes in early stages of development. Scientists have been wondering for some time now how these maps get formed. ‘They emerge by self-organization, there is no engineer overseeing this development’, says Wolf.



© S. Löwel, Universität Jena

Image opposite page: Neurons in the visual cortex preferentially react to contours in a defined direction. Cells that react to the same direction are depicted in the same colour.

Various models for self-organization in the brain were able to explain the formation of the orientation preference map, but not its stability: Pinwheels with different orientation appeared to cancel out. Trying to understand the stability of pinwheels, the scientists analyzed whether the different maps somehow influenced each other. In their models, pinwheels try to keep as much distance as possible from the boundaries of the ocular dominance maps. Computer simulations showed that under these assumptions pinwheels survive. The ocular dominance map stabilizes the orientation preference map. However this only happens under one condition: It is vital that the process starts with an asymmetrical ocular dominance map – the feature in which the mammal brain is similar to the fish brain. In newborn children the majority of cells in the visual cortex responds to stimuli originating from the opposite eye, information from the other eye becomes more important only later on. The scientists were able to show that this archetypical development is crucial even today: It is essential for the correct formation of the ocular dominance map, and can therefore also influence the development of the orientation preference map.

Reichl, L., Löwel, S. & Wolf, F. *Physical Review Letters*, 102, 208101, 18. May 2009



From racing bike to mountain bike

If we know how to ice-skate, we will more rapidly learn how to rollerblade. If we learned to ride a bike on a Dutch bike or on a racing bike, we will rapidly learn how to ride a mountain bike – though the feedback from our muscles and the exact movement sequences are quite different. How do we generalize motion sequences, how do we transfer the ability to ride a bike from one bike to the other? This has now been investigated by scientists around Carsten Mehring from the Bernstein Center for Computational Neuroscience and the University of Freiburg. They showed that we learn in a ‘structured’ manner – i.e.: we learn which movement aspects are connected in which way.

In complex motor activities like riding a bike, we must control many parameters – e.g. the position of arms and legs and the tension of the trunk musculature. If we learn a similar activity, these parameters are also similar. But is this enough to explain how we generalize motion sequences? According to the current study by Mehring and his colleagues, there is more behind it. We learn which control parameters characterize a certain motion class and how they are connected. For example, when we push down the bike’s pedal with the left foot, we move our right foot

upwards. And that’s not all: ‘There are more than 600 muscles in the human body that each need to be more or less contracted in a coordinated manner, and there are many sensory, visual and haptic responses, which are connected in a certain way for one class of motor tasks, e.g. riding a bike,’ says Mehring. ‘If we switch from one bike to another, we only change the motor aspects that are important to this motion class and we only test parameter combinations that make sense for this motion class.’

In various experiments, Mehring and his colleagues have verified the hypothesis that such a motion principle can be learned. In one experiment, for example, the subjects were asked to move the cursor to a certain point on a computer screen. In this experiment, there was a rotation between the movement of the hand and the movement of the cursor on the computer screen – if the subjects moved the mouse to the right, the cursor moved e.g. diagonally down, and the subjects had to adjust their movement accordingly. From trial to trial the rotation angle changed, thus making it impossible to learn a specific angle of rotation.

Nevertheless, after a couple of trials, the subjects had learned something. If they were now asked to perform the same rotation task several times in a row, they managed to make straight and quick movements much more rapidly than subjects without previous experience. ‘They had learned the principle that the resulting cursor movement is rotated relative to their own movement – as opposed to being scaled or mirrored, for example,’ says Mehring. Therefore, they only had to vary a few parameters in order to achieve the right motion sequence. That’s what scientists call ‘structural learning’. The generalization of motion sequences – as shown by the scientists around Mehring – is based on structural learning.

Braun, D.A., Aertsen, A., Wolpert, D.M. & Mehring, C. *Curr Biol.* 2009 Feb 24;19(4):352-7.



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RECENT PUBLICATIONS

The brain from different perspectives

Functional magnetic resonance imaging (fMRI) is a modern technique for observing which parts of the brain are active in a particular task. The method has one disadvantage, however: It does not have a very good temporal resolution. This is due to the fact that the activity of the nerve cells is measured only indirectly, via the oxygen consumption of the blood. The “language” of the brain, however, is based on the rapid sequence of neuronal signals and cannot be decoded by fMRI alone. Scientists around Petra Ritter and Arno Villringer from the Charité University Medicine and the Bernstein Center for Computational Neuroscience in Berlin have shown how this problem can be avoided.

The scientists have succeeded by combining fMRI with electroencephalography (EEG). During EEG, rapid voltage changes in the brain are measured by means of electrodes that are attached to the scalp – this technique, however, does not have a good spatial resolution. It does not allow to precisely determine which brain regions are active. By means of a sophisticated experimental set-up, the scientists now managed to relate the spatial signals provided by fMRI to the temporal signals provided by EEG. For this purpose, the subjects were exposed to sensory stimulation at the wrist. The brain activity during this perception was then recorded by fMRI as well as by EEG. Since the magnetic field created by fMRI interferes with the EEG measurement, the two signals were measured in quick alternation.

The brain activity that follows stimulation at the wrist evokes a typical signal in the high-frequency range of the EEG, which can be subdivided into an early and a late component and which occur 16-18 and 18-25 milliseconds after the stimulation respectively. The relative signal strength of the two components varies depending on the frequency of stimulation, but also



MRI scanner

© Ryanphoto / Dreamstime.com

spontaneously from trial to trial. The scientists took advantage of this ‘spontaneous’ variability. They compared experimental trials in which the early or late component was especially high or especially low with the respective fMRI measured data. In this way, the temporal EEG signal and the spatial fMRI signal could be clearly related to each other. The scientists demonstrated that the early EEG signal is based on an activity in the thalamus, and the late signal on an activity in the somatosensory cerebral cortex. Thus, for the first time, neuronal voltage changes could be attributed to specific activity areas in the fMRI.

This methodical progress will have significant impact on clinical applications. For example, this method could allow a better control of brain tissue regeneration after a stroke. With fMRI, one can only see whether the blood supply in the affected area increases. Whether this is also accompanied by increasing neuronal activity can only be shown by the combination method. Moreover, it will be possible to gain a better understanding of diseases like migraine or certain movement disorders, if the information provided by fMRI measurements can be combined with information provided by EEG measurements.

Ritter, P., Freyer, F., Curio, G., Villringer, A. *Neuroimage*. 2008 Aug 15;42(2):483-90.



RECENT PUBLICATIONS

Two at one stroke

How are odors encoded in the brain? How are memories stored? For many decades, thousands of scientists have dealt with questions concerning the function of the brain or just small parts of the nervous system. Detlev Schild (Bernstein Center and University Medicine Göttingen), together with his colleagues Stephan Junek, Tsai-Wen Chen and Mihai Alvera, has now developed a method that will help to make major progress in this field of research. Based on the new technology, the scientists can reconstruct the exact circuit diagram of the nerve cells in a nervous tissue and, at the same time, examine the electrical activity of the nerve cells involved. Previous methods mainly focused on one or the other aspect of the analysis.

When we see, hear or smell, our sensory organs convert light, sound or odors into neuronal signals that are transmitted from nerve cell to nerve cell via long cellular extensions. The spatio-temporal pattern of the electrical activity of the nerve cells contains the information that enables our brain to recognize the typical smell of freshly ground coffee or the ringing of an alarm-clock. But how is the information encoded in this activity? In order to answer this question, scientists need to determine the structure of the neuronal circuits as well as the activity of the individual nerve cells. Schild and his colleagues have now managed to combine the two aspects.

The concentration of calcium ions in nerve cells increases when they send an electrical impulse. By staining the complete tissue with calcium-binding dyes, the activity of hundreds of cells can be measured simultaneously. Such staining, however, only allows the identification of the cell bodies. The contrast is not sufficient to identify the fine cellular extensions with which the cells contact each other. Previous applications of this



Partial network structure of the olfactory bulb as revealed by the method of Schild and his colleagues. Long thin cellular extensions, which are not perceptible in the original recordings, have been made visible by the new analysis method. Cells that are represented in the same color are active at the same time. They are responsible for the perception of the same odors.

method thus allowed to observe the cells' activity, but not their circuit structure.

The method developed by the Göttingen scientists will now solve this problem. In a first step, the researchers recorded the calcium changes in the whole tissue almost simultaneously by using a fast microscope. These image data were then analyzed by means of a program specifically designed for this purpose. Based on the change of the signal in one of the cell bodies, the program determines which other image elements vary according to the same dynamic. In most cases, these image elements belong to the same cell – or to different cells with very similar activity. Taking the tadpole olfactory bulb as an example, the researchers tested their method and managed to show how the cells of the olfactory bulb that are active at the same time are connected to each other. A detailed knowledge of the network structure now allows for a much more specific approach to scientific questions. 'One can now for example select specific cell types on the basis of their connections and can observe the network's reaction when these are manipulated,' explains Junek.

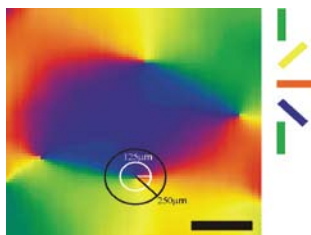
[Junek, S., Chen, T.W., Alvera, M. & Schild, D. *Biophysical Journal*, Vol. 96, 2009](#)



Seeing as balancing act

In order to be able to see, the brain must perform a number of “calculations”. During the first steps of neuronal image processing, the image information that reaches the retina is transmitted to the visual cortex in the cerebrum, where it is processed by strongly interconnected networks of neurons. In these networks, the relative strength of the excitatory and inhibitory feedback is crucial: An excess of excitation may cause migraine or epilepsy-like states, and inhibitions that are too strong may cause a blockade of processing. The exact underlying neuronal circuits have now been systematically analyzed by scientists from the Bernstein Center and the Berlin Institute of Technology, in collaboration with their colleagues at the Massachusetts Institute of Technology (USA). Their results show that excitatory and inhibitory signals must be precisely balanced, thereby being surprisingly close to the limit of critical hyperactivation. Moreover, their work contributes to a better understanding of how attentional processes influence the process of seeing.

One task of the primary visual cortex is to analyze the distribution of edges and contours. Cells in this brain region preferentially respond to edges of defined orientation. There are various scientific models that explain how the behavior of these nerve cells is achieved. In order to distinguish between the different possible mechanisms, the scientists around Klaus Obermayer took subtle variations in the cell properties into consideration.



Distribution of orientation preference in the visual cortex. Most cells are surrounded by cells with similar orientation preference, but there are exceptions (e.g. in the encircled region).

Cells in the visual cortex each receive neuronal input signals from their neighboring cells. Depending on the position of the cell in the visual cortex, however, the composition of these input signals may vary quite a bit. Nevertheless, all cells perform the same arithmetic task: They react very precisely to the orientation of lines. In their model, the scientists systematically test which circuit pattern can reflect the reaction of all cells to their various input signals. ‘Thus, we have not only found a model that explains the data, but we have also excluded that another model may explain the data equally well,’ says Obermayer. The scientists’ model shows that there are a great many excitatory as well as inhibitory local connections between the cells in the primary visual cortex. The contribution of the feedback signals is more than double the contribution of the direct input signals from the retina.

But why does the brain invest so much energy into the simultaneous activation and inhibition of certain cells? Couldn’t there in theory be an easier way to calculate contours and edges? The scientists have found a plausible answer to this question, as well: As they have shown in their computer simulations, the complex circuit structure allows the activity of the cells in the primary visual cortex to be adjusted very easily by small influences from outside. Such adjustments could, for example, be realized by attentional processes. It was shown previously that higher brain functions, such as attention or prior knowledge, intervene already in the first steps of visual image processing in the brain – if we observe something attentively, the neurons in the visual cortex are more active and we can see more sharply. The scientists’ model now contributes to a better understanding of the underlying neurobiological mechanisms.

Stimberg, M., Wimmer, K., Martin, K., Schwabe, L., Mariño, J., Schummers, J., Lyon, D.C., Sur, M. & Obermayer, K. *Cereb Cortex*. 2009 Feb 16.

Events

The second bilateral **German-Japanese Workshop 'Computational & Systems Neuroscience'** took place from May 25-28 in Berlin. The aim of the workshop was – besides the scientific exchange – also the discussion of existing and possible future funding instruments to foster collaboration in the Computational Neurosciences. To this end, representatives of the Federal Ministry of Education and Research, the project management agency PT-DLR and several German research funding agencies, as well as representatives from the 'Japan Society for the Promotion of Science' and the 'Japan Science and Technology Agency' were present. The workshop was organized by a German Japanese committee under the lead management of Klaus Obermayer (BCCN and TU Berlin). Local organizers were Margret Franke and Robert Martin (BCCN and TU Berlin).

<http://www.nncn.de/termine-en/japanworkshop/>



Participants of the German-Japanese Workshop

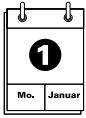
The **'CNS*2009 - Eighteenth Annual Computational Neuroscience Meeting'** of the Organization for Computational Neurosciences will take place in Berlin from July 18-23, 2009 under the local organization of Udo Ernst (BGCN Bremen), John-Dylan Haynes (BCCN Berlin), Andreas Herz (BCCN Munich) and Klaus Obermayer (BCCN Berlin). Apart from the main meeting, there will also be a multitude of tutorials and workshops, several of them with contributions of members of the Bernstein Network. A core element of the workshops is a symposium on neuroinformatics organized by the German Node (G-Node) of the International Neuroinformatics Coordinating Facility (INCF).

<http://www.cnsorg.org/2009/>

The **'Science Express'** exhibition train, which tours through Germany as a part of the German 'Science Year' 2009, aims to give a '...general idea of which scientific fields are evolving globally in a particularly dynamic and promising way...' One of the twelve coaches, to which also scientists from the Bernstein Network have contributed, is dedicated to the topic of brain science.

<http://www.expedition-zukunft.org/>





NEWS AND EVENTS

The documentary movie **‘Auf der Suche nach dem Gedächtnis’ (In search for memory)** about the Nobel Prize laureate Eric Kandel was released in Germany starting June 25th. Expert discussions with scientists from the Bernstein Network took place in Freiburg (June 24th) and Göttingen (June 25th).
<http://www.kandel-film.de/>



Participants at the „Klügste Nacht des Jahres“ in Berlin

During the **‘Klügste Nacht des Jahres’ (Smartest night of the year)**, 67 scientific institutions in Berlin and Potsdam opened their doors to the public. Three events, organized by members of the Bernstein Center, informed about different aspects of perception and about the behavioral analysis and brain function of the Etruscan shrew.

<http://www.langenachtderwissenschaften.de/>

Accreditation of the Berlin Master Program

The ‘Master Program Computational Neuroscience’ of the Bernstein Center for Computational Neuroscience Berlin, which was set up in October 2006, has now successfully been accredited by the ‘Akkreditierungsagentur für Studiengänge der Ingenieurwissenschaften, der Informatik, der Naturwissenschaften und der Mathematik e.V.’ (accrediting agency for study programs in the engineering sciences, informatics, natural sciences and mathematics / ASIIN e.V.). It has thus been approved that the program, which is unique in Germany, has high educational standards and quality. The international program is chaired by Klaus Obermayer and is supported by the three Berlin universities and the Charité Universitätsmedizin Berlin.

Personalia

Marc Timme, scientist at the BCCN Göttingen and the Max Planck Institute for Dynamics and Self-Organization, has been appointed adjunct professor by the University of Göttingen.

Tim Gollisch, BCCN Munich, received the Career Development Award of the Human Frontier Science Program (HFSP). The competitive award is addressed to Long-Term HFSP Fellows who return to their home country at the end of the fellowship.

Supported by the Alexander von Humboldt Foundation, **Michael Gutnick**, professor at the Hebrew University of Jerusalem, will visit the BCCN Göttingen for a three month research stay. Together with **Fred Wolf** he will investigate, how the emergence of action potentials is influenced by the geometry of the cell body axon complex.



NEWS AND EVENTS

Events

Date	Title	Organisation	URL
08.-10. July, Berlin	BBCI Workshop 2009	K.-R. Müller, G. Curio, J.-D. Haynes, B. Blankerz, S. Lemm, M. Tangermann (BCCN + BFNT Berlin)	bbci.agilemeetings.com/
18.-23. July, Berlin	CNS*2009 - 18th Annual Computational Neuroscience Meeting	U. Ernst (BGCN Bremen), J.D. Haynes (BCCN Berlin), A. Herz (BCCN München), K. Obermayer (BCCN Berlin)	www.cnsorg.org/2009/
22. July, Berlin	G-Node Symposium on Neuroinformatics - Data Sharing and Data Analysis in Neurophysiology	A. Herz (BCCN Munich), M. Nawrot (BCCN Berlin), T. Wachtler (G-Node)	http://www.g-node.org/symposium/
24. - 26. July, Frauenwörth	IATD Processing 2009 meeting	Christian Leibold, BCCN Munich	http://www.nncn.de/termine-en/iatd2009/
03. - 28. August, Freiburg	14th annual Advanced Course in Computational Neuroscience	N. Brunel, J. Rinzler, P. Latham, Y. Prut / F. Dancoisne (BCCN, Admin. Director)	www.neuroinf.org/courses/EUCOURSE/F09/
31. Aug - 04. Sept., Berlin	G-Node Summer School: „Advanced Scientific Programming in Python“	M. Schmucker, T. Zito (BCCN Berlin)	www.gnode.org/Teaching
6.- 08. Sept, Pilsen	INCF Congress of Neuroinformatics	David Willshaw (chair / Edinburgh, UK)	www.neuroinformatics2009.org
16. - 18. Sept., Tübingen	Autumn School: ‚Wiring the brain‘	Members of BFNT Tü/Fr and others	www.mp.uni-tuebingen.de/mp/index.php?id=281
21. - 25. Sept., Göttingen	7th Fall Course on Computational Neuroscience, Göttingen	Hecke Schrobsdorff (BCCN Göttingen)	www.bccn-goettingen.de/events-1/cns-course
30.Sept. - 2.Oct., Frankfurt	Bernstein Conference on Computational Neuroscience	J. Triesch, Ch. v.d. Malsburg, R. Mester (BFNT Frankfurt)	http://bccn2009.org/
12. - 16. Oct., Freiburg	NWG Course 2009	S. Rotter, S. Grün, U. Egert, A. Aertsen (BCCN Freiburg) / J. Kirsch (BCCN / Local Organizer)	www.bccn-freiburg.de/news/events/nwg-course2009

Imprint

Published by:
National Bernstein Network Computational Neuroscience
<http://www.nncn.de>

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Design:
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Layout:
Katrín Weigmann

Print: Elch Graphics, Berlin

The Bernstein Network for Computational Neuroscience is funded by the Federal Ministry of Education and Research (BMBF).

*Title image: Neuronal Map of orientation preference
(modified after F. Wolf, see page 6/7)*

The Bernstein Network

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Bernstein Award for Computational Neuroscience (BPCN)
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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

GEFÖRDERT VOM



Bundesministerium
für Bildung
und Forschung