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Bernstein Centers for Computational Neuroscience
Katrin Weigmann

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The brain on the edge of chaos

Researchers in Göttingen have shown how avalanches of neuronal discharge occur in the brain.

Many systems of nature automatically head for a critical state which can be characterized as an extremely instable equilibrium. For example, if sand slowly trickles onto a surface, it will pile up until the slope of the sand pile is so steep that avalanches of sand occur and tumble down the slope. In doing so there is no typical avalanche size. In a defined period of time, many small avalanches or, in other cases, just a few big ones may occur in a random sequence . The build-up of tension in the continental drift of the earth's crust and the consequential discharge resulting in an earthquake similarly demonstrates this "self-organized criticality", as the lingo puts it. In 2002, a staff of researchers including of Michael Herrmann had already proposed, based on theoretical calculations, that the transmission of signals in the nervous system also follows this principle. In the ensuing years these assumptions were supported by experimental observations. With a new study, Anna Levina, Michael Herrmann and Theo Geisel, researchers at the Bernstein Center for Computational Science, the Max Planck Institute for Dynamics and Self-Organization and the University of Göttingen, have now successfully identified the neuronal mechanisms underlying this phenomenon. This work will be published online on November 18, 2007 in the reputable scientific journal Nature Physics.

Avalanches can also occur in the nervous system - not sand avalanches, but avalanches of neuronal discharge. When a neuron transmits an electric impulse, this can effectively, however not inevitably, release an impulse in a downstream neuron. When the transmission is repeated a number of times, this results in a chain of neuronal discharges, which can respectively vary in the number of neurons it comprises. "In doing so, the nervous system can make use of the full potential of all possible reactions - sometimes it reacts strongly, other times less strongly", Herrmann explains. To date, it has been successful in only a few exceptional cases to yield a neuronal network in such a critical state in a computer simulation. In their latest study, the researchers from Göttingen were able to realistically model and explain the self-organized criticality in a computer-simulated network by taking into account the attenuation of the connection strength between the neurons resulting from repeated neuronal activity.

Neurons transfer information in the form of electric signals. However, where two neurons connect, at the synapse, the transfer of information is interrupted and the signal is transmitted to the next neuron with the help of chemical substances. "The supply of these neurotransmitters is reduced by the activity of the synapses so that the strength of the signal transmission deteriorates. Only then can the reserves be replenished and the efficiency of the synapse recovered", Levina explains. For a long time, the exhaustion of the supply of neurotransmitters was believed to be a mere biologically determined short-coming.Only in the past few years was this mechanism - the so-called synaptic depression - seen to play a significant role for the functioning of the brain. Geisel and his co-workers have for the first time been able to show that this synaptic mechanism of adaptation pushes the neuronal network into this state of self-organized criticality, on the border of chaos.

Original publication:

A. Levina, J. M. Herrmann, T. Geisel (2007). Dynamical Synapses Causing Self-Organized Criticality in Neural Networks.
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Contact:
Prof. Theo Geisel
Abteilung Nichtlineare Dynamik
Max Planck Institut für Dynamik und Selbstorganisation
Bunsenstr. 10
37073 Göttingen

Tel.: (0)551-5176-401
Email: geisel@nld.ds.mpg.de

URL zur Pressemitteilung: http://www.nld.ds.mpg.de

URL zur Pressemitteilung: http://www.bccn-goettingen.de

Many systems of nature automatically evolve into a state which is barely stable. If sand or rice slowly trickles onto a surface, the slope will become so steep that any new grain may cause an avalanche. The occurrence of neuronal discharges in the brain follows these same principles of "self-organized criticality"
Image: Anna Levina