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For rapid non-linear information processing in the brain, small synaptic impulses are key

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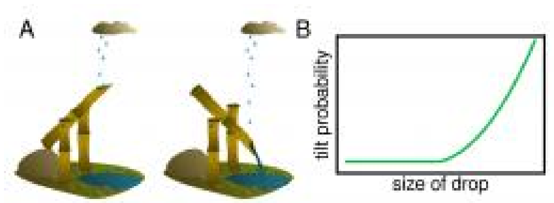

Figure 1: The dynamics of raindrops falling onto a shishi odoshi (deer scarer), a device used in Japanese gardens to scare away birds, provides an excellent model for understanding the operating principles of a nerve cell. (Artwork by Susanne Kunkel) A) The raindrops correspond to the incoming synaptic impulses, each of which increases the water level by a tiny amount. A single additional drop of water ultimately causes the shishi odoshi to tilt and drain. When the shishi odoshi swings back and hits the stone it produces a knocking sound. This corresponds to the emission of an action potential by the neuron. Thus, a single synaptic impulse can strongly affect the state of the neuron. The novel theory of the researchers takes this into account, while previous theories neglected this fact. B) The effect of a single drop on the tilting (response) of the shishi odoshi depends on the size of the drop. The probability that a response occurs is quadratically proportional to the size of the drop, meaning that a doubling of the drop size, for example, would make tilting four times more likely. This "non-linearity" is the basis for multiplications performed by neurons. Copyright : RIKEN

A novel theoretical framework for mathematically modeling nerve cells has illuminated for the first time how small synaptic impulses enable non-linear information processing in the brain. Reported in *PLoS*

Computational Biology, the findings offer fundamental insights relevant to a wide range of biological, physical and technical systems.

In the field of neuroscience, neurons are known to communicate via so-called "action potentials", brief impulses which cause a cell's membrane potential to rise and fall. Only when many such impulses together exceed a threshold value does the neuron "fire", releasing its action potential to target neurons. How neurons transfer action potentials from inputs into outputs determines which elementary operations they are able to perform, and at what rate.

With their latest work, researchers at the RIKEN Brain Science Institute and Bernstein Center for Computational Neuroscience set out to resolve contradictory findings uncovered earlier regarding this input-output relationship. At issue was the conventional theory of spiking neuronal networks, which approximates impulses in the limit where they become vanishingly tiny and infinitely numerous, limiting the capabilities of individual neurons to simple addition of inputs.

Using a newly-developed high-precision method for simulating nonlinear neuron models (see references), the team had previously uncovered contradictions in this theory. To unravel this mystery, the researchers developed a new analytic framework which explicitly incorporates the finite effect of each input at the critical boundary near the firing threshold. With this change, they show that not only can neurons process information far faster than previously believed, they can also perform nonlinear operations such as multiplication that are key to complex information processing.

While more accurately capturing the network aspect of neural dynamics, the new framework also reveals how cooperation between seemingly uncoordinated input signals enables neurons to perform many non-linear operations at the same time. Future work will build on these findings toward a better understanding of brain function, a fundamental requirement for treating neural diseases.

More information: Moritz Helias, Moritz Deger, Stefan Rotter and Markus Diesmann. Instantaneous non-linear processing by pulse-coupled threshold units. *PLoS Computational Biology* (2010).

Hanuschkin A, Kunkel S, Helias M, Morrison A and Diesmann M (2010). A general and efficient method for incorporating precise spike times in globally time-driven simulations. *Front. Neuroinform*. 4:113. doi:10.3389/fninf.2010.00113

he simulation software is freely available from the NEST Initiative: www.nest-initiative.org

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