Neuronal diversity impacts the brain's information processing

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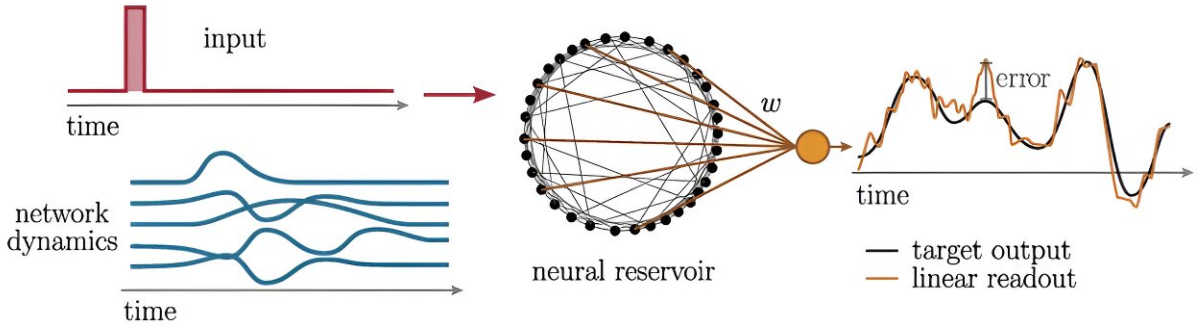

Spike threshold heterogeneity affects the function generation properties of spiking neural networks. (A) Reservoir computing architecture used for function generation. A pulse is fed into a recurrent neural network and a linear readout is trained to minimize the mean squared error between a target time-dependent function and a network output obtained as a linear combination of the stimulus-evoked neural dynamics within the network. Credit: *Proceedings of the National Academy of Sciences* (2024). DOI: 10.1073/pnas.2311885121

Northwestern Medicine investigators have revealed new insights into the impact of neuronal structural diversity on neural computation, the basis of brain function, according to a recent study published in the *Proceedings of the National Academy of Sciences*.

The nervous system is made up of a web of interacting neuronal networks that filter, remember and transform information about a

person's internal and external states. The networks which mediate this information processing are made up of cells with a high level of diversity, with neurons varying in structure, gene expression and electrical properties.

This structural and genetic diversity among these neurons leads them to produce varied responses to inputs, but exactly how this diversity impacts overall computation and information processing in larger neural networks has remained poorly understood.

"While there's a growing body of research aimed at identifying and understanding neuronal cell types, mathematical models of the brain typically neglect this diversity," said Ann Kennedy, Ph.D., assistant professor of neuroscience and senior author of the study.

In the current study, the investigators used a new mathematical model to introduce diversity into a network of neurons by adding variation to neuronal spike thresholds—an electrical property that determines when a neuron "spikes" and sends an output to neighboring neurons. Based on this model, the investigators examined how increasing the diversity of spike thresholds in a network affected the network's ability to gate, encode and decode information.

The investigators discovered that adjusting spike threshold diversity supports different computational functions, depending on how a neuron communicates with its neighboring neurons. Specifically, in neurons that suppress spiking of their neighbors, changing spike threshold diversity determined how well cells could gate the flow of information in a network.

Furthermore, reducing this diversity too much could lead to seizure-like events to dominate network activity, according to the authors.

In other neuron populations, they found that increasing spike threshold diversity helped neural networks precisely control their activity, which is important for daily functions such as controlling movement. Conversely, reducing this diversity improved the network's ability to address problems requiring short-term memory.

"It's not that more heterogeneity is always beneficial for the function of a neural population, but we need to consider it in order to understand how a particular level of heterogeneity that we see when we record from a neural population in the brain translates to the functional capacity of that population," said Richard Gast, Ph.D., a postdoctoral fellow in the Kennedy laboratory and lead author of the study.

The findings also have the potential to shift the focus for neuroscientists toward using models that account for neural heterogeneity in neural networks, according to Gast. He added that, moving forward, the team will be applying their mathematical model to investigate the role that neuronal diversity plays in the basal ganglia, a part of the brain that is strongly affected by Parkinson's Disease.

"If we just ignore heterogeneity in the basal ganglia, and we model it mathematically, our results suggest that we will get the functional properties of the neuronal populations in the basal ganglia very wrong, so it's definitely an important variable to consider here," Gast said.

More information: Richard Gast et al, Neural heterogeneity controls computations in spiking neural networks, *Proceedings of the National Academy of Sciences* (2024). DOI: 10.1073/pnas.2311885121

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