Engineering the Brain's Blueprint: Integrating Synaptic Nanoarchitecture with Next-Gen Electronics

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Research Question

Degeneracy the ability of structurally distinct components to perform the same function is a foundational principle in both biological and electronic systems. In the brain, compositional degeneracy enables robust and adaptive synaptic signaling, even under noisy or variable conditions. Despite its critical role in ensuring neural resilience, no current framework explicitly incorporates this concept into the nanoscale organization of synapses or leverages it to inform neuromorphic circuit design. Conventional imaging and analysis methods often provide fragmented insights into synaptic architecture, limiting our understanding of plasticity and hindering the development of biologically inspired electronic systems. In this project, we combine super-resolution microscopy with statistical modeling to investigate the nanoscale organization of synaptic proteins. We model these assemblies as information processing units, revealing how molecular clustering within synaptic nanodomains modulates uncertainty and precision in information transfer. In parallel, we translate these biological insights into the design of advanced semiconductor devices. By integrating principles of synaptic computation with innovations in materials science and device engineering, we aim to develop next-generation neuromorphic hardware that mirrors the complexity, adaptability, and energy efficiency of the brain. This interdisciplinary effort at the interface of neuroscience, statistical physics, materials science, and electronics lays the foundation for a new class of neuroelectronic systems. By unifying nanoscale biological computation with physical design, we seek to establish a fundamental framework for building adaptive, resilient, and biologically inspired artificial intelligence.

Preferred background

Applied physics, Applied Mathematics or Engineering with an aptitude for Neuroscience.

For more information, see:

https://www.nature.com/articles/s41586-021-03748-0