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Neuromorphic Computing Using Superconducting Electronics

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***Abstract*–The human brain is a powerful computing system, exhibiting many desired computing properties like fault tolerance, parallelism and energy efficiency. The recent rise of artificial neural networks and deep learning, which in turn have led to systems like Alpha Zero and Chat GPT, have been fueled by the imitation of the information-processing mechanisms in the brain. These advances have come despite the fact that the aforementioned neural network and AI (Artificial Intelligence) programs are typically run on conventional digital hardware, whose architecture and operating principles are fundamentally different than the brain; this has resulted in excess power dissipation and slowdown for these systems. Over the past decade, significant efforts have been made to produce hardware that works closer to biological neural systems, igniting the field of neuromorphic computing. Although this field is still fairly new, neuromorphic hardware has already been successful in increasing speed and reducing power when running neural networks and AI programs.**

Superconducting Electronics are a natural fit for neuromorphic computing. Many of the basic operations of neuromorphic computing like spiking and thresholding are fundamental to the physics of Josephson junctions. Low-loss superconducting transmission lines can carry pulses without distortion like dendrites and axons, and mutually-coupled superconducting loops can perform storing and weighting operations like synapses. Neuromorphic processors do not rely as heavily on dense memory circuits, typically a weakness of superconducting digital computing. Recent studies have shown that a superconducting neuromorphic processor would potentially be faster, more energy efficient and more biologically realistic than any semiconducting neuromorphic hardware available today.

In this talk the most recent and exciting developments in superconducting neuromorphic computing will be discussed. Basic neuron and synaptic circuits will be presented along with examples of spiking neural network architectures. Recent experimental results will be highlighted along with projections of future performance. Applications such as image and video processing, biological brain simulation, and fast pattern recognition will be discussed. The presentation will conclude with a possible pathway to human cortex complexity.

***Keywords (Index Terms)*–neuromorphic, neuromorphic computing, neuron, superconducting, Josephson junction, nanowire, bio-inspired, neural network, spiking neural network, Hopfield**

network, single flux quantum, action potentials, learning, spike-timing dependent plasticity, fan-in, fan-out

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