Energy-Efficient Hardware for AI: Subthreshold Silicon Neurons and Gain-Cell Analog In-Memory Computing

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Abstract:

Emerging devices and circuits open a path to energy-efficient AI hardware beyond what conventional digital accelerators reach. This talk presents two complementary efforts at Duke. The first is a compact subthreshold Izhikevich silicon neuron in the SkyWater SKY130 process, operating at 0.487 V with picoampere-level bias currents. Operational transconductance amplifiers set the recovery and coupling parameters through external tail currents, which eliminates the fixed transistor-ratio control of prior subthreshold neurons and holds biological time scales in an 18 um x 19 um footprint. The design reproduces seven canonical cortical firing patterns across five process corners in post-layout extracted simulation. The second effort is a 4T1C gain-cell for output-stationary analog in-memory computing in 40 nm CMOS. The cell accumulates a matrix multiplication inside the array over 29,000 analog states with a 50 ps, 0.02 fJ write, and per-cell calibration holds the result within two 7-bit codes of a digital baseline. The dataflow runs 1572x fewer multiply-accumulate cycles and uses 4.5x less energy than a weight-stationary baseline.