Classical Reversible Computation by Quantum Coherence

Daniel Loss

Rising energy demand from data-centre and AI applications has renewed interest in reversible computation, where logic need not dissipate heat at every step if information is uncomputed. Implementations have so far been classical: adiabatic CMOS reduces dissipation by slowing charge motion but is still limited by the threshold physics of transistors. Here we propose classical reversible logic implemented by coherent spin dynamics in a spin quantum-dot array, with inputs and outputs in classical basis states and no algorithmic use of superposition [1]. The same spin stores, transports, and computes, with unitary rotation replacing irreversible switching. The universal building block is an iToffoli gate driven by DC voltage pulses and anisotropic exchange in Ge/Si hole spins. Simulations with experimental parameters reproduce the Toffoli truth table and yield a testable error landscape. Because shuttling transports the bit without measurement, logic and data movement remain reversible until readout. Millivolt pulses on femtofarad gates yield a gate energy below the 4~K Landauer scale, about five (eight) orders of magnitude below a room-temperature CMOS Toffoli with (without) 4 K cooling overhead. The same semiconductor hardware is therefore dual-use, supporting quantum algorithms when superposition is used and classical reversible logic otherwise.

[1] D. Loss, arXiv:2607.06219.