Quantum-dot Cellular Automata: Beyond the Transistor Paradigm

Craig S. Lent
Department of Electrical Engineering
University of Notre Dame
Notre Dame, IN 46556

Synthetic chemistry confers the ability to construct to specification the smallest structures possible—individual molecules. As we become increasingly able to measure and manipulate molecules one-by-one the opportunity to create integrated structures with single-molecule functional building blocks comes into view. Not everything benefits from being shrunk down to the nanoscale, but information processing certainly does—witness the down-scaling that has driven computing hardware for the last thirty years. Unfortunately, shrinking transistors to the size of single molecules fails because they dissipate too much energy as heat. Forming the interconnection between molecular transistors is also prohibitively difficult.

An attractive alternative, molecular quantum-dot cellular automata (QCA), encodes binary information in the charge configuration of individual molecules and has the potential to enable general-purpose computing without catastrophic power problems. Molecular QCA cells interact with their neighbors through Coulomb coupling, so no other interconnect is needed. Prototype devices and circuits have been built using small metal dots in the single-electron tunneling regime. Although these prototypes require milli-Kelvin operating temperatures, they have established a proof-of-principle—using single-electron transfer as the basis of device operation. Molecular implementations work at room temperature and could operate at the thermodynamic limits of computation. Work has begun on reconceiving circuit and computer architecture on this new transistor-less basis; QCA has an architectural, not just a single-device, future. Several types of mixed-valence molecules have been synthesized and exhibit the bistable switching behavior under an applied field required for QCA operation. Recent results using single dangling bonds on a Si surface to form QCA cells have demonstrated room temperature operation. Various other implementations are being explored. Magnetic QCA has been demonstrated using nanomagetic dots. Semiconductor quantum-dots can be formed by several methods and QCA operation has been demonstrated in lithographically defined GaAs, etched Si, and precision doped Si.