Structure of Reversible Cellular Automata

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Abstract. Cellular automata are examples of discrete complex systems where non-trivial global behavior emerges from the local interaction of trivial components. Cellular automata have been studied, among other perspectives, as models of massively parallel computation tightly connected to the microscopic physics. Physics is time reversible and satisfies various conservation laws, and by a careful design these properties can be implemented in cellular automata as well. The concept of time reversibility is important in this context, as irreversible logical operations such as AND and OR are "wasteful" and necessarily lead to dissipation of energy. It is well known that simple cellular automata rules can be computationally universal, and universal cellular automata exist even under the additional constraints of reversibility and conservation laws.

In this talk we discuss computational universality in (reversible) cellular automata and the connection to reversible logic. We demonstrate how any globally reversible one-dimensional cellular automaton can be implemented using locally reversible logical gates. Analogous result is true also among two-dimensional cellular automata, while in higher dimensions the question is open. Note that locally reversible cellular automata are the classical counter part of quantum cellular automata, which can be most conveniently defined as infinite, regular arrays of locally unitary operators. Many of the structure results concerning reversible cellular automata can then be naturally extended to hold for the quantum cellular automata as well.

C.S. Calude et al. (Eds.): UC 2009, LNCS 5715, p. 6, 2009.