Fundamenta Informaticae 52 (2002) i-ii

IOS Press

Introduction to the special issue on Cellular Automata

Cellular automata (CA) were originally proposed by John von Neumann as formal models of biological systems with the goal of describing self-reproducing organisms with the rigor of an axiomatic and deductive approach. The automaton originally described by von Neumann is a two-dimensional infinite array of uniform cells, originally called a cellular space, where each cell is connected to its four orthogonal neighbors.

During the past few years, CA have been studied from many different angles, and applied to a wide variety of purposes with respect to which they are referred to by different names, such as tessellation automata, cellular structures, iterative arrays. In particular, there is a growing interest in CA both in theoretical Computer Science, Physics, Biology and many other fields opening new perspectives of mutual relation among these different areas of scientific knowledge. Relationships of these structures to existing problems are constantly being sought and discovered. Physicists and biologists began to study cellular automata for the purpose of modeling in their respective domains since, although they have a simple structure, they show a rich dynamical behavior that is reminiscent of real systems. As for computer science, CA are computing devices that are as powerful as Turing machines. Computation universality and other computation-theoretic questions were considered important. Moreover, CA are well-suited for parallel implementation and thus the growing interest on parallel computation has provided further reasons of interest in this field.

The usually CA are studied which consist of a one- or two-dimensional (possibly infinite) grid of cells, though higher dimension can be also considered. The cells of the grid are arranged on a discrete regular lattice, where the neighborhood of each cell (i.e., the cells to which the cell is connected to) has the same structure. Time is discrete, and at each time instant each cell of the grid is in one of a finite set of possible states. A specification of a state to each cell at a given time instant forms a configuration or global state of the CA.

The function that determines the state evolution is the same for all cells and is called local rule. The local rule is usually assumed to be deterministic. This, however, is not necessary, and non-deterministic maps have been studied in connection with fluid dynamics (lattice gas CA) and also in language theory. At time $t = 0$, the CA is in some initial configuration, and henceforth proceeds under the effect of the local rule, which is applied in a uniform way to the state of each cell and those of all the other cells of its neighborhood. The global evolution is thus obtained by the synchronous updating of all states according to the local rule. This produces a transformation from the set of all configurations into itself, called the global transition map (or rule) of the CA. Summarizing, a CA is characterized by four features: the geometry of the underlying grid of cells, the invariant neighborhood of each cell, the set of states each cell can assume, and the local transition rule.

From the global viewpoint CA can be considered as models of complex systems because, despite their simple structure (in many cases the local rule is very simple), they can give rise to extremely complicated dynamics and can describe complicated phenomena. The mathematical simplicity in CA description is considered to be a significant advantage for modeling.

This special issue includes 13 papers, that cover different aspects of Cellular Automata, mainly on the theoretical side. In some papers classes of automata with specific properties of their local rule are studied. This is the case of the paper by Boccara and Fuks, that studies the class of CA's with number-conserving rules. The same class is the subject of the paper by Imai, Morita and Sako, where the stress is on algorithmic aspects, and on the solution of the classical Firing Squad Synchronization Problem with this special kind of CA. Another variant of CA is introduced in the paper by Buchholz, Klein and Kutrib, where interaction and limited determinism capabilities are added. A different topology, hyperbolic networks, is introduced by Nichitiu and Remila, showing how CA can be effectively simulated on it. Finally, Umeo and Kamikawa study CA where communication between cells is severely restricted, being limited to 1 bit, looking in particular at their capability to generate in real-time non-regular sequences.

Dynamical properties of CA (i.e., stability of subshifts) are studied in the paper by Kurka and Maass. Subshifts are a very important class of CA rules: in the paper by Cattaneo, Dennunzio and Margara a correlation is established between some transitivity conditions of subshifts and the classification of the corresponding languages. The characterization of languages recognized by CA is another relevant research topics: Merkle and Worsch give interesting results using CA with a stochastic evolution rule. Generalizing to 2D automata, Delorme and Mazoyer characterize families of figures recognized by pebble automata, with some results on their universality properties. CA are also used to establish a geometrical hierarchy of graphs in the paper by Martin. The computational power of (one-dimensional) CA is also the subject of the paper by Sutner: CA whose reachability and confluence problems have arbitrary r.e. degree of unsolvability are exhibited. Reaction-diffusion systems are well simulated by CA, and many applications based on CA are related to reaction-diffusion systems: the paper by Weimar treats the 3D case.

At the end, the paper by Sanders, Vollmar and Worsch treats a very interesting issue, i.e. energy consumption and physical feasibility of CA, which is traditionally a question of great interest for more conventional models of computation, like Turing machines, and is also of great importance in the recently developed field of quantum computing.

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