Abstract

The field of bio-inspired digital hardware was pioneered by John von Neumann. A gifted mathematician and one of the leading figures in the development of the field of computer engineering, von Neumann dedicated the final years of his life on what he called the theory of automata. His research, which was unfortunately interrupted by his untimely death in 1957, was inspired by the parallel between artificial automata, of which the paramount example are computers, and natural automata, such as the nervous system, evolving organisms, etc.

Through his theory of automata, von Neumann conceived a set of machines capable of many of the same feats as biological systems: evolution, learning, self-repair, self-replication, etc. At the core of his approach was the development of self-replicating machines, that is, machines capable of producing identical copies of themselves.

This thesis is part of a more general research project, called Embryonics (a contraction of the words *embryonic electronics*), which aims at establishing a bridge between the world of biology and that of electronics, and in particular between molecular biology and digital systems. One of the main goals of the Embryonics project is to determine if, given modern technology, Von Neumann's dream of a self-replicating machine can be realized in hardware.

Thus, inspired by von Neumann ideas, the first goal of this thesis was to realize, using the Embryonics architecture, the first hardware implementation of a machine capable of self-replication and exhibiting the property of universal computation, i.e., a universal Turing machine. The hardware architecture of the machine consists of a multicellular two-dimensional array of artificial cells (MICTREE cells) developed in our laboratory.

These MICTREE cells, a new kind of *coarse-grained field-programmable gate array*, are used for the implementation of multicellular artificial organisms with biological-like properties, i.e., capable of self-repair and self-replication. But the design of the software programs defining the behavior of the MICTREE cells is difficult and until now, had to be realized by hand, an approach that often led to errors in the software description. These hard-to-find errors increased considerably the design time of an Embryonics system.

Thus, the second goal of this thesis was to develop a programming methodology to deal with complex applications in the Embryonics project. We present, in order to demon-

strate this methodology, a detailed description of the implementation of some examples (from simple to complex), all based on a top-down design process characterized by the systematic decomposition of a complete microprogram (an artificial genome) into a set of smaller sub-microprograms, by the systematic construction and optimization of binary decision trees and diagrams, and by a rigorous organization of these sub-microprograms according to the demands of the Embryonics architecture. We finally developed a coherent family of software tools (MIC Editor, MIC Compiler, Visual BDD, MIC Sim, and a serial loader) that have been integrated into a single graphical design environment in order to achieve versatility and user-friendliness.