Some Applications of FPGAs in Bio-Inspired Hardware

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If one considers life on Earth since its very beginning, three levels of organization can be distinguished: the *phylogenetic* level concerns the temporal evolution of the genetic programs within individuals and species, the *ontogenetic* level concerns the developmental process of a single multicellular organism, and the *epigenetic* level concerns the learning processes during an individual organism's lifetime In analogy to nature, the space of *bio inspired* hardware systems can be partitioned along these three axes, phylogeny, ontogeny, and epigenesis, giving rise to the *POE* model, recently introduced by Sipper *el al* [1, 2]

In this short paper we briefly present three FPGA based systems, each situated along a different axis of the POE model [3]

The firefly machine: A phylogenetic system. The firefly machine is part of an ongoing effort within the burgeoning field of bio inspired systems and evolvable hardware [4] The system is an evolving cellular machine in which evolution takes place completely *online* This latter term means that *all* evolutionary operations (selection, crossover, mutation), as well as fitness evaluation, are carried out online, in hardware This is to be distinguished from *offline* evolution, where parts of the evolutionary process are carried out in software, on a remote computer (this issue is discussed in detail by Sipper *el al* [1])

The FPGA based machine is a one dimensional cellular automaton, evolving via the *cellular programming* evolutionary algorithm [5] Each of the system's 56 binary state cells contains a genome that represents its rule table These genomes are initialized at random, thereupon to be subjected to evolution The environment imposed on the system specifies the resolution of a global synchronization task: upon presentation of a random initial configuration of cellular states, the system must reach, after a bounded number of time steps, a configuration whereupon the states of the cells oscillate between all 0s and all 1s on successive time steps This may be compared to a swarm of fireflies, thousands of which may flash on and off in unison, having started from totally uncoordinated flickerings Each insect has its own rhythm, which changes only through local interactions with its neighbors' lights Due to the local connectivity of the system, this global behavior involving the entire grid comprises a difficult task Nonetheless, applying the cellular programming evolutionary algorithm, the system evolves (i e , the genomes change) such that the task is solved [6]

L hardware: An ontogenetic system. The ontogenetic axis involves the *development* of a single individual from its own genetic material, essentially without environmental interactions The main process involved in the ontogenetic axis can be summed up as *growth*, or *construction* Ontogenetic hardware exhibits such characteristics as replication and regeneration which find their use in many applications [1, 7]

Our L hardware is based on the concept of L systems, originally conceived as a mathematical theory of plant development [8] The central concept of L systems is that of rewriting, which is essentially a technique for defining complex objects by successively replacing parts of a simple initial object using a set of *rewriting rules* or *productions* We constructed a L hardware system in an FPGA, which implements a certain set of axioms and productions [9, 10]

The FAST neural network: An epigenetic system. The epigenetic axis involves *learning* through environmental interactions that take place after formation of the individual To the best of our knowledge, there exist three major epigenetic systems in living multicellular organisms: the nervous system, the immune system, and the endocrine system, the first two having already served as inspiration for engineers

We have developed a network architecture dubbed *FAST* (Flexible Adaptable Size Topology) that implements an unsupervised clustering algorithm, where the network must discover correlations within the input data and cluster, or categorize them accordingly [11, 12, 13] The network's topology changes dynami cally, a new neuron being *added* (or activated) when a *sufficiently distinct* input pattern is encountered, and an active neuron being *deleted* through the application of probabilistic deactivation To date, a four neuron FAST prototype has been implemented using FPGAs and applied to the solution of pattern recognition and enhancement problems

FPGA devices, with their capacity for online re configuration, afford a viable platform for realizing bio inspired hardware The future may see this tech nology put to use in the creation of more adaptive systems, exhibiting such characteristics as evolution, growth, and learning

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