Workshop on Regeneration and Learning in Developmental Systems

Preface

The WORLDS workshop at the Genetic and Evolutionary Computation Conference in 2004 is the first to be devoted to the important and neglected field of computational development within the evolutionary computation community. Evolutionary algorithms are inspired by Darwin's magnificent theory of evolution by natural selection. However why should it stop there? There are many other processes in living systems that are fundamental to the existence of life that can also inspire us. In particular we would like to emphasize the extraordinary way that the genetic information in DNA is unwrapped via genetic regulatory networks and also process of development of a multicellular organism. These processes are not just involved in the creation of a new born embryo but go on for the entire lifetime of an organism. Nature has found a way of building and evolving organisms with of the order of 10^{13} cells (approximately the number of cells in an adult human) from a single genotype resident in a fertlised egg. This process not only creates all the organs of the animal body but also is responsible for the central nervous system and the brain of the organism. Often we seem to struggle with our evolutionary algorithms to make them scalable to large problems. Nature has learned this trick long ago and can build "simple" organisms and "complex" organisms with comparative ease. How does it do it? What is the trick? What can we learn from it?

Computational development is concerned with these questions and in particular the building of software and hardware systems that are modeled on biological development of multicellular organisms. There is much that we could learn from this process that might allow us to construct and evolve very large systems. The huge growth in information content from the genotype to the enormously complex phenotype is testimony to the extraordinary ability of natural evolution to exploit *emergence*. How does nature achieve this feat of engineering? In his lovely book, 'The Way of the Cell', the eminent biologist Frank Harold explains:

“Genes specify the cell’s building blocks; they supply raw materials, help regulate their availability and grant the cell independence of its environment. But the higher levels of order, form and function are not spelled out in the genome. They arise by the collective self-organization of genetically determined elements, affected by cellular mechanisms that remain poorly understood.”

The six papers in this workshop cover a variety of topics within the field.

Miller and Thomson argue that there must be a limit to the complexity of software and hardware that human beings can practically build using the top down design process. The most complex software we build today is incredibly expensive to maintain and build. They note that this is alarming since modern software is extremely simple when compared with living systems. They argue that it raises the question: How could we design systems of the complexity of human beings? They make a strong case that this will only be possible if we are prepared to turn to the master builder for inspiration, nature herself. They present a method for evolving multicellular structures (e.g. national flags) by evolving the program for a cell that allows it to replicate, change type and read and emit simulated chemicals. Many of their solutions naturally exhibit great regenerative powers and are robust to large amounts of damage.

Bentley, inspired by nature's ability to utilize physical complexity, has created an interesting evolvable genetic regulatory model for a single cell using the idea of fractal proteins. Just as with proteins in real biology, his fractal proteins are the *lingua franca* of his cells. He has applied the ideas to the control of a robot. He has introduced sensors that produce fractal proteins that can influence the expression of genes in the cellular program. He finds that this greatly increases the evolvability of the robot controller.

Edwards targets his developmental system for evolvable hardware. In a system somewhat like a Lindenmayer system, he evolves a set of rules which are used to re-write symbols in a string of symbols. The rules continue to be applied until the resulting symbol string stops changing (so in a sense it is self-oraganising). Finally the symbol string can be mapped to binary hardware configuration data (e.g. for a FPGA). The definition of this mapping can be tailored appropriately for the intended hardware.

Heng, Miller and Tyrrell present work that built on Miller's previous work. They have modified that work in a number of places to make it suitable for implementation on FPGA hardware and also to increase its efficiency. They evolved a cell that constructs a 36 cell French flag with impressive powers of regeneration from transient faults. The eventual intention is to build a real world application that uses development to autonomously recover from actual damage to hardware.

Lehre and Hartmann present some nice work that addresses a fundamental question in this field: *For which classes of problems is it beneficial to apply developmental mappings over more traditional direct encodings*? They attack this problem by cleverly modifying a fitness function so that the problem becomes harder (or remains fixed) to solve for a direct mapping but whose difficulty remains fixed (gets more difficult) for the developmental mapping. They apply their analysis to direct binary encodings and the Kitano matrix re-writing (developmental) mapping on a number of problems.

In the final paper in this workshop Federici evolves a cellular growth program in the form of a feed-forward Artificial Neural Network that reads the states of cells in the Von Neumann neigbourhood, the cells internal metabolism, the chemical concentration and the cell age. The ANN decides where the new cell may grow and the new metabolisms and also new chemical production. He evolves a multi-stage development process, these operate by locking early phases of development and adding resolution to later stages. He presents results for a number of well-chosen target patterns. He, like Miller, finds that the organisms are very robust to damage, even though it is not selected for in the fitness function.

There is much food for thought in these interesting papers and it is hoped that they will encourage others to take part in the workshop and be inspired to join this very interesting and important nascent field of research.

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