Biologically Inspired Fault-Tolerant Computer Systems

Andy Tyrrell

Bio-Inspired Architectures Laboratory
Department of Electronics
University of York, YO10 5DD, UK.
amt@ohm.york.ac.uk

Researchers have recently begun investigating both evolutionary and developmental approaches to reliable system design in the form of Embryonics and Immunotronics. This discussion suggests a completely new approach to creating fault-tolerant systems that takes inspiration from biology.

Reducing the failure probability and increasing reliability has been a goal of electronic systems designers ever since the first components were developed. No matter how much care is taken designing and building an electronic system, sooner or later an individual component will fail. For systems operating in remote environment such as space applications, the effect of a single failure could results in a multi-million pound installation being rendered useless. With safety critical systems such as aircraft the effects are even more severe. Reliability techniques need to be implemented in these applications and many more. The development of fault tolerant techniques is driven by the need for ultra-high availability, reduced maintenance costs, and long life applications to ensure systems can continue to function in spite of faults occurring.

Nature has achieved levels of complexity that far surpass any man-made computing system, and phenomenal robustness: in the trillions of cells that make up a human being, faults are rare, and in the majority of cases, successfully detected and repaired. This level of reliability is remarkable.

In any living being, every one of its constituent cells interprets the DNA strand allocated in its nucleus to produce the proteins needed for the survival of the organism, independently of the particular function it performs. Which part or parts of the DNA are interpreted will depend on the physical location of the cell with respect to its neighbours.

Embryonics (*embryonic electronics*) is inspired by the basic processes of molecular biology and by the embryonic development of living beings. By adopting certain features of cellular organization, and by transposing them to the two-dimensional world of integrated circuits, properties unique to the living world, such as *self-replication* and *self-repair*, can also be applied to artificial objects (integrated circuits). Self-repair allows partial reconstruction in case of a minor fault, while self-replication allows complete reconstruction of the original device in cases where a major fault occurs.

The aim of Embryonics is to transport these basic properties to the 2-dimensional world of cellular arrays using specifically designed FPGAs as building blocks. In any embryonic system, every one of its FPGA-based cells interprets a configuration register allocated in its memory, independently of the particular logic function it performs. Which configuration register is interpreted will depend on the co-ordinates of the cell determined by those of its neighbours. Embryonic cellular arrays share the following properties with their biological counterparts.

To increase still further the potential reliability of these systems, inspiration has also been taken from biological immune systems – Immunotronics. The acquired immune system in humans (and most vertebrates) has a mechanism for error detection, which is simple, effective and adaptable.

Artificial immune systems take their inspiration from the operation of the human immune system to create novel solutions to problem solving. Although still a relatively new area of research, the range and number of applications is already diverse. Computer security, virus protection, anomaly detection, process monitoring, pattern recognition, robot control, and software fault tolerance are some of the applications artificial immune systems are being applied too. One important feature links all of these applications – they operate in a software domain. Our approach demonstrates that artificial immune systems can also exist in the hardware domain.

The early history of the theory of self-replicating machines is basically the history of John von Neumann's thinking on the matter. Von Neumann's automaton is a homogeneous two-dimensional array of elements, each element being a finite state machine. In his historic work, von Neumann showed that a possible configuration of his automaton can implement a universal constructor able to build onto the array any computing machine described in a dedicated part of the universal constructor, the tape. Self-replication is then a special case of construction, occurring when the universal constructor itself is described on the tape. Moreover, von Neumann demonstrated that his automaton is endowed with two major properties: construction universality, the capability of describing on the tape and building onto the array a machine of any dimension, and computation universality, the capability of describing and building a universal Turing machine.

May be we should look towards biology and back to von Neumann to consider how we can manage such huge complexities in our computing systems and still place our lives in their hands.