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Abstracts of Invited Talks

**Abstracts of invited talks presented
at Unconventional Computing 2007,
12-14 July 2007, Bristol, United
Kingdom**

**Tetsuya Asai (Sapporo, Japan): Neuromorphic
VLSIs: Past, Present and Future**

“Neuromorphic Engineering” introduced by Carver Mead is a new research field based on the design and fabrication of neural systems whose architecture and design principles are based on biological nervous systems. I will briefly review the past and present works including my developments on neuromorphic VLSIs, and will discuss the future perspectives.

**Julian Miller and Simon Harding (York, UK):
Evolution in Materio: evolving computation in
materials**

In 1958 Gordon Pask described a method of manipulating a physical system (a series of electrodes in a chemical chamber) so that it would carry out a new function. This work was largely forgotten for many years. In 1996, Adrian Thompson demonstrated that when artificial evolution is sufficiently unconstrained it is possible for it to exploit physical properties for computation. He demonstrated this using an re-programmable electronic device called an Field Programmable Gate Array (FPGA). This inspired the idea that artificial evolution might be able to used to discover hitherto unknown ways of configuring matter to carry out computation. This led to a research project that demonstrated that artificial evolution can be used to manipulate a liquid crystal device so that it can do computations that solve a number of tasks (frequency discrimination, robot control, Boolean logic). We describe this work and discuss further prospects for evolving computation in materials.

Jonathan Mills (Indiana, USA): Natural Computing

Drawing on over a decade of experience with Rubel's extended analog computer (EAC), some simple but important questions are addressed. What is a natural computer? How does a natural computer differ from a digital computer? How does a natural computer perform computation? What is an analogy, for those machines that are configured by analogy? How is a natural computer programmed? For what classes of applications are natural computers the most efficient choice? The relationships between the laws of physics, important mathematical principles, and the technology and architecture of natural computers are presented to answer these questions. Applications with a real natural computer, Rubel's EAC, are used to illustrate our growing understanding of the principles of natural computing. Participants will be able to explore these ideas for themselves using several EACs that will be available during the conference.

Kenichi Morita (Hiroshima, Japan): Computation-Universality in Simple Reversible Systems

Reversible computers that are defined as "backward deterministic" systems are unconventional models of computation having an analogous property of physical reversibility. Until now, many kinds of reversible models, such as reversible Turing machines, reversible logic circuits, and reversible cellular automata, have been proposed and investigated. In this talk, we mainly discuss reversible cellular automata and their computation-universality. We can see that even very simple reversible cellular automata have universal computing ability. We first give a brief survey on this topic, and show several simple models of 2-dimensional universal reversible cellular automata [1]. Then, we show that also in the 1-dimensional case there are very simple universal reversible cellular automata [2]. Universality issues on simple reversible logic elements and Turing machines are also discussed.

[1] Morita, K., Tojima, Y., Imai, K., and Ogiro, T. Universal computing in reversible and number-conserving two-dimensional cellular spaces, in *Collision-based Computing* (ed. A. Adamatzky), 161-199, Springer-Verlag, (2002).

[2] Morita, K., Simple universal one-dimensional reversible cellular automata, *Journal of Cellular Automata*, (in press).

Toshiyuki Nakagaki, Tetsu Saigusa, Atsushi Tero, Ryo Kobayashi (Sapporo, Japan): Solving Networking Problems by Amoeba: Dynamics and Computation

We demonstrate that an amoeboid organism, a plasmodium, of the true slime mold can solve certain computational tasks while foraging in a complex environment. Thus when presented with two food sources separated one from each other by a maze of obstacles the plasmodium calculates a shortest path connecting the sources through the maze by forming a tubular structure of protoplasm so that absorptions of nutrients and intracellular communication are maximised. We propose a mathematical model for the plasmodium-based problem-solving, based on physiological mechanism of morphogenesis of the tubular structure. The mathematical model indicates prospective ways of designing unconventional computing architectures on biological substrates.

Susan Stepney (York, UK): The Neglected Pillar of Material Computation

Biological organisms and processes are often touted as information processing systems, and then analysed in computational terms. But their properties differ in many important ways from our “classical” mathematical-computational system formalisms, and the way these are implemented “in silico”. In particular, they have an extra important feature: their operation is deeply entwined with the physical and chemical properties of the substrates of which they are composed. Those properties both impose constraints on, and provide capabilities to, the computations being performed. Here I discuss the “missing pillar”, of “in materio” computation, that is needed to complement classical computational models, before we can understand biological information processing in full.

Christof Teuscher (Los Alamos, USA): Computation in Self-Assembled Avogadro-Scale Systems — Challenges and Opportunities

By using chemical self-assembly and self-organizing principles at the cellular, molecular, or atomic scale, it is nowadays relatively straightforward to “build” functional assemblies in a bottom-up way that involve

an Avogadro number (10^{23}) of interconnected components. The hope in using such unconventional fabrication paradigms is to eventually be able to go beyond Moore's law by creating highly complex information processing devices in a simple and cheap way. Avogadro-scale engineering is not only concerned with building such devices, but also addresses the challenges of how one can efficiently and reliably compute and how the component's functionality can be programmed and controlled. Since such large-scale nano, bio, and chemical systems often don't work according to the principles we know from silicon-based digital computers, there is a clear lack of design principles and programming paradigms. Usual irregularities, inhomogeneities, and unreliabilities in the physical substrate make the entire undertaking even more challenging. In this talk, I will review the challenges and opportunities of Avogadro-scale engineering, identify possible show-stoppers, and delineate a roadmap of both the issues that need to be addressed and the routes to avoid.

Klaus-Peter Zauner (Southampton, UK): Biological Computing Substrates

A crucial difference sets apart present computing technology from information processing mechanisms utilised by organisms: The former is based on formalisms which are defined in disregard of the physical substrate used to implement them, while the latter directly exploit the physico-chemico properties of materials. There are many advantages to isolating the operation from implementation as is the case in current computers—but these come at the cost of low efficiency. In applications where size and energy-consumption is tightly restricted, or where real-time response to ambiguous data is required organisms cope well, but existing technology is unsatisfactory. Taking heed of the clues from biology the question arises how the realm of computer science can be extended from formal to physical information paradigms. The aim is to arrive at a technology in which the course of computation is driven by the physics of the implementation substrate rather than arbitrarily enforced. The traditional tools and approaches of computer science are ill suited to this task. In particular it will be necessary to orchestrate autonomously acting components to collectively yield desired behaviour without the possibility of prescribing individual actions. Bio-electronic hybrid systems can serve as a starting point to explore approaches to computing with autonomous components. We take a two-pronged approach in which we recruit both molecules and complete cells as biological computing substrate. Molecules offer reproducible nonlinearity, self-assembly, and high integration density of complex input-output map-

pings. Cells, on the other hand, provide cheap and fast nano-engineering through self-reproduction, build in quality-assurance through testing at the point of assembly, self-reconfiguration, and self-repair. Molecules, however, require infrastructure and cells are typically too complex for efficient computation. Our expectation therefore is that in the long term practical biological computing substrates will be situated at the sub-pramolecular and subcellular level, i.e., at the interface between inanimate and animate matter.

