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Abstracts of Presentations

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Unentangling nuclear magnetic resonance computing by Matthias Bechmann, John A. Clark, Angelika Sebald, Susan Stepney

Nuclear magnetic resonance (NMR) is typically thought of as a possible technology for quantum computation. Here we instead outline how commercially available NMR spectrometers could be used to perform non-quantum computation: from addressable 3D memory, to a programmable 3D reaction-diffusion computer.

Cellular automata networks by Xin-She Yang and Young Z. L. Yang

A small-world cellular automaton network has been formulated to simulate the long-range interactions of complex networks using unconventional computing methods in this paper. Conventional cellular automata use local updating rules. The new type of cellular automata networks uses local rules with a fraction of long-range shortcuts derived from the properties of small-world networks. Simulations show that the self-organized criticality emerges naturally in the system for a given probability of shortcuts and transition occurs as the probability increases to some critical value indicating the small-world behaviour of the complex automata networks. Pattern formation of cellular automata networks and the comparison with equation-based reaction-diffusion systems are also discussed.

Halting in quantum Turing computation by Willem Fouché, Johannes Heidema, Glyn Jones, Petrus H.Potgieter

The paper considers the halting scheme for quantum Turing machines. The scheme originally proposed by Deutsch appears to be correct, but

not exactly as originally intended. The relationship of the halting scheme to the quest for a universal quantum Turing machine is considered.

A cellular-automaton-based anisotropic diffusion algorithm for subjective contour generation and its digital VLSI implementation by Takashi Morie, Takahiro Yamamoto

Subjective contours are imaginary contours that humans generate in the visual systems of their brains to perceive incomplete natural scene images. Therefore, generating subjective contours is important to realize human-like high-level vision functions. This paper proposes a cellular automaton (CA) based anisotropic diffusion algorithm for subjective contour generation. The diffusion state at each pixel is binary and it is updated using the neighboring pixel's states. By using two-step updating rules, gradually spreading diffusion is achieved, and it leads to successful subjective contour generation. For its VLSI implementation, we have designed a digital pixel circuit and verified the correct diffusion operation in the pixel circuit array by logic circuit simulation.

Implementation of logical operations on a domino substrate by Simon O'Keefe

This paper presents some simple ideas about domino gates. Domino gates are implementations of logical operations using toppling dominos to represent the movement of information (bits). The actively toppling domino represents a logic one, and absence of toppling represents logic zero. The domino model can be used as a representation of single-shot wave gates in unconstrained media, such as sub-excitable Belousov-Zhabotinsky reactors. On a practical note, they are slightly easier to set up and use than collision logic models using 'billiard balls'.

Collective perception of absolute brightness from relative contrast information — an emergent pattern formation approach by Jeff Jones and Mohammed Saeed

The human visual system is able to effortlessly perceive absolute brightness in a scene even though the output of retinal processing is a relative spatial encoding of local edge contrast information. Neural filling-in

processes are one suggested mechanism of reconstructing the original global surface brightness values from the local contrast edges but controversy continues as to whether such mechanisms are necessary, possible and biologically plausible. A low-level emergent pattern formation approach is described using a simple, reactive multi-agent system whose components perform a collective emergent perception of the scene. The population is able to generate absolute global brightness levels from local contrast based stimuli and can accurately perceive both real world imagery and classical illusory brightness phenomena. Recent brightness illusions that were introduced specifically to rule out low-level mechanisms of brightness perception can also be collectively perceived with the framework. The behaviour of the framework is analogised to the distortion of the background grey (*eigengrau*) by the diffusive flux of brightness and darkness information across brightness interfaces.

Mapping virtual self-assembly rules to physical systems by Navneet Bhalla, Peter J. Bentley, Christian Jacob

Throughout nature, decentralized components emerge into complex forms. It is through their interaction that components, governed by simple rules, self-assemble to create specific entities. The programs constituting these entities are based on the rules present in a given system and are executed on the physically and chemically encoded information comprising the components and their environment. A three-level approach is presented here which encompasses specifying a set of rules, modeling these rules to determine the outcome of a specific system in software, and translating to a physical system based on the set of rules present. The benefit of this approach is that no knowledge of the end result is required to create the physical system, mirroring the bottom-up process in nature. Five experiments, based on an example implementation of this approach, show that the translated physical systems self-assemble into the desired entities achieved by the simulations. These successful results demonstrate how this three-level approach is used for mapping virtual self-assembly rules to physical systems.

On the computational complexity of physical computing systems by Ed Blakey

By far the most studied model of computation is the Turing machine model. It is the suggestion of Church's Thesis that, as far as *computabil-*

ity is concerned, consideration of this model alone is sufficient; but what of *complexity*?

The traditional notion of computational resource, in terms of which computational complexity may be defined (since, in essence, complexity is nothing more than required resource viewed as a function of input size), caters almost exclusively for algorithmic models of computation such as the Turing machine model. Accordingly, the most commonly encountered computational resource is run-time of a Turing machine or algorithm or equivalent.

We here extend the definition of resource, notably so as to include the physical notion of precision with which we can make measurements; this allows characterization in a more insightful way of the complexity of computations performed by analogue, DNA, quantum and other physical computers.

The primary intent of this (ongoing) work is not that it be of practical use by, for example, offering physical solution methods that improve upon the speed, efficiency or similar offered by existing—especially digital—computers. Rather, the work is a theoretical study: the wider, more physical framework of computation is presented as a context in which to generalize the closely related notions of resource and complexity. The ultimate aim, from this theoretical viewpoint, is to shed light on whether complexity is inherent in *problems* as opposed to *solution methods*, whether the latter be physical or algorithmic.

The computing power of structured molecules with gaps: Watson-Crick insertion systems by Kaoru Onodera

New operations based on DNA complementarity called *Watson-Crick insertion operations* are introduced in order to investigate the computational power of insertion operations in case of taking double strands into consideration through operation processes. A *Watson-Crick insertion system* makes it possible for a computation to proceed by using sticking for incomplete molecules with *gaps* (i.e. missing nucleotides) in one of the strand. The difference between the new type of computing models and the existing insertion systems is due to the data structures they handle, double stranded sequences with gaps in Watson-Crick insertion systems, while linear strings in insertion systems. By introducing a variety of types of insertion rules, our results suggest that restrictions on insertion rules as well as on computation processes influence on the computational powers of Watson-Crick insertion systems with those types of rules.

A kinematic Turing machine by William M. Stevens

A Turing Machine in a three dimensional discrete space environment containing movable cubic parts is described. All of the cubic parts are identical in function. The only function that a part performs is to move a neighbouring part by one unit. Parts can be connected to neighbouring parts. When one part moves, parts that it is connected to also move. An example program for the Turing Machine is given.

Evaluation of a multi-path maze-solving cellular automata by using a virtual slime-mold model by Masayuki Ikebe and Yusuke Kitauchi

We describe cellular-automata that will enable solving a multi-path maze. When a slime mold and a food are put in an entrance and a goal of a maze, a shape of the slime mold indicates a shortest path from the entrance to the goal. We propose CA algorithm in which a slime mold changes its body to obtain food effectively. We simulated the virtual slime-mold model and the simulation results indicated obtaining shortest path of a multi-path maze.

Design of DNA spike oscillator by Kohta Suzuki and Satoshi Murata

A model of DNA spike oscillator is proposed. The behavior of the proposed oscillator depends on DNA sequences; thus, the frequency and amplitude of the DNA oscillator can be determined a priori. If we use sets of orthogonal DNA sequences, we can realize many independent oscillators working in parallel in a single tube. The oscillator is a double feedback system implemented by three elementary reactions composed of restriction, enzyme, and DNA hybridization. We have built a numerical model of the oscillator to determine the parametric domain of oscillation and have verified each elementary reaction by PAGE experiment. This kind of oscillator will be useful for generating periodic clock signal for various DNA-based nanosystems.

Wholeness based on gluing of incomplete information by Eugene S. Kitamura and Yukio-Pegio Gunji

The cause of emergence is described as a constant collapse and restoration of intent-extent relationships in robust systems. We use a cellular

automata (CA) model as a platform with conditions such that 1) each cell is not fully aware of the reference CA rule (indeterminacy), therefore it must make up its own rule by partial disjunctive normal form (PDF), and consequently, 2) every cell obeys a different CA rule. By incorporating such conditions to a CA model, Class 4 “complex” behavior is seen more ubiquitously, unrestricted to “the edge of chaos.” Standard deviation of entropy is examined to quantitatively measure the Class 4 behavior. When internal-perturbation is applied to the CA (map-perturbation), the system shows even greater robustness.

Physical Hypercomputation by Mike Stannett

We argue that observable values and the physical systems that generate them need not have representations belonging to the same computational class. It is possible both for computable systems to generate uncomputable values, and also for uncomputable systems to generate computable values. In particular, while quantum wave functions are typically uncomputable, the relationships between quantum theoretical operators are generally computable. At the same time we clarify an apparent temporal anomaly in recent attempts to provide a category theoretical semantics for quantum theory.

Nucleic acid enzymes: The fusion of self-assembly and conformational computing by Effirul I. Ramlan and Klaus-Peter Zauner

Macromolecules are the predominant physical substrate supporting information processing in organisms. Two key characteristics—conformational dynamics and self-assembly properties—render macromolecules unique in this context. Both characteristics have been investigated for technical applications. In nature’s information processors self-assembly and conformational switching commonly appear in combination and are typically realised with proteins. At the current state of biotechnology the best candidates for implementing artificial molecular information processing systems that utilise the combination self-assembly and conformational switching are functional nucleic acids. The increasingly realised prevalence of oligonucleotides in intracellular control points towards potential applications.

The present paper reviews approaches to integrating the self-assembly and the conformational paradigm with allosterically controlled nucleic acid enzymes. It also introduces a new computational workflow to design functional nucleic acids for information processing.

