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Martyn Amos · Anne Condon (Eds.)

Unconventional Computation and Natural Computation

15th International Conference, UCNC 2016
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Editors
Martyn Amos
Manchester Metropolitan University
Manchester
UK

Anne Condon
University of British Columbia
Vancouver, BC
Canada

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Preface

This volume contains papers presented at the 15th Unconventional Computation and Natural Computation Conference (UCNC 2016), which was held in Manchester, UK, during July 11–15, 2016.

As a field of research, *unconventional computation* augments classical modes of computation (i.e., the Turing and von Neumann models), by offering new conceptual frameworks, abstractions, substrates, and applications. Intersecting with this field is the study of *natural computation*, which draws inspiration from the physical world to develop new forms of computing. Taken together, these two deeply related fields offer the possibility of entirely new forms of computational devices and applications, as well as providing a space in which to rethink the entire notion of "computation" and "computability."

Topics that are generally considered to be within scope of the conference include (but are not limited to):

- Molecular, cellular, quantum, optical, and chaos computing
- Cellular automata
- Neural and evolutionary computation
- Artificial immune systems
- Ant algorithms and swarm intelligence
- Amorphous computing
- Membrane computing
- Computational systems biology and computational neuroscience
- Synthetic biology

The first UCNC was held in Auckland, New Zealand, in 1998, organized by the Centre for Discrete Mathematics and Theoretical Computer Science, University of Auckland, and the Santa Fe Institute. Since then, it has been held in Brussels, Belgium (2000), Kobe, Japan (2002), Seville, Spain (2005), York, UK (2006), Kingston, Canada (2007), Vienna, Austria (2008), Ponta Delgada, Portugal (2009), Tokyo, Japan (2010), Turku, Finland (2011), Orléans, France (2012), Milan, Italy (2013), London, Ontario, Canada (2014), and Auckland, New Zealand (2015, the first time the conference has returned to a site).

The 15th iteration of UCNC was organized and hosted by the Informatics Research Centre of Manchester Metropolitan University, UK. The conference received 30 full-paper submissions, of which we accepted 15 for oral presentation. We were also pleased to host six distinguished speakers:

Invited Lectures:

- Bob Coecke (University of Oxford, UK): "In Pictures: From Quantum Foundations to Natural Language Processing"
- Steve Furber (University of Manchester, UK): "The SpiNNaker Project"

– Friedrich Simmel (Technische Universität München, Germany): "Chemical Communication Between Cell-Sized Reaction Compartments"

Tutorials

– Masami Hagiya (University of Tokyo, Japan): "Gellular Automata"
– Rebecca Schulman (Johns Hopkins University, USA): "Self-Assembling Adaptive Structures with DNA"
– Jon Timmis (University of York, UK): "Many Hands Make Light Work: A Case Study in Swarm Robotics"

Fundamental to the spirit of UCNC are the satellite workshops, which allow participants to focus on specific areas of interest. We were delighted to host two such sessions:

– Membrane Computing (organized by Marian Gheorghe and Savas Konur)
– Physics and Computation (organized by Alastair Abbott and Dominic Horsman)

We thank the authors and invited speakers for contributing to the meeting, and the workshop organizers for enriching the event. We thank the Program Committee and the additional reviewers for their exemplary work in assessing the submissions, and the Organizing Committee for their efforts on behalf of the meeting. We also thank the Dean of Science and Engineering and the Informatics Research Centre for sponsoring the event, the LNCS team at Springer (Alfred Hofmann and Anna Kramer) for supporting the continued publication of the UCNC proceedings, and the EasyChair project for providing essential infrastructure.

July 2016

Martyn Amos
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Abstracts of Invited Talks

In Pictures: from Quantum Foundations to Natural Language Processing

Bob Coecke

Department of Computer Science, University of Oxford, UK
coecke@cs.ox.ac.uk

Abstract. This talk requires no background in physics, nor in linguistics, nor in fancy math! Earlier work on an entirely diagrammatic formulation of quantum theory, which is soon to appear in the form of a textbook [1], has somewhat surprisingly guided us towards an answer for the following question [2]: how do we produce the meaning of a sentence given that we understand the meaning of its words? This work has practical applications in the area of natural language processing, and the resulting tools have meanwhile outperformed existing methods.

References

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The SpiNNaker Project

Steve Furber

School of Computer Science, The University of Manchester,
Manchester M13 9PL, UK
steve.furber@manchester.ac.uk

Abstract. Just two years after the world's first stored program computer ran its first program at Manchester in 1948, Alan Turing published his seminal paper on "Computing Machinery and Intelligence". The paper opens with the words: 'I propose to consider the question, "Can machines think?"'. Turing then goes on to explore this question through what he calls "The Imitation Game", but which subsequent generations simply call "The Turing Test". Despite spectacular progress in the performance and efficiency of machines since Turing's time, we have yet to see any convincing demonstration of a machine that can pass his test. This would have surprised Turing - he believed that all that would be required was more memory. Although cognitive systems are beginning to display impressive environmental awareness, they do not come close to the sort of "thinking" that Turing had in mind. My take on the problems with true artificial intelligence is that we still really haven't worked out what natural intelligence is. Until we do, all discussion of machine intelligence and the "singularity" are specious. Based on this view, we need to return to the source of natural intelligence, the human brain.

The SpiNNaker project has been 18 years in conception and 10 years in construction, but is now ready to contribute to the growing global community (exemplified by the EU Human Brain Project) that is aiming to deploy the vast computing resources now available to us to accelerate our understanding of the brain, with the ultimate goal of understanding the information processing principles at work in natural intelligence. SpiNNaker is a massively-parallel computer system, ultimately to incorporate a million ARM processor cores (the largest machine to date has 500,000 cores) with an innovative lightweight packet-switched communications fabric capable of supporting typical biological connectivity patterns in biological real time.

Gellular Automata

Masami Hagiya

University of Tokyo, Japan
hagiya@is.s.u-tokyo.ac.jp

Abstract. Computational models derived from the research efforts to implement cellular automata by gel materials are presented. The models are given the name "gellular automata" using the adjective "gellular" which resembles "cellular". The efforts have been made in the research project "Molecular Robotics". In addition to computational models and their theoretical investigations, implementation techniques and possible applications of gellular automata are also touched upon.

Two kinds of gellular automata models have been investigated. One is diffusion-based and implemented by capsules made of gel shells containing water solutions. The problems caused by relying only on free molecular diffusion for cellular communication are discussed together with some approaches to solve the problems. The efforts to actually implement this kind of model using the alginic acid gel are also presented.

The other kind of model is based on gel walls (or valves) that can be opened or closed by molecules in solutions separated by the gel walls. In relation to this kind of model, DNA-based gels have been examined for implementing gel walls. Theoretical contributions in this line of research include the proof of computational universality and the implementation of block cellular automata with the Margolus neighborhood.

Possible applications of gellular automata include soft materials that form patterns possibly under stimuli from the environment, e.g., artificial organs.

Some efforts in the research project to go beyond models of cellular automata are also touched upon, i.e., efforts to realize swarm intelligence by molecular robots.

Self-Assembling Adaptive Structures with DNA

Rebecca Schulman

Chemical and Biomolecular Engineering and Computer Science,
Johns Hopkins University, USA
rschulm3@jhu.edu

Abstract. How could we program the self-assembly of a something as complex as an animal or a human being? From a strictly organizational point of view, self-assembly of such a structure would require organization across scales ranging from the angstrom scale to the meter scale. At the smallest size scales, it is possible to directly encode structure using a molecular sequence or set of sequences such that each unit of the structure is encoded by a specific molecular unit. But at larger size scales new mechanisms for organization are required. One general emerging principle of organization at these scales is that molecules encode a self-assembly process in which the final structure is functional but its shape can vary from one incarnation to the next. I'll describe how we might phrase such a problem of "adaptive" or "self-adjusting" self-assembly as a computational question and how we might implement such processes using molecules such as DNA.

As a case study of adaptive materials, we will consider networks formed from one-dimensional structures and junctions. Such networks exist across all size scales: networks of wires and devices form circuits, beams and joints form buildings. In biological systems, networks of axons, dendrites and neuronal cell bodies make up the brain and filaments such as actin and organizing proteins make up the cytoskeleton. I'll describe how we can consider how local programmable rules could be used to form such complex structures and how we could program many of these rules using interactions between DNA molecules.

Many Hands Make Light Work: A Case Study in Swarm Robotics

Jon Timmis

Department of Electronics, University of York, UK
jon.timmis@york.ac.uk

Abstract. There is increasing research in the area of swarm robotics, that is using many robots working together to solve problems, inspired (typically) by social insects. In this tutorial we will explore the area of swarm robotics, but also the wider area of collective robotics and how to develop collaborative distributed systems. We will also examine the use of evolutionary algorithms in swarm robotics to evolve both the controller and morphology of the robot at the same time, creating embodied artificial intelligence. We will end the tutorial on challenges for the area. This tutorial assumes no knowledge of swarm robotics.

Chemical Communication Between Cell-Sized Reaction Compartments

Friedrich Simmel

TU München – Physics Department E14, 85748 Garching, Germany

Abstract. The exchange of signals between information-processing agents is an important requirement for the coordination of their actions and may be utilized for the implementation of various "amorphous" computing schemes [1]. In biology, chemical interactions between cells are utilized, e.g., in differentiation and pattern formation, sensing and signaling. One of the most studied processes in bacteria is the "quorum sensing" phenomenon, in which bacteria exchange small diffusible genetic inducers and thus mutually influence their gene expression [2]. In this talk, we will discuss various implementations of synthetic chemical communication schemes between artificial cell-sized compartments, between bacteria, and also between bacteria and cell-free compartments [3–5]. In particular, we will discuss the production and detection of quorum sensing signals within emulsion droplets containing either genetically engineered bacteria or bacterial cell extract, and their utilization for simple computation and pattern formation processes.

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