Chapter 1
Introduction

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Abstract This chapter provides an introduction to the book *Computational Matter*, providing the historical background to the production of the book, and an overview of its scope and content.

1.1 Historical background

Stanislaw Ulam famously said that "using a term like non-linear science is like referring to the bulk of zoology as the study of non-elephant animals" (Campbell et al., 1985; Gleick, 1987): non-linear science actually forms the bulk of natural science. So we contend it is with *non-standard computing*, also referred to as *unconventional computing* (UCOMP): UCOMP actually forms the bulk of computational science.

UCOMP is the study of computation outside the standard model of conventional computing (which we refer to as *classical computation*, or CCOMP). By 'standard model' we mean the model underlying the implementation of almost all commercially available devices, and where the design of the devices make no special claims about their methods of computation. There is extensive territory outside this standard model, in terms both of theoretical models and of physical implementations, for UCOMP to occupy.

In order to help map out this territory, in 2009 the European Commission's Future and Emerging Technologies agency commissioned and published an Expert Consultation report on *Unconventional Formalisms for Computation* (European Commission, 2009), drafted by one of the editors of this book (SS).

> Conventional (classical) computation may be baldly characterised as that of the Turing/von Neumann paradigm: based on the mathematical abstraction of Turing Machines (or equivalents) with exact provable results, and an implementation in terms of sequential program v data models. It has been incredibly successful. How-

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> ever, there is increasing argument that it encompasses only a small subset of all computational possibilities, and increasing evidence that it is failing to adapt to novel application domains. — (European Commission, 2009)

That report summarised the then-current state of UCOMP research, and made a recommendation:

> The recommendation of this consultation is for a funded programme in **advanced unconventional computation**, intended to take the discipline beyond its current state of relatively isolated individual topics: to fill the gaps, unify areas, break new ground, and build a unified discipline of computation as a whole. Individual projects funded in such a programme should clearly demonstrate how they intend to progress the field as a whole. — (European Commission, 2009)

In 2011 the agency opened the ICT FP7 Call 8 FET Proactive in Unconventional Computation[1], and for associated Coordination Actions. As a result, seven research projects were funded:

- BIOMICS: Biological and Mathematical Basis of Interaction Computing (Dini et al., 2012), www.biomicsproject.eu
- MICREAgents: MIcroscopic Chemically Reactive Electronic Agents (McCaskill et al., 2012), www.micreagents.eu
- MolArNet: Molecular Architectures for QCA-inspired Boolean Networks (Rinaldi et al., 2012), www.molarnet.eu
- Multi: Multi-Valued and Parallel Molecular Logic (Collini et al., 2012), www.multivalued.eu
- NASCENCE: NAnoSCale Engineering for Novel Computation using Evolution (Broersma et al., 2012), www.nascence.eu
- PhyChip: Growing Computers from Slime Mould (Adamatzky et al., 2012), www.phychip.eu
- SYMONE: SYnaptic MOlecular NEtworks for Bio-inspired Information Processing (Wendin et al., 2012), www.symone.eu

One coordination action was also funded:

- TRUCE: Training and Research in Unconventional Computation in Europe (Amos et al., 2012), www.truce-project.eu

The objectives of the TRUCE coordination action were (1) to formulate, develop and maintain a European vision and strategy for UCOMP; (2) to identify areas of importance in UCOMP, and help to focus research in these areas; (3) to provide a framework for the discussion and resolution of current issues in UCOMP; (4) to facilitate improvement in the quality, profile and applicability of European UCOMP research; (5) to encourage and support the involvement of students and early career researchers in UCOMP; (6) to facilitate industrial involvement with UCOMP (Amos et al., 2012).

[1] (Floeck, 2012), cordis.europa.eu/fp7/ict/fet-proactive/calls_en.html#previousfetproactive

This book, edited by TRUCE project leaders, comprises a distilled collection of outputs from the UCOMP projects, including a roadmap for Unconventional Computing (UCOMP) research and development in Europe and beyond, in order to identify new trends, challenges and opportunities.

1.2 Scope and content of the book

1.2.1 Roadmap: Mapping the UCOMP territory

Part I of the book comprises outputs from the TRUCE project's UCOMP roadmap activity. The resulting roadmap has been iteratively developed through information gathering from the literature, from specific experts, and from the wider community. The roadmap provides analyses of several specific UCOMP implementations, leading to a range of recommendations for the future of UCOMP research in Europe and beyond.

The chapters in Part I are:

- Chapter 2. UCOMP Roadmap: Survey, Challenges, Recommendations
- Chapter 3. *In materio* Computation Using Carbon Nanotubes
- Chapter 4. Computing by Non-linear Optical Molecular Response
- Chapter 5. Bioinspired Computing with Synaptic Elements
- Chapter 6. Microscopic Chemically Reactive Electronic Agents
- Chapter 7. Cellular Computing and Synthetic Biology
- Chapter 8. PhyChip: Growing Computers with Slime Mould
- Chapter 9. Decoding Genomic Information

1.2.2 Delving into UCOMP concepts

Part II of the book discusses certain aspects of UCOMP across the breadth of the domain, distilling findings from across the funded UCOMP projects. It covers: philosophy of UCOMP, computability and complexity of UCOMP devices, encoding and representing information in UCOMP devices, a theory of interactive computing, reservoir computing with unconventional material, multivalued logics in nanoscale materials, and molecular automata.

The chapters in Part II are:

- Chapter 10. Philosophy of Computation
- Chapter 11. Computability and Complexity of Unconventional Computing Devices
- Chapter 12. Encoding and Representation of Information Processing in Irregular Computational Matter

- Chapter 13. BIOMICS: A Theory of Interaction Computing
- Chapter 14. Reservoir Computing with Computational Matter
- Chapter 15. Multivalued Logic at the Nanoscale
- Chapter 16. Nanoscale Molecular Automata: From Materials to Architectures

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We hope that this collected material will be of value to the entire UCOMP community, and more broadly to the computer science and related communities, gathering together common findings from the broadest disciplinary background.

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