Unconventional Computing: A Brief Subjective History

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Abstract In this article we present a few stages of the evolution of the emerging area of unconventional computing from a personal perspective.

1 Introduction

In 1994 John Casti[1] and I started talking about the eventual decay of Moore's law and the advance of new models of computation, which we called *unconventional*.[2]

The famous open problem NP versus P informally asks whether every problem whose solution can be quickly verified by a Turing machine can also be quickly solved by a Turing machine.[3] By mid 1990's there was a wide spread belief that the problem will be solved in the negative before the end of the century. This motivated the imperious need of "fast" ways to solve NP problems (quickly checkable) not in P (quickly solvable), a computational challenge unlikely, if not impossible, to succeed using Turing computability.

The third reason was the Turing barrier derived from the Church-Turing Thesis: all computations are extensionally equivalent to Turing machines. Is it possible to design new models of computation capable of transgressing Turing's barrier?

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[1] At that time at the Santa Fe Institute.

[2] The earliest written reference to the term which I have is from an email sent by Seth Lloyd to John Casti Sat on 27 Jul 1996 17:12:41 in which Seth, answering an email from John, lists some researchers in "unconventional and non-Turing models of computation".

[3] The problem was formulated in an equivalent form by Kurt Gödel in a letter to John von Neumann in 1956. Its current mathematical formulation was given by Steven Cook in 1971 using the classes NP and P defined via polynomial time computability, a debatable model of "feasible computation", see also [19].

The need to have a conference on that subject appeared obvious. The first conference of the new series called *Unconventional Models of Computation* was held in 1998; 13 further conferences followed. Journals in the area of unconventional computing started to appear in 2002.

2 Moore's law and Turing's barrier

Moore's law is a famous empirical trend stating that the number of transistors in a dense integrated circuit doubles approximately every two years.[4] It was proposed in 1965 by Gordon Moore, co-founder of Intel, in [22]; hence this year we mark its 50th anniversary.

In the IT world the law informally translates into the prediction that the silicon chips that power servers, PCs, phones, and wifi gadgets can run faster and consume less power roughly doubling every two years or so. The law is so accurate that it is used in the semiconductor industry to guide long-term planning and to set targets for research and development.

Various analyses concluded that the law will run out of steam, i.e. the improvements of conventional ways of manufacturing microprocessors, graphics chips and other silicon components will hit a wall: drastically new ideas will be required. Predictions are notoriously difficult and this case is no exception. Indeed, 2000 was a failed estimation; other dates, 2013 and 2015, suffered the same fate. At the 2015 IEEE international Solid-State Circuits Conference[5] organised in San Francisco, USA on February 22–26, Intel engineers discussed the challenges of moving from current 14nm chips to the 10nm manufacturing node and even smaller. Moore's law is not (yet) dead!

The Church-Turing Thesis[6] states that a function on the natural numbers is computable in an informal sense (i.e. computable by a human being using a pencil-and-paper method, ignoring any resource limitations) if and only if it is computable by a Turing machine. Identifying an informal concept with a mathematical one makes the "thesis" mathematically unprovable; however, in principle, it can be disprovable. There are many studies on the Church-Turing Thesis, see for example [15].

The major challenge posed by the Church-Turing Thesis is *whether there are any possibilities of going beyond Turing's barrier, i.e. whether one can develop tools to compute (in some meaningful way) uncomputable functions*. This problem is both theoretical as well as practical. There is an active community devoted to this problem—called hypercomputation—see [26]. Davis [17, 18] argues strongly against hypercomputation on the ground that it is physically unfeasible. Curiously enough, there exists a practical model of hypercomputation (see [5]) which has a

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[4] The period is often quoted as 18 months.

[5] One of the top academic conferences on chip design.

[6] Named after American mathematician Alonzo Church and his British Ph. D. student Alan Turing.

(yet) unknown computational capability (in particular, it is not know whether it can solve the Halting Problem).

3 Unconventional computation or unconventional computing?

The adjective unconventional means "not conforming to accepted rules or standards". The name *unconventional computation* was chosen for its "neutrality": it included both major new computing trends at the time when it was coined, in 1994—biological/molecular/DNA and quantum physics models—and gives none of them any preference. The year 1994 was an exceptional time for both molecular and quantum computation: Adleman's molecular computation paper appeared in *Science* [7] and Shor's quantum algorithm for factoring quickly large integers was published in the same year [23]. They both generated an immense interest across disciplines.

The adjective unconventional has also shortcomings. For example, it is time-dependent: what is unconventional today might become conventional tomorrow. Also, various researchers may have different opinions regarding whether a model of computation is unconventional or not. For example, a model using a finite automaton seems hardly unconventional now as it was in 1994: however, if the use of the automaton is essentially different from the standard ones, then one could argue that the model of computation is unconventional.

The initial title of the book [9] was *The Human Face of Computation*, a title coined by Solomon Marcus, one of its contributors. Then, in a private exchange of emails, Joseph Sifakis, another contributor, argued that "computing" is a better term than "computation". An interesting discussion, involving also Solomon Marcus, followed.

Computation refers to any type of calculation or use of computing technology in information processing [24], while computing denotes any goal-oriented activity requiring, benefiting from, or creating algorithmic processes, e.g. through computers [25]. Computing connotes the use (or study) of computers. Computation connotes calculation (not necessarily by computer and not necessarily via mathematical operations, though this is technically what a computer does). Computation seems to be more theoretical; computing tends to be more general.[7] Also, as Marcus noted, "Computing has only three syllables while computation has four; musically, the former is better than the latter". So the title of the book has been changed!

The initial title of the conference *Unconventional Models of Computation* has been changed in 2005 to *Unconventional Computation*[8] and again in 2012 to the current *Unconventional Computation and Natural Computation*.[9] Here the term "computation" has (till now?) survived.

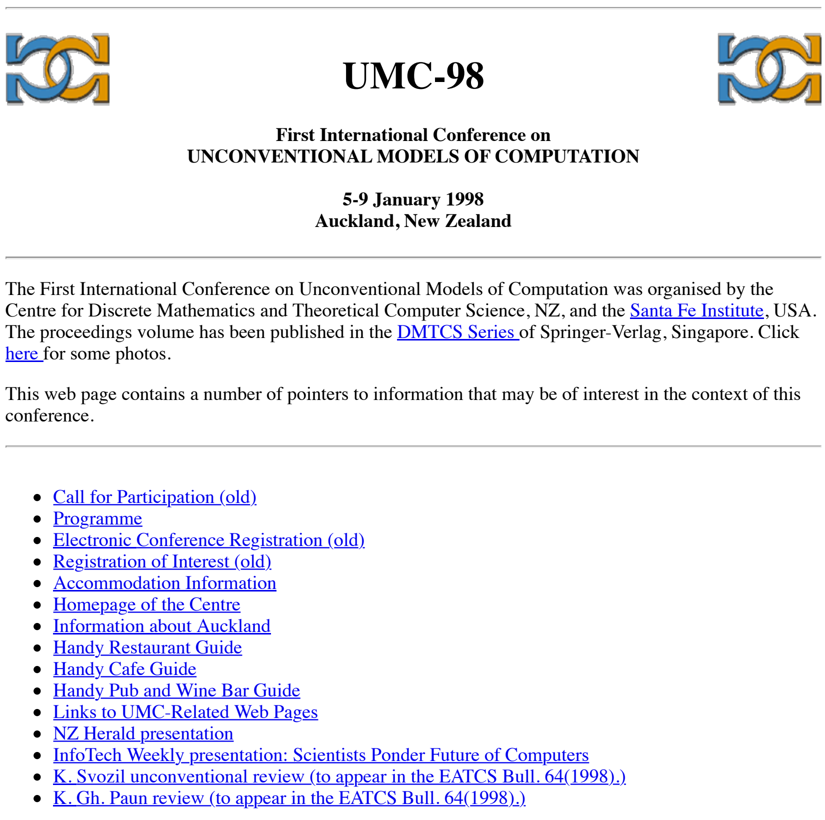
[7] See more at [1].

[8] To emphasise both theoretical and practical studies.

[9] UCNC page: https://www.cs.auckland.ac.nz/research/groups/CDMTCS/conferences/uc/uc.html.

4 Unconventional Models of Computation 1998 (UMC'98)

The first conference in the series was organised in Auckland New Zealand on 6–9 January 1998 by the Centre for Discrete Mathematics and Theoretical Computer Science in Auckland and the Santa Fe Institute.



UMC-98

First International Conference on
UNCONVENTIONAL MODELS OF COMPUTATION

5-9 January 1998
Auckland, New Zealand

The First International Conference on Unconventional Models of Computation was organised by the Centre for Discrete Mathematics and Theoretical Computer Science, NZ, and the Santa Fe Institute, USA. The proceedings volume has been published in the DMTCS Series of Springer-Verlag, Singapore. Click here for some photos.

This web page contains a number of pointers to information that may be of interest in the context of this conference.

- Call for Participation (old)
- Programme
- Electronic Conference Registration (old)
- Registration of Interest (old)
- Accommodation Information
- Homepage of the Centre
- Information about Auckland
- Handy Restaurant Guide
- Handy Cafe Guide
- Handy Pub and Wine Bar Guide
- Links to UMC-Related Web Pages
- NZ Herald presentation
- InfoTech Weekly presentation: Scientists Ponder Future of Computers
- K. Svozil unconventional review (to appear in the EATCS Bull. 64(1998).)
- K. Gh. Paun review (to appear in the EATCS Bull. 64(1998).)

Fig. 1 UMC'98 website

The website of the conference appears in Fig. 1. Its proceedings [11] were published by Springer and distributed to participants during the conference, see Fig. 2. Pictures from the conference can be found at UMC98 pictures.

The conference attracted a lot of attention. Various reports were published in prestigious international publications like *Nature* [12], *Complexity* [13] and the *Bulletin of the European Association for Theoretical Computer Science* (64 (1998), presentations by G. Păun and K. Svozil) as well as in local media, New Zealand Herald and InfoTech Weekly. Bob Doran's Computer History Time Line which includes computing history displays in the Computer Science Department at the University of Auckland also marks the UMC'98 event.

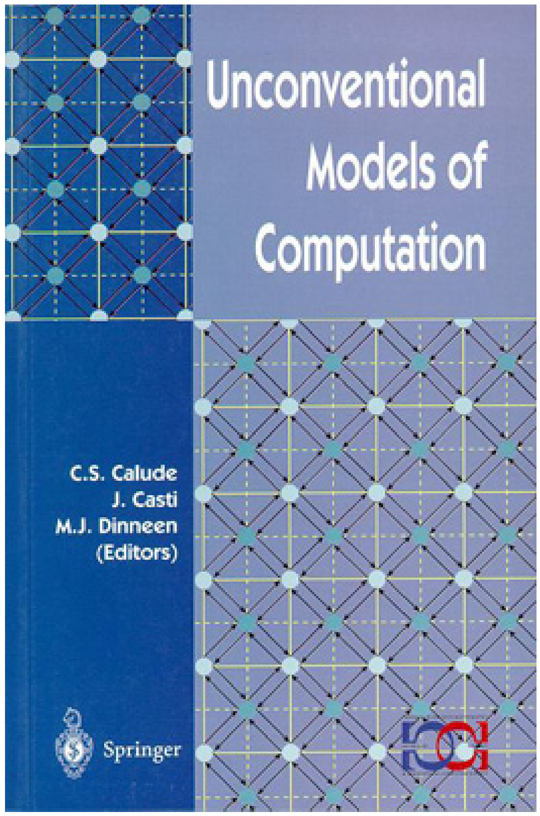


Fig. 2 UMC'98 Proceedings

4.1 Scope

By mid 1990's both areas of biological and quantum computing had their own specialised conferences. The scope of UMC'98 was *to bring together* researchers from as many as possible areas of unconventional computing and encourage/stimulate interaction. The organisers paid special attention to "merge" in the programme papers from different areas, to avoid the creation of clusters of specialised mini-conferences and to stimulate interdisciplinarity.

4.2 Preparation

The conference took almost four years to prepare. As mentioned above, discussions had started in 1994. The title included the word "model" because of the theoretical nature of the domain at that stage: unconventional computation was on paper only!

In 1998 the area of unconventional computation included biological/molecular/DNA and quantum models of computation, neural networks, cellular automata, reversible computation, genetic algorithms, hyper-Turing machines or any other model of computation going beyond Turing's barrier and the meaning and relevance of Church-Turing Thesis for the physics of computation.

4.3 Invited speakers

The list of invited speakers consisted of a rather "unconventional" mixture of [10]

- well-known eminent researchers, H. Jeff Kimble, John. H. Reif and Arto Salomaa,
- and young rising stars, Martyn Amos, Artur Ekert, Seth Lloyd, and Christopher Moore,

with slightly more from the latter category (all well-known researchers today).

4.4 Opposing "philosophies"

In the final session we discussed the goals of biological and quantum computing. In both areas "computers" were understood "by default" to be universal, i.e. equivalent in power to a universal Turing machine.

Regarding the future, two interesting, divergent "philosophies" for quantum computing emerged:

- for the Europeans the main interest was in using the new framework of quantum computing to prove new impossibility results in quantum physics, in particular the impossibility of building a "real" quantum computer, while
- the Americans didn't care much whether quantum computers can be built or not, they were determined to build and commercialise them.

Today the idea of universality has been by and large abandoned. Various proposals to solve "quickly" NP-hard problems have also been discarded because of practical unfeasibility.

[10] In alphabetical order.

The European preference can be illustrated with the work on locating "value indefinite observables" [4, 6] which led to a new form of the Kochen-Specker theorem [20] and a better understanding of the unpredictability of quantum mechanics [3, 2].

In the area of quantum computing a new emerging trend called *quassical computing*[11] combines classical and quantum computing by taking advantage of their complementary capabilities.[12] The example of the adiabatic quantum machines D-Wave produced by the Canadian company D-Wave Systems confirms the American prediction. D-Wave One (2011) operates on a 128-qubit chipset while D-Wave Two (2013) works with 512 qubits [16].

5 Unconventional Computation and Natural Computation 2015 (UCNC'2015)

After Brussels, Belgium (December 2000), Kobe, Japan (October 2002), Sevilla, Spain (October 2005), York, UK (September 2006), Kingston, Canada (August 2007), Vienna, Austria (August 2008), Ponta Delgada, Portugal (September 2009), Tokyo, Japan (June 2010), Turku, Finland (June 2011), Orléans, France (September 2012) Milano, Italy (June 2013) and London, Ontario, Canada (July 2014), the 14th Unconventional Computation and Natural Computation conference returns to Auckland, New Zealand and will be held from 31 August to 4 September 2015.

The UCNC conference series is overseen by a Steering Committee which includes Thomas Back (Leiden University, The Netherlands), Cristian S. Calude (University of Auckland, New Zealand), as founding chair, Lov K. Grover (Bell Labs, Murray Hill, New Jersey, USA), Nataša Jonoska (University of South Florida, USA), as co-chair, Jarkko Kari (University of Turku, Finland), as co-chair, Lila Kari (University of Western Ontario, Canada), Seth Llloyd (Massachusetts Institute of Technology, USA), Giancarlo Mauri (University of Milano-Bicocca, Italy), Gheorghe Păun (Institute of Mathematics of the Romanian Academy, Romania), Grzegorz Rozenberg (Leiden University, The Netherlands), as emeritus chair, Arto Salomma (University of Turku, Finland), Tommaso Toffoli (Boston University, USA), Carme Torras (Institute of Robotics and Industrial Informatics, Barcelona, Spain), and Jan Van Leeuwen (Utrecht University, The Netherlands).

The list of main areas of interest of the conference has expanded considerably: molecular (DNA) computing, quantum computing, optical computing, chaos computing, physarum computing, computation in hyperbolic spaces, collision-based computing; cellular automata, neural computation, evolutionary computation, swarm intelligence, nature-inspired algorithms, artificial immune systems, artificial life, membrane computing, amorphous computing; computational systems biology,

[11] A term coined by N. Allen [8].

[12] An early example of quassicality appears in [21] where a method to enhance Grover's quantum search by incorporating it into classical procedural algorithms is presented. See also [10].

genetic networks, protein-protein networks, transport networks, synthetic biology, cellular (in vivo) computing. computations beyond the Turing model and philosophical aspects of computing.

6 Unconventional Computing Journals

As in any new area of computer science, conferences dominate in the beginning, then, after maturing, new international refereed specialised journals are founded. For unconventional computing this process started in 2002:

- Springer journal Natural Computing founded in 2002 by G. Rozenberg.
- Elsevier journal Theoretical Computer Science C—Theory of Natural Computing founded in 2004 by G. Rozenberg.
- Old City Publishing journal International Journal of Unconventional Computing founded in 2005 by A. Adamatski.
- IGI Global publisher journal International Journal of Nanotechnology and Molecular Computation founded in 2009 by B. MacLennan.

7 Unconventional Computing: An area in full expansion

An interesting article titled "Unconventional Computing" [14] commenting on recent achievements in the field was written by V. Cerf, the Chief Internet Evangelist at Google. Among them is the IBM TrueNorth, the one million neuron brain-inspired processor. The chip consumes just 70 milliwatts and is capable of 46 billion synaptic operations per second, per watt--"literally a synaptic supercomputer in your palm".

The advance in neural chips, Watson-like systems and quantum computers require strategies, solutions and programming styles very different from those used in conventional computing (see, for example [10]). Academia[13] is not anymore the sole place for such studies: commercial companies, from those with a well-established research track-record like IBM and Lockheed Martin, to new ones, like D-Wave Systems or TDK-Headway Technologies, and to IT giants like Google and Microsoft, have ambitious programmes.

International projects like Truce, Training and Research in Unconventional Computing, a Coordination Action, supported by the Future and Emerging Technologies (FET) programme within the ICT theme of the Seventh Framework Programme for Research of the European Commission, play an important role.

[13] From specialised centres, like International Center of Unconventional Computing in Bristol, UK, to groups scattered all around the globe.

Acknowledgment

I am grateful to Andy Adamatzki, Elena Calude, John Casti, Michael Dinneen, Bob Doran, Grzegorz Rozenberg, Karl Svozil and Garry Tee for conversations on the topic of the paper and personal recollections.

This work was supported in part by Marie Curie FP7-PEOPLE-2010-IRSES Grant RANPHYS.

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