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How the World Computes

Turing Centenary Conference and
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Preface

CiE 2012: How the World Computes, and the Alan Turing Centenary

In 2003, a group of researchers started their funding proposal for a *Research Training Network* of the European Commission under the unfamiliar acronym CiE with the words:

> We can see now that the world changed in 1936, in a way quite unrelated to the newspaper headlines of that year concerned with such things as the civil war in Spain, economic recession, and the Berlin Olympics. The end of that year saw the publication of a thirty-six page paper by a young mathematician, Alan Turing, claiming to solve a long-standing problem of the distinguished German mathematician David Hilbert.

The proposal (eventually unfunded) went on to describe how "computability as a theory is a specifically twentieth-century development," and how subsequently computability became "both a driving force in our daily lives" and a concept one could talk about with a new precision.

The work and personality of Turing has had a key influence on the development of CiE as an important player in the new multi-disciplinary landscape of twenty-first century computability theory. It has been said that Alan Turing did not so much inhabit different disciplines as investigate one discipline that was fundamental. In recent times, CiE has sought to break down disciplinary barriers, and to sponsor a return to this questioning approach of Turing to "How the World Computes."

Computability in Europe (CiE) is now a hugely successful conference series; an association with close on a thousand members, and growing; has its own journal *Computability*; and edits a high-profile book series *Theory and Applications of Computability*. It was just under five years ago, toward the end of 2007, that the CiE Board set out to acknowledge its debt to Turing by making the Alan Turing Year 2012 a unique and scientifically exciting year. Since

then, CiE has formed an international *Turing Centenary Advisory Committee*, which has played an important part in the development of the Turing Centenary programme into a world-wide celebration. The CiE 2012 Turing Centenary Conference will be remembered as a historic event in the continuing development of the powerful explanatory role of computability across a wide spectrum of research areas. We believe that the work presented at CiE 2012 represents the best of current research in the area, and forms a fitting tribute to the short but brilliant trajectory of Alan Mathison Turing (June 23, 1912 – June 7, 1954).

Apart from being a celebration of the Turing Centenary, CiE 2012 was the eighth meeting in our conference series. Both the conference series and the association promote the development of computability-related science, ranging over mathematics, computer science and applications in various natural and engineering sciences such as physics and biology, and also including the promotion of related non-scientific fields such as philosophy and history of computing. This conference was held at the University of Cambridge in England, linking naturally to the semester-long research programme *Semantics & Syntax* at the *Isaac Newton Institute for Mathematical Sciences*.

The first seven of the CiE conferences were held at the University of Amsterdam in 2005, at the University of Wales Swansea in 2006, at the University of Siena in 2007, at the University of Athens in 2008, at the University of Heidelberg in 2009, at the University of the Azores in 2010, and at Sofia University in 2011. The proceedings of these meetings, edited in 2005 by S. Barry Cooper, Benedikt Löwe and Leen Torenvliet, in 2006 by Arnold Beckmann, Ulrich Berger, Benedikt Löwe and John V. Tucker, in 2007 by S. Barry Cooper, Benedikt Löwe and Andrea Sorbi, in 2008 by Arnold Beckmann, Costas Dimitracopoulos and Benedikt Löwe, in 2009 by Klaus Ambos-Spies, Benedikt Löwe and Wolfgang Merkle, in 2010 by Fernando Ferreira, Benedikt Löwe, Elvira Mayordomo and Luís Mendes Gomes, and in 2011 by Benedikt Löwe, Dag Normann, Ivan Soskov,

and Alexandra Soskova were published as *Springer Lecture Notes in Computer Science*, Volumes 3526, 3988, 4497, 5028, 5365, 6158, and 6735, respectively.

The annual CiE conference has become a major event, and is the largest international meeting focused on computability theoretic issues. The next meeting in 2013 will be in Milan, Italy, and will be co-located with the conference UCNC 2013 (*Unconventional Computation and Natural Computation*). The series is coordinated by the CiE Conference Series Steering Committee consisting of Luís Antunes (Porto, Secretary), Arnold Beckmann (Swansea), S. Barry Cooper (Leeds), Natasha Jonoska (Tampa FL), Viv Kendon (Leeds), Benedikt Löwe (Amsterdam and Hamburg, Chair), Dag Normann (Oslo), and Peter van Emde Boas (Amsterdam).

The Programme Committee of CiE 2012 was responsible for the selection of the invited speakers and special session organizers and consisted of Samson Abramsky (Oxford), Pieter Adriaans (Amsterdam), Franz Baader (Dresden), Arnold Beckmann (Swansea), Mark Bishop (London), Paola Bonizzoni (Milan), Douglas A. Cenzer (Gainesville FL), S. Barry Cooper (Leeds), Ann Copestake (Cambridge), Anuj Dawar (Cambridge), Solomon Feferman (Stanford CA), Bernold Fiedler (Berlin), Luciano Floridi (Oxford), Marcus Hutter (Canberra), Martin Hyland (Cambridge), Viv Kendon (Leeds), Stephan Kreutzer (Berlin), Ming Li (Waterloo ON), Benedikt Löwe (Amsterdam and Hamburg), Angus Macintyre (Edinburgh), Philip Maini (Oxford), Larry Moss (Bloomington IN), Amitabha Mukerjee (Kanpur), Damian Niwinski (Warsaw), Dag Normann (Oslo), Prakash Panangaden (Montréal QC), Jeff Paris (Manchester), Brigitte Pientka (Montréal QC), Helmut Schwichtenberg (Munich), Wilfried Sieg (Pittsburgh PA), Mariya Soskova (Sofia), Bettina Speckmann (Eindhoven), Christof Teuscher (Portland OR), Peter Van Emde Boas (Amsterdam), Jan Van Leeuwen (Utrecht), Rineke Verbrugge (Groningen).

Structure and Programme of the Conference

The conference had 12 invited plenary lectures, given by Dorit Aharonov (Jerusalem), Verónica Becher (Buenos Aires), Lenore Blum (Pittsburgh PA), Rodney Downey (Wellington), Yuri Gurevich (Redmond WA), Juris Hartmanis (Ithaca NY), Richard Jozsa (Cambridge), Stuart Kauffman (Santa Fe NM), James D. Murray (Princeton NJ), Stuart Shieber (Cambridge MA), Paul Smolensky (Baltimore MD), and Leslie Valiant (Cambridge MA). Six of these plenary lectures have abstracts in this volume. Blum's lecture was the *2012 APAL Lecture* funded by Elsevier, Gurevich's lecture was the *EACSL Invited Lecture* funded by the *European Association for Computer Science Logic*, Murray's lecture was the *Microsoft Research Cambridge Lecture* funded by Microsoft Research, and the lectures by Josza and Valiant were part of a joint event with King's College, Cambridge, on Alan Turing's 100th birthday (June 23, 2012). In addition to the plenary lectures, the conference had two public evening lectures delivered by Andrew Hodges (Oxford) and Ian Stewart (Warwick).

The 2012 conference CiE had six special session on a range of topics. Speakers in the special sessions were invited by the special session organizers and could

contribute a paper to this volume. Eighteen of the invited special session speakers made use of this opportunity and their papers are included in these proceedings.

Cryptography, Complexity, and Randomness.
Organizers. Rod Downey (Wellington) and Jack Lutz (Ames IA).
Speakers. Eric Allender, Laurent Bienvenu, Lance Fortnow, Valentine Kabanets, Omer Reingold, and Alexander Shen.

The Turing Test and Thinking Machines.
Organizers. Mark Bishop (London) and Rineke Verbrugge (Groningen).
Speakers. Bruce Edmonds, John Preston, Susan Sterrett, Kevin Warwick, and Jiří Wiedermann.

Computational Models After Turing: The Church-Turing Thesis and Beyond.
Organizers. Martin Davis (Berkeley CA) and Wilfried Sieg (Pittsburg PA).
Speakers. Giuseppe Longo, Péter Németi, Stewart Shapiro, Matthew Szudzik, Philip Welch, and Michiel van Lambalgen.

Morphogenesis/Emergence as a Computability Theoretic Phenomenon.
Organizers. Philip Maini (Oxford) and Peter Sloot (Amsterdam).
Speakers. Jaap Kaandorp, Shigeru Kondo, Nick Monk, John Reinitz, James Sharpe, and Jonathan Sherratt.

Open Problems in the Philosophy of Information.
Organizers. Pieter Adriaans (Amsterdam) and Benedikt Löwe (Amsterdam and Hamburg).
Speakers. Patrick Allo, Luís Antunes, Mark Finlayson, Amos Golan, and Ruth Millikan.

The Universal Turing Machine, and History of the Computer.
Organizers. Jack Copeland (Canterbury) and John Tucker (Swansea).
Speakers. Steven Ericsson-Zenith, Ivor Grattan-Guinness, Mark Priestley, and Robert I. Soare.

CiE 2012 received 178 regular submissions. These were refereed by the Programme Committee and a long list of expert referees without whom the production of this volume would have been impossible. Based on their reviews, 53 of the submissions (29.8%) were accepted for publication in this volume. We should like to thank the subreferees for their excellent work; their names are listed at the end of this preface.

Organization and Acknowledgements

CiE 2012 was organized by Arnold Beckmann (Swansea), Luca Cardelli (Cambridge), S. Barry Cooper (Leeds), Ann Copestake (Cambridge), Anuj Dawar (Cambridge, Chair), Bjarki Holm (Cambridge), Martin Hyland (Cambridge), Benedikt Löwe (Amsterdam), Arno Pauly (Cambridge), Debbie Peterson (Cambridge), Andrew Pitts (Cambridge), and Helen Scarborough (Cambridge).

At the conference, we were able to continue the programme "Women in Computability" funded by the publisher Elsevier and organized by Mariya Soskova

(Sofia). There were five co-located events: the workshop *The Incomputable* organized as part of the Isaac Newton Institute program *Semantics & Syntax* at Chicheley Hall (June 12–15, 2012; organizers: S. Barry Cooper and Mariya Soskova), the conference ACE 2012 at King's College (June 15–16, 2012; organized by Jack Copeland and Mark Sprevak), the workshop *Developments in Computational Models* (DCM 2012) at Corpus Christi College (17 June 2012; organized by Benedikt Löwe and Glynn Winskel), the CiE-IFCoLog student session (June 18–23, 2012; organizers: Sandra Alves and Michael Gabbay), and the conference *Computability and Complexity in Analysis* (CCA 2012) at the Computer Lab of the University of Cambridge (June 24–27, 2012; organizers: Arno Pauly and Klaus Weihrauch).

The organization of CiE 2012 would not have been possible without the financial and/or materials support of our sponsors (in alphabetic order): the Association for Symbolic Logic, Cambridge University Press, Elsevier B.V., the European Association for Computer Science Logic (EACSL), the International Federation for Computational Logic (IFCoLog), IOS Press, the Isaac Newton Institute for Mathematical Sciences, King's College, Cambridge, Microsoft Research Cambridge, Robinson College Cambridge, Science Magazine/AAAS, Springer-Verlag, and the University of Cambridge.

We should also like to acknowledge the support of our non-financial sponsors, the Association Computability in Europe and the European Association for Theoretical Computer Science (EATCS).

We thank Andrej Voronkov for his EasyChair system which facilitated the work of the Programme Committee and the editors considerably. The final preparation of the files for this proceedings volume was done by Bjarki Holm, Steffen Lösch, and Nik Sultana.

April 2012

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