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## Frontiers of Computability, Randomness, and Complexity (dedicated to the 70th birthday of Professor Cristian Calude)

This Special Issue of Theoretical Computer Science Section C – Theory of Natural Computing – is dedicated to Professor Cristian Calude on the occasion of his 70th birthday. Cristian Sorin Calude is a world-class New Zealand and Romanian computer scientist.

Cristian’s scope of research and network are vast, having more than 100 collaborators, *having published in more than 60 refereed venues, and having been an editor for more than 35 books*. During his career, Cristian supervised and mentored more than 20 PhD students, 35 Honours and Masters students, and four Postdoctoral Fellows.

He is highly influential in several areas of theoretical computer science, particularly in algorithmic information theory, quantum randomness and quantum computing, and the philosophy and history of mathematics and computer science. He has also made significant contributions in other areas of mathematics and theoretical computer science, including formal language theory, automata theory, and natural computing.

Since he was a student, Cristian has been awarded numerous prizes. We mention here just a few of the most recent ones: *Ordinul Național “Serviciul Credincios” în grad de Cavaler* (Romanian National Order of “Faithful Service” in the degree of Knight) in 2019; Fellow of the Asia-Pacific Artificial Intelligence Association (AAIA) in 2021; and recipient of the Nerode Prize 2021, by The European Association for Theoretical Computer Science – International Symposium on Parameterized and Exact Computation (EATCS-IPEC).

The scientific community holds Cristian’s achievements in high regard. He has been a member of Academia Europea since 1999. He is an established and active editor for more than 25 well-known international journals, such as Springer Nature Journal of Computer Science (Springer), Theoretical Computer Science C (Elsevier), International Journal of Foundations of Computer Science (World Scientific), Natural Computing (Springer), and Fundamenta Informaticae (IOS Press). A complete list of Cristian’s awards and publications is available on his personal website, and on Wikipedia (C.S. Calude).

Without a doubt, we can also say that Cristian is the most prominent artisan behind the creation of the Centre for Discrete Mathematics and Theoretical Computer Science (CDMTCS), University of Auckland.

This Special Issue of TCS-C superbly highlights Cristian’s broad research

interests. We received enthusiastic responses from the scientific community, proving once again the widespread admiration and respect for Cristian. This Special Issue consists of 14 articles that went through an independent peer-review process following the standard review process of Theoretical Computer Science. We discuss each of them briefly below.

In “Computable model discovery and high-level-programming approximations to algorithmic complexity,” Eduardo Acuña-Yeomans, Francisco Hernández-Quiroz, Vladimir Lemusa, Víctor Zamora, and Hector Zenil present a proof of concept of an approach to algorithmic complexity based on a high-level imperative programming language, IMP. Its main advantage is that conceptually complex computational routines are more succinctly expressed, unlike lower level models such as Turing machines or cellular automata.

“Quantum circuits with classical channels and the principle of deferred measurements” by Andreas Blass and Yuri Gurevich defines quantum circuits’ syntax and semantics, allowing measurement gates and classical channels. They prove that, semantically, any such circuit-based algorithm is equivalent to a single measurement that depends only on the underlying quantum circuit. The authors use this formalization of quantum circuits to state precisely and prove the principle of deferred measurements.

The paper “A parametric worst-case approach to fairness in TU-cooperative games” by Cosmin Bonchiş and Gabriel Istrate studies worst-case fairness in resource allocation and cooperative games with transferable utility.

“Verification of component-based systems with recursive architectures” by Marius Bozga, Radu Iosif, and Joseph Sifakis studies a sound verification method for parametric component-based systems. For parametric systems specified in this logic, they show that decision problems, such as reaching deadlock or violating critical sections, are generally undecidable. Despite this negative result, the authors provide practical semi-algorithms for these decision problems, relying on the automatic synthesis of structural invariants (which allows the proof of general safety properties).

“Morse set theory as a foundation for constructive mathematics” by Douglas Bridges presents a constructive development of set theory in the style of A.P. Morse’s classical counterpart. The paper shows that using an exact formal language allows computer assisted proof-checking and program extractions from proofs.

The paper “Geometry of information: classical and quantum aspects” by Noemie Combe, Yuri I. Manin, and Matilde Marcolli describes various aspects of categorification of the structures appearing in information theory.

These aspects include probabilistic models of classical and quantum physics, the emergence of  $F$ -manifolds, and motivic enrichment.

In “Machines that perform measurements by machines that perform measurements,” Jose Felix Costa and Eduardo Skapinakis study the computational complexity classes related to diverse protocols between the digital and the analogue parts of a digital-analogue machine. These machines were recently presented at recent Unconventional Computation (UC) and Unconventional Computation and Natural Computation (UCNC) conferences for various unconventional models of computations.

“Sublinear  $P$  system solutions to  $NP$ -complete problems,” by Michael J. Dinneen, Alec Henderson, and Radu Nicolescu is about the capabilities of a certain type of  $P$  systems, dubbed  $cP$  systems. The authors present a sub-linear solution to  $k$ -SAT and demonstrate that  $k$ -colouring can be reduced to  $k$ -SAT in constant time. This work shows that traditional reductions are efficient in  $P$  systems with compound terms ( $cP$  systems), and that reductions can sometimes produce more efficient solutions than the previous problem-specific solutions.

The paper “Deciding path size of nondeterministic (and input-driven) pushdown automata” by Yo-Sub Han, Sang-Ki Ko, and Kai Salomaa proves that deciding the finiteness of the path size of a nondeterministic pushdown automaton can be done in polynomial time. The authors also prove that the  $k$ -path problem for nondeterministic input-driven pushdown automata (respectively, for nondeterministic finite automata) is complete for exponential time<sup>1</sup> (respectively, complete for polynomial space<sup>2</sup>).

In “Remarks on the effective Jordan decomposition,” Peter Hertling shows that there exists a polynomial time computable, absolutely continuous function  $f : [0, 1] \rightarrow \mathbb{R}$  with a polynomial modulus of absolute continuity such that the so-called standard Jordan decomposition of  $f$  is computable. However, neither the standard Jordan decomposition of  $f$ , nor any other Jordan decomposition of  $f$  can be easily computed (for example, in polynomial or exponential time).

“Individual codewords” by Alexander Shen observes that it is possible to define list-decodable codes in the language of algorithmic information theory.

“A computation model with automatic functions and relations as primitive operations” by Ziyuan Gao, Sanjay Jain, Zeyong Li, Ammar Fathin Sabili and Frank Stephan proposes a computational model that uses up-

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<sup>1</sup>Exp-time complete

<sup>2</sup>P-Space complete

dates and comparisons with automatic functions as primitive operations on constantly many registers. The authors investigate the deterministic complexity of various natural problems and give an overview of the nondeterministic complexity of this new model.

The paper “Varieties of contextuality based on probability and structural non-embeddability” by Karl Svozil refines the notion of contextuality for quantum probabilities by delineating different strong and weak forms of contextuality. The work achieves this by contrasting different probabilistic signatures of contextuality with the stronger logico-algebraic contextuality due to non-embeddability of quantum observables in extended Boolean Algebras.

In “Execution trace sets for real computation,” Declan Thompson combines the perspective of transition functions over a given space. He studies the behaviour generated by the algorithms implementing these functions with a domain-independent, trace-based account of computational and algorithmic processes. The author focuses on the Blum–Shub–Smale machine model of real computation providing a precise characterization of the execution trace sets generated by their machines introduced in 1989.

We end this Preface with a message from Arto Salomaa, one of Cristian’s collaborators and friends. Arto summarizes very well Cristian’s contribution to computer science:

“I knew the name of *Cris Calude* already in April 1991 when he arrived in Turku, after an eventful railroad trip through the recently upset Eastern countries. Our common interests were immediate. We continued our discussions about languages, algorithmic information theory, etc, during my first trip to Romania, 1992, which turned out to be one of my most memorable trips ever. The time after that is history. We have met numerous times at numerous places, with many cooperators and many projects. Our new stronghold was New Zealand, and new research area Unconventional computing. Cris wrote and edited many important books [...] I remember with pleasure our common work and times together, most recently in connection with my birthday celebrations in Turku. Dear Cris, Kaarina joins me in wishing you Many Happy Returns, Success in Science and Happiness in Life.

Monia armorikkaita vuosia!

Kauhajoki,  
Spring 2021, ARTO”

All of us, including the Guest Editors, reviewers, and contributors to this Special Issue, congratulate Cristian on his achievements and wish him many years of success, happiness, joy, and satisfaction in his personal and professional life.

### **Acknowledgements**

First of all, we would like to thank all the authors for their enthusiastic responses and the high-quality contributions of the papers. We are also grateful to the reviewers for their professional courtesy and time spent on the manuscripts received for this special issue. We end this preface by thanking Elsevier's team, the Editor-in-Chief, Lila Kari, and the Senior Journal Manager, Sudhakar Sandacoumar, for their continuous support in publishing this volume.

#### *Special Issue Guest Editors*

Alastair A. Abbott, Grenoble, France

Cezar Câmpeanu, Charlottetown, Canada

Ludwig Staiger, Halle, Germany

Marius Zimand, Towson, MD, USA

#### *Special Invited Guest*

Arto Salomaa, Kauhajoki, Finland