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Theory and Applications of Models of Computation

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Preface

Theory and Applications of Models of Computation (TAMC) is a series of annual conferences that aims at bringing together a wide range of researchers with interest in computational theory and its applications. These conferences have a strong interdisciplinary character; they are distinguished by an appreciation of mathematical depth and scientific rather than heuristic approaches as well as the integration of theory and implementation.

Some of the most important theoretical aspects of a model of computation are its power, generality, simplicity, synthesizability, verifiability, and expressiveness. The TAMC series of conferences explores the algorithmic foundations, computational methods, and computing devices to meet the rapidly emerging challenges of complexity, scalability, sustainability, and interoperability, with wide-ranging impacts on virtually every aspect of human endeavor.

Due to a policy change in China, the 13th such conference had to be canceled. As a consequence, the Steering Committee of TAMC decided to give the authors of those articles that had been accepted for TAMC 2016 the option to present them at TAMC 2017. For TAMC 2016 a total of 24 papers was accepted out of 35 submissions. For TAMC 2017, which was held in Bern during April 20–22, we had 68 submissions and could accept 27. In both cases the reviewing process was rigorous and conducted by international Program Committees. The authors and reviewers for TAMC 2017 were from 29 countries. This volume contains 45 of the 51 accepted submissions of TAMC 2016 and TAMC 2017.

The main themes of TAMC 2017 were computability, computer science logic, complexity, algorithms, models of computation, and systems theory, as reflected also by the choice of the invited speakers.

This volume contains abstracts or full papers of the invited lectures of TAMC 2017 and the written versions of those contributions to TAMC 2016 and TAMC 2017 that were presented at Bern.

> If indeed, as Hilbert asserted, mathematics is a meaningless game played with meaningless marks on paper, the only mathematical experience to which we can refer is the making of marks on paper.
>
> Eric Temple Bell, *The Queen of the Sciences*, 1931

We are very grateful to the Program Committees of TAMC 2016 and TAMC 2017, and the many external reviewers they called on, for the hard work and expertise that they brought to the difficult selection process. We thank all those authors who submitted their work for our consideration. We thank the members of the Editorial Board of *Lecture Notes in Computer Science* and the editors at Springer for their encouragement and cooperation throughout the preparation of this conference.

Last but not least we thank our sponsors for providing the financial and structural basis to have TAMC 2017 in Bern:

- Universität Bern
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Abstracts of Invited Talks

Cognitive Reasoning and Trust in Human-Robot Interactions

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Abstract. We are witnessing accelerating technological advances in autonomous systems, of which driverless cars and home-assistive robots are prominent examples. As mobile autonomy becomes embedded in our society, we increasingly often depend on decisions made by mobile autonomous robots and interact with them socially. Key questions that need to be asked are how to ensure safety and trust in such interactions. How do we know when to trust a robot? How much should we trust? And how much should the robots trust us? This paper will give an overview of a probabilistic logic for expressing trust between human or robotic agents such as "agent A has 99% trust in agent B's ability or willingness to perform a task" and the role it can play in explaining trust-based decisions and agent's dependence on one another. The logic is founded on a probabilistic notion of belief, supports cognitive reasoning about goals and intentions, and admits quantitative verification via model checking, which can be used to evaluate such trust in human-robot interactions. The paper concludes by summarising recent advances and future challenges for modelling and verification in this important field.

Approximate Counting via Correlation Decay

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In this talk, I will survey some recent development of approximate counting algorithms based on correlation decay technique. Unlike the previous major approximate counting approach based on sampling such as Markov Chain Monte Carlo (MCMC), correlation decay based approach can give deterministic fully polynomial-time approximation scheme (FPTAS) for a number of counting problems. Based on this new approach, many new approximation schemes are obtained for counting problems on graphs, partition functions in statistical physics and so on.

On Extraction of Programs from Constructive Proofs

Maria Emilia Maietti

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A key distinctive feature of constructive mathematics with respect to classical one is the fact that from constructive proofs one can extract computable witnesses of provable existential statements. As a consequence all the constructively definable number theoretic functions are computable.

In this talk we argue that for certain constructive dependent type theories known to satisfy the proofs-as-programs paradigm, the extraction of computable witnesses from existential statements must be done in a stronger proofs-as-programs theory, for example in a realizability model. This is the case both for Coquand's Calculus of Constructions in [1] extended with inductive definitions and implemented in the proof-assistant Coq, and for its predicative version represented by the intensional level of the Minimalist Foundation in [2, 3].

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Computational Complexity for Real Valued Graph Parameters

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A *real-valued graph parameter* is a function f which maps (possibly weighted) graphs into the real number $\mathbb{R}$ such that two isomorphic (weighted) graphs receive the same value. Typical examples are graph polynomials $F(G; \bar{X}) \in \mathbb{R}[\bar{X}]$ in k indeterminates, partition functions and Holant functions. The talk is based [1, 2]. We address the following issues:

(i) How to choose the computational model?
the complexity of evaluating $F(G; \bar{a})$ The weighted graphs are best modeled as *metafinite structures*. In our discussion computations over the reals $\mathbb{R}$ are performed in unit cost in the computation model of Blum-Shub-Smale (BSS).

(ii) What are the complexity classes?
In BSS polynomial time $\mathbf{P}_{\mathbb{R}}$ and non-determinsitic time $\mathbf{NP}_{\mathbb{R}}$ are well defined. However, we are looking for an analogue of $\#\mathbf{P}$, which captures the complexity of evaluating a graph polynomial $F(G; \bar{X})$ at real values of $\bar{X}$, for which there are complete problems.

(iii) Are there dichotomy theorems?
For a graph polynomial $F(G; \bar{X})$ we look at the complexity spectrum which describes how the complexity of evaluating $F(G; \bar{a})$ varies for different $\bar{a} \in \mathbb{R}^k$. The analogue of Ladner's Theorem, which states that there are many intermediate complexity classes, unless $\mathbf{P} = \mathbf{NP}$, also holds in BSS. However, in all the cases known in the literature, the complexity of evaluating $F(G; \bar{a})$ is either in $\mathbf{P}_{\mathbb{R}}$ or $\mathbf{NP}_{\mathbb{R}}$-hard (the Difficult Point Dichotomy). We present infinitely many new graph polynomials for which this dichotomy holds. We shall also discuss the difficulties in proving such a dichotomy in general, and formulate various conjectures, which state that such a dichotomy holds for wide classes of graph polynomials.

Johann A. Makowsky—During 2016 partially supported by the Simons Institute, Berkeley, USA.

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Natural Language Processing, Moving from Rules to Data

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Abstract. During the last decade, we assist to a major change in the direction that theoretical models used in natural language processing follow. We are moving from rule-based systems to corpus-oriented paradigms. In this paper, we analyze several generative formalisms together with newer statistical and data-oriented linguistic methodologies. We review existing methods belonging to deep or shallow learning applied in various subfields of computational linguistics. The continuous, fast improvements obtained by practical, applied machine learning techniques may lead us to new theoretical developments in the classical models as well. We discuss several scenarios for future approaches.

Joint work with Adrian-Horia Dediu and Joana M. Matos.

An All-or-Nothing Flavor to the Church-Turing Hypothesis

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Abstract. Landauer's principle claims that "Information is Physical." It is not surprising that its conceptual *antithesis*, Wheeler's "It from Bit," has been more popular among computer scientists — in the form of the *Church-Turing hypothesis:* All natural processes can be computed by a universal Turing machine; physical laws then become descriptions of subsets of *observable*, as opposed to merely *possible*, computations. Switching back and forth between the two traditional styles of thought, motivated by quantum-physical Bell correlations and the doubts they raise about fundamental space-time causality, we look for an intrinsic, physical randomness notion and find one around the second law of thermodynamics. Bell correlations combined with *complexity as randomness* tell us that beyond-Turing computations are either physically impossible, or they can be carried out by "devices" as simple as individual photons.

Computing on Streams and Analog Networks

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In [5] John Tucker and I defined a general concept of a network of analog processing units or modules connected by analog channels, processing data from a metric space A, and operating with respect to a global continuous clock $\mathbb{T}$, modelled by the set of non-negative reals. The inputs and output of a network are continuous streams $u : \mathbb{T} \to A$, and the input-output behaviour of a network with system parameters from A is modelled by a function of the form

$$\Phi : \mathcal{C}[\mathbb{T}, A]^p \times A^r \to \mathcal{C}[\mathbb{T}, A]^q,$$

where $\mathcal{C}[\mathbb{T}, A]$ is the set of all continuous streams equipped with the compact-open topology. We give an equational specification of the network, and a semantics when some physically motivated conditions on the modules, and a stability condition on the behaviour of the network, are satisfied. This involves solving a fixed point equation over $\mathcal{C}[\mathbb{T}, A]$ using a contraction principle based on the fact that $\mathcal{C}[\mathbb{T}, A]$ can be approximated by metric spaces. We analysed in detail a case study of analogue computation, using a mechanical system involving a mass, spring and damper, in which data are represented by displacements. The curious thing about this solution is that it worked only for certain ranges in the values of the parameters M (mass), K (spring constant) and D (damping constant), namely $M > \max(K, 2D)$, www which has no obvious physical interpretation. (More on this below.)

The fixed points found as above are functions of the parameters of the system, considered as inputs (in our example, the external force applied to the mass, as a function of time). The functionals characterizing the system are then *stream transformations*. Tucker and I showed [6, 7] that these transformations are (respectively) *continuous* (w.r.t. a suitable topology) and *computable*, w.r.t. a suitable notion of *concrete computation* on the reals, where the computable reals, and operations on them, are represented respectively by codes for effective Cauchy sequences, and operations on them – essentially equivalent to Grzegorczyk-Lacombe computability.

The significance of *continuity* of the fixed point function is that it implies *stability* of the fixed point as the solution to the specification. This is related to *Hadamard's principle* which (as (re-)formulated by Courant and Hilbert) states that for a scientific problem to be well posed, the solution must (apart from existing and being unique) depend continuously on the data.

This work was done in collaboration with John Tucker, Nick James and Diogos Poças. Research supported by NSERC (Canada).

Returning to the problem indicated above that the functionals (apparently) converge to fixed points only for certain values in the range of the parameters, this was successfully solved by Nick James [1, 2] who, developing a theory of stream functions on Banach spaces, showed that the important thing is *how* the network is modularized. By re-modularizing our original mass/spring/damper suitably, he obtained an equivalent system in which the (unnatural seeming) limitations on the sizes of the parameters are removed.

We turn to the next development in this theory. Diogo Poças [3] investigated analog networks which were based on Shannon's GPACs (general purpose analog computers). He has made a number of significant developments in this theory, which also impacts on the work described above: (1) He worked in the context of Fréchet spaces, not Banach spaces, which provides a more natural framework for investigating the space $\mathcal{C}[\mathbb{T}, A]$. (2) He characterized the class of functions over the reals, computable by GPACS, as the *differential algebraic* functions. (3) He has extended the structure of GPACS to X-GPACS, which allows *two* independent variables: t, ranging over *time*, as before, and also x, ranging over *space*. This to the use of *partial differential equations*.

It turns out that the X-GPAC generable functions are precisely those solvable by partial *differential algebraic systems* [4]. Now certain interesting functions, such as the *gamma function*, and the *Riemann zeta function*, are not differentially algebraic, and (therefore) not X-GPAC computable. (4) This motivates a further extension of the X-GPAC model to the LX-GPAC model, ("L" for limit), which permits the use of limit operations (either discrete, over the naturals, or continuous, over segments of the reals). This facility permits the generation of both the gamma function and Riemann zeta function [3, Ch. 4]

It remains to find a useful characterization, in terms of concrete computation models, of the class of functions generated by LX-GPACs.

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