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Jouko Väänänen · Åsa Hirvonen
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Editors
Jouko Väänänen
Department of Mathematics and Statistics
University of Helsinki
Helsinki
Finland

Åsa Hirvonen
Department of Mathematics and Statistics
University of Helsinki
Helsinki
Finland

Ruy de Queiroz
Centro de Informática
Recife, Pernambuco
Brazil

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Preface

This volume contains the papers presented at the 23rd Workshop on Logic, Language, Information and Computation (WoLLIC 2016) held during August 16–19, 2016, at the Department of Computer Science, Benemérita Universidad Autónoma de Puebla, Puebla, Mexico. The WoLLIC series of workshops started in 1994 with the aim of fostering interdisciplinary research in pure and applied logic. The idea is to have a forum that is large enough in the number of possible interactions between logic and the sciences related to information and computation, and yet is small enough to allow for concrete and useful interaction among participants.

There were 41 submissions this year. Each submission was reviewed by at least three Program Committee members. The committee decided to accept 23 papers. The program also included six invited lectures by Pablo Barceló (Universidad de Chile, Chile), Dana Bartošová (University of Sáo Paulo, Brazil), Johann A. Makowsky (Technion - Israel Institute of Technology, Israel), Alessandra Palmigiano (TU Delft, The Netherlands), Sonja Smets (University of Amsterdam, The Netherlands), and Andrés Villaveces (Universidad Nacional de Colombia, Colombia). There were also five tutorials given by Barceló, Makowsky, Palmigiano, Smets, and Villaveces.

As a tribute to a recent breakthrough in mathematics, there was also a screening of Csicsery's "Counting from Infinity: Yitang Zhang and the Twin Prime Conjecture" (2015), which centers on the life and work of Yitang Zhang in the celebrated twin prime conjecture, his result being that there are infinitely many pairs of primes separated by at most 70 million.

We would very much like to thank all Program Committee members and external reviewers for the work they put into reviewing the submissions. The help provided by the EasyChair system created by Andrei Vorokonkov is gratefully acknowledged. Finally, we would like to acknowledge the generous financial support by the Benemérita Universidad Autónoma de Puebla's Department of Computer Science, and the scientific sponsorship of the following organizations: Interest Group in Pure and Applied Logics (IGPL), The Association for Logic, Language and Information (FoLLI), Association for Symbolic Logic (ASL), European Association for Theoretical Computer Science (EATCS), European Association for Computer Science Logic (EACSL), Sociedade Brasileira de Computação (SBC), and Sociedade Brasileira de Lógica (SBL).

May 2016

Åsa Hirvonen
Ruy de Queiroz
Jouko Väänänen

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Tutorial/Abstracts

Ultrafilters in Dynamics and Ramsey Theory

Dana Bartošová

Department of Mathematics, University of Toronto, Toronto, Canada
dana.bartosova@mail.utoronto.ca

Abstract. I will recall some famous Ramsey-type statements that admit a simple proof with the use of ultrafilter on discrete semigroups. Gowers' Ramsey theorem will be an example that up-to-date does not posses an ultrafilter-free proof. Stepping up from discrete (semi)groups to groups of automorphisms of homogeneous structures, I will show how their dynamics connects with structural Ramsey theory and how combinatorics on ultrafilters is relevant to dynamical problems. This is partially a joint work with Andrew Zucker (Carnegie Mellon University).

When is $\mathbf{P}_{\mathfrak{A}} = \mathbf{NP}_{\mathfrak{A}}$ over Arbitrary Structures $\mathfrak{A}$? (A tutorial)

J.A. Makowsky

Department of Computer Science, Technion - Israel Institute of Technology,
Haifa, Israel
janos@cs.technion.ac.il

Abstract. In a series of lectures we review the complexity theory for computations over arbitrary relational and algebraic structures $\mathfrak{A}$.

We will cover the following topics:

(i) Register machines over arbitrary relational and algebraic structures $\mathfrak{A}$. Some history, H. Friedman's work of the 1970 ties, [FM92]. The Blum-Shub-Smale approach to complexity, [BCSS96, BCSS98].
(ii) What do we expect from a theory of computability over the reals? Critical evaluations, [Fef15, BC06, Mam14].
(iii) The role of quantifier elimination: B. Poizat's characterization of P = NP over $\mathfrak{A}$, [Poi95, Pru06].
(iv) Proving quantifier elimination. Presburger arithmetic and the field of complex numbers. Shoenfield's quantifier elimination theorem, [KK67, Hod93].
(v) Disproving quantifier elimination. The missing predicates.
(vi) For which structures $\mathfrak{A}$ can we prove $\mathbf{P}_{\mathfrak{A}} \neq \mathbf{NP}_{\mathfrak{A}}$? Abelian groups and boolean algebras, [Pru02, Pru03]
(vii) The logical content of the P = NP problem. Fast quantifier elimination vs. descriptive complexity, [Lib04].

Similar courses were given:

2013: At the Computer Science Department of the Technion–Israel Institute of Technology as Graduate Seminar 238900 under the title *The millennium question* **P = NP** *over the real numbers.*
2014: At the 5th Indian School of Logic and Applications (ISLA-2014) at Tezpur University, Assam, India, under the title $\mathbf{P} =_? \mathbf{NP}$ *over arbitrary structures.*
2014: At the 26th European Summer School in Logic, Language and Information (ESSLLI 2014) in an enlarged form together with K. Meer, also under the title $\mathbf{P} =_? \mathbf{NP}$ *over arbitrary structures*.

See www.cs.technion.ac.il/∼janos/#invitations.

Partially supported by a grant of Technion Research Authority. Work done in part while the author was visiting the Simons Institute for the Theory of Computing in Spring 2016.

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Proof Systems for the Logics for Social Behaviour

Alessandra Palmigiano

Technical University of Delft, Delft, The Netherlands

The range of 'logics for social behaviour' (by which I mean those logics aimed at capturing aspects such as agency and information flow) is rapidly expanding, and their theory is being intensively investigated, especially w.r.t. their semantic aspects. However, these logics typically lack a comparable proof-theoretic development. More often than not, the hurdles preventing their standard proof-theoretic development are due to the very features which make them capture essential aspects of the real world, such as their not being closed under uniform substitution, or the presence of certain extralinguistic labels and devices encoding key interactions between logical connectives [5].

In this talk I will focus on *multi-type calculi*, a methodology introduced in [3, 4, 7] to provide DEL and PDL with analytic calculi, and pursued also in [1, 2, 6].

Multi-type languages allow the upgrade of actions, agents, coalitions, etc. from *parameters* in the generation of formulas, to *terms*. Like formulas, they thus become first-class citizens of the framework, endowed with their corresponding structural connectives and rules. In this richer environment, many features which were insurmountable hurdles to the standard treatment can be understood as symptoms of the original languages of these logics lacking the necessary expressivity to encode certain key interactions *within the language*. The success of the multi-type methodology in defining analytic calculi for logics as proof-theoretically impervious as DEL lies in its providing a mathematical environment in which the expressivity problems can be clearly identified.

I will argue that multi-type calculi can provide a platform for a uniform proof-theoretic account of the logics for social behaviour.

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Sahlqvist Correspondence via Duality and Its Applications

Alessandra Palmigiano

Technical University of Delft, Delft, The Netherlands

Since the 1970s, correspondence theory has been one of the most important items in the toolkit of modal logicians. Unified correspondence [6] is a very recent approach, which has imported techniques from duality, algebra and formal topology [10] and exported the state of the art of correspondence theory well beyond normal modal logic, to a wide range of logics including, among others, intuitionistic and distributive lattice-based (normal modal) logics [8], non-normal (regular) modal logics [18], substructural logics [5, 7, 9], hybrid logics [13], and mu-calculus [2, 3, 4].

The breadth of this work has stimulated many and varied applications. Some are closely related to the core concerns of the theory itself, such as the understanding of the relationship between different methodologies for obtaining canonicity results [7, 17], or of the phenomenon of pseudo-correspondence [11]. Other, possibly surprising applications include the dual characterizations of classes of finite lattices [14], the identification of the syntactic shape of axioms which can be translated into analytic rules of proper display and Gentzen calculi [15, 16], and the design of display-type calculi for the logics of resources and capabilities, and their applications to the logical modelling of business organizations [1]. Finally, the insights of unified correspondence theory have made it possible to determine the extent to which the Sahlqvist theory of classes of normal DLEs can be reduced to the Sahlqvist theory of normal Boolean expansions, by means of Gödel-type translations [12].

The most important technical tools in unified correspondence are: (a) a very general syntactic definition of the class of Sahlqvist formulas, which applies uniformly to each logical signature and is given purely in terms of the order-theoretic properties of the algebraic interpretations of the logical connectives; (b) the algorithm ALBA, which effectively computes first-order correspondents of input term-inequalities, and is guaranteed to succeed on a wide class of inequalities (the so-called *inductive* inequalities) which, like the Sahlqvist class, can be defined uniformly in each mentioned signature, and which properly and significantly extends the Sahlqvist class.

In this tutorial, the fundamental principles and conceptual insights underlying these developments will be illustrated in the setting of Boolean algebras with operators [10].

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Informational Cascades: A Test for Rationality?

Sonja Smets

Institute for Logic, Language and Computation,
University of Amsterdam, Amsterdam, The Netherlands

Abstract. I report on joint work with A. Baltag, Z. Christoff and J.U. Hansen in [3], based on our investigation of the decision processes of individuals that lead to the social herding phenomenon known as informational cascades. The question we address in our paper deals with whether rational agents who use their higher-order reasoning powers and who can reflect on the fact that they are part of an informational cascade, can ultimately stop the cascade from happening. To answer this question we use dynamic epistemic logic to give a complete analysis of the information flow in an informational cascade, capturing the agent's observations, their communication and their higher-order reasoning power. Our models show that individual rationality isn't always a cure that can help us to stop a cascade. However, other factors that deal with the underlying communication protocol or that focus on the reliability of agents in the group, give rise to conditions that can be imposed to prevent or stop an informational cascade from happening in certain scenarios.

Informational cascades are social herding phenomena in which individual agents in a sequence decide to follow the decisions of their predecessors while simply ignoring their own private evidence. In such situations, individuals are given information about their predecessors' decisions but not about the reasons or the evidence on which these decisions are based. So when the first agents in the sequence made a correct decision, their followers will all get it right. However, the opposite can easily happen and when everyone gets it wrong we end up with a potential social-epistemic catastrophe. Such phenomena can illustrate a clear case of when social features interfere with agent's truth-tracking abilities. Hence not all situations involving communication and rational deliberation seem to be epistemically beneficial at the group level.

In this context we study the logical mechanism behind such informational cascades. It is important to note that we are looking at situations in which the total sum of private information should in principle be enough for the group to track the truth, yet in an informational cascade the group fails to do so. To gain a better understanding of this phenomenon, it is our aim to check whether this failure to track the truth can be due to any form of irrationality present when agents form or aggregate their beliefs. Our investigation is driven by questions such as: are rational and introspective agents, who reflect upon their own knowledge and beliefs and who can reason about the knowledge and beliefs of their predecessors, able to stop or prevent a cascade? Even more, are agents with unboundedly rational powers, and who are aware of the dangers of the

sequential deliberation protocol that they are part of, able to block a cascade? Indeed, in some cases a cascade can be prevented by making agents aware of it. However, as is shown in [3] this is not always the case.

There are examples of informational cascades in which no amount of higher-order reasoning is enough to stop an informational cascade. Our argument is based on a model of examples of informational cascades in [3], allowing us to represent the individual reasoning of each agent involved. Formally, we use the tools of dynamic epistemic logic [4, 5, 6, 9]. On the one hand we use a probabilistic dynamic epistemic logic to represent agents who apply probabilistic conditioning. On the other hand we also model the situation in which agents do not use sophisticated probabilistic tools but rather apply a simply non-Bayesian form of heuristic reasoning. We note that a full syntactic encoding of an informational cascade in the presence of a common knowledge operator, is offered in [2] based on a logic that combines a variant of the Logic of Communication and Change from [7] and a variant of Probabilistic Dynamic Epistemic Logic in [8].

Based on our logical analysis in [3], we conclude that cascades cannot always be avoided by rational means. Our model of unboundedly rational agents, equipped with full higher-order reasoning powers, shows that these agents (irrespective of whether they adopt Bayesian reasoning or another non-Bayesian heuristic) still end up in a cascade. Even more, the group's inability to track the truth may actually be a direct consequence of each agent's rational attempt to track the truth individually.

Investigations of different cascade scenarios point out that changes in the underlying communication protocol can make a difference. In most cascade scenarios, agents announce their decisions to their followers, i.e. they communicate about their opinions and beliefs but not about the reasons for their beliefs. Following [3], one can argue that exactly the fact that this communication protocol is based on the exchange of partial information, is the problem. Indeed allowing for more communication in which agents can share not only their beliefs but also their justifications, may stop the cascade. In ideal cases, when total communication can be achieved and agents share all their evidence, reasons, beliefs, etc., we can effectively stop a cascade. It is interesting to investigate different types of communication protocols and their effect on the formation of cascades. An analysis in which such protocols are formalised as strategies in a game theoretic setting, is provided in [1]. Further investigations point out that other social factors can similarly affect the outcome of an informational cascade. For instance the level of trust among agents in a group can make a difference. In [10] the results of an experiment are shown which indicates that agent's perceived reliability of their predecessors can affect the formation of a cascade.

Acknowledgement. Sonja Smets' research on this topic is funded by the European Research Council under the European Community's Seventh Framework Programme (FP7/2007-2013)/ERC Grant agreement no. 283963.

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Belief Dynamics in a Social Context

Sonja Smets

University of Amsterdam, Amsterdam, The Netherlands

This tutorial is addressed to researchers and students who are interested in the logical/philosophical study of notions of belief and knowledge, including group beliefs and collective "knowledge". We are interested both in the representation of these different types of attitudes as well as in their dynamics, i.e. how these attitudes change in communities of interconnected agents capable of reflection, communication, reasoning, argumentation etc. I will start by introducing the basic concepts and models, using standard techniques from Dynamic Epistemic Logic and their adaptations for dealing with belief revision. I will further focus on characterizing a group's "epistemic potential" and I touch on cases in which a group's ability to track the truth is higher than that of each of its members. This tutorial paves the way for my invited lecture in which I focus on situations in which the group's dynamics leads to informational distortions (i.e. the "madness of the crowds", in particular the phenomenon of informational cascades). This tutorial is based on a number of recent papers that make use of a variety of formal tools ranging over dynamic epistemic logics, game theory and network theory.

Generalized Amalgamation Classes and Limit Models: Implicit Logics

Andrés Villaveces

Departamento de Matemáticas, Universidad Nacional de Colombia
Bogotá 111321, Colombia
avillavecesn@unal.edu.co

Abstract. This is a two-hour tutorial on two kinds of (generalized) amalgamation classes and the emergence of language (implicit logic) from their semantical properties: abstract elementary classes and sheaves of structures. I will provide definitions, examples and a description of the emergence of logic from their purely semantical properties.

- Amalgamation classes. Ordered and controlled by topologies. Examples and problems.
- Examples: sheaves of structures and abstract elementary classes with amalgamation. Orbital (Galois) types and language.
- Implicit language from semantics. The Presentation Theorem.
- Interpolation in AECs: comparing languages.

Contents