Report from Dagstuhl Seminar 13071

Dependence Logic: Theory and Applications

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Abstract

This report documents the programme and outcomes of Dagstuhl Seminar 13071 "Dependence Logic: Theory and Applications". The seminar brought together researchers from different areas such as mathematical logic, quantum mechanics, statistics, social choice theory, and theoretical computer science. A key objective of the seminar was to bring together, for the first time, researchers working in dependence logic and in the application areas so that they can communicate state-of-the-art advances and embark on a systematic interaction.

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Edited in cooperation with Miika Hannula

1 Executive Summary

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Brief Introduction to the Topic

Dependence Logic is a new tool for modeling dependencies and interaction in dynamical scenarios. Reflecting this, it has higher expressive power and complexity than classical logics used for these purposes previously. Algorithmically, first-order dependence logic corresponds exactly to the complexity class NP and to the so-called existential fragment of second-order logic.

Since the introduction of dependence logic in 2007, the framework has been generalized, e. g., to the contexts of modal, intuitionistic and probabilistic logic. Moreover, interesting connections have been found to complexity theory and database theory, and dependence logic has been applied in areas such as linguistics, social choice theory, and physics. Although significant progress has been made in understanding the computational side of these formalisms, still many central questions remain unsolved so far.

The notions of logical dependence and independence are pervasive, and occur in many areas of science. The development of logical and semantical structures for these notions provides an opportunity for a systematic approach, which can expose surprising connections between different areas (e. g., quantum mechanics, social choice theory, and many more), and may lead to useful general results.

One of the main aims of this Dagstuhl Seminar was to bring together, for the first time, researchers working in this area so that they can communicate state-of-the-art advances and embark on a systematic interaction. In particular, bringing together researchers from areas of theoretical studies with the application areas will enhance the synergy between the different communities working on dependence logic.

Organization of the Seminar and Activities

The workshop brought together 35 researchers from mathematics, theoretical physics, statistics, social choice theory, and theoretical computer science. The participants consisted of both senior and junior researchers, including a number of postdocs and a few advanced graduate students.

Participants were invited to present their work and to communicate state-of-the-art advances. Seventeen talks of various lengths took place over the five days of the workshop. Introductory and tutorial talks of 90-60 minutes were scheduled prior to workshop. Most of the remaining slots were filled, mostly with shorter talks, as the workshop commenced. The organizers considered it important to leave ample free time for discussion.

The tutorial talks were scheduled during the beginning of the week in order to establish a common background for the different communities that came together for the workshop. The presenters and topics were:

- Jouko Väänänen, Dependence Logic
- Erich Grädel, Logics with team semantics and second-order reachability games
- Philip Dawid, Conditional Independence and Irrelevance
- Pietro Galliani, Definability Issues in Team Semantics
- Phokion Kolaitis, Foundations and Applications of Schema Mappings
- Samson Abramsky, From Quantum Mechanics to Logic, Databases, Constraints, Complexity and Beyond
- Sebastian Link, Dependence, Independence, Logic
- Wilfrid Hodges, Compositionality: Its history and formalism
- Eric Pacuit, Dependence and Independence in Social Choice Theory

There were additionally 8 other talks with a more focused and technical topic.

1. Georg Gottlob, From Local Hidden Variables in Quantum Mechanics to Robust Colorability and Satisfiability
2. Panayiota Constantinou, Extended Conditional Independence
3. Fan Yang, Uniform definability in propositional dependence logic
4. Pierfrancesco La Mura, A double-slit experiment for non-classical interference effects in decision-making
5. Julian Bradfield, Concurrency, causality and dependency
6. Miika Hannula, Axiomatizing first-order consequences in independence logic
7. Andreas R. Blass, Introduction to Secret Sharing
8. Arnaud Durand, Complexity issues in dependence logic

The workshop achieved its aim of bringing together researchers from various related communities to share state-of-the-art research. The organizers left ample time outside of this schedule of talks and many fruitful discussions between participants took place throughout the afternoons and evenings.

Concluding Remarks and Future Plans

The organizers regard the workshop as a great success. Bringing together researchers from different areas fostered valuable interactions and led to fruitful discussions. Feedback from the participants was very positive as well. Many attendants expressed their wish for a continuation and stated that this seminar was among the most fruitful Dagstuhl seminars they attended.

Finally, the organizers wish to express their gratitude toward the Scientific Directorate of the Center for its support of this workshop, and hope to establish a series of workshops on *Dependence Logic: Theory and Applications* in the future.

2 Table of Contents

Executive Summary
Samson Abramsky, Juha Kontinen, Jouko Väänänen, and Heribert Vollmer 45

Overview of Talks

Concurrency and (in)dependence
Julian Bradfield 49

Extended Conditional Independence
Panayiota Constantinou 49

Conditional Independence and Irrelevance
A. Philip Dawid 49

Definability Issues in Team Semantics
Pietro Galliani 50

Robust Constraint Satisfaction and hidden variable detection in quantum mechanics
Georg Gottlob 50

Axiomatizing first-order consequences in independence logic
Miika Hannula 50

Compositionality: its history and formalism
Wilfrid Hodges 51

A double-slit experiment for non-classical dependencies in decision-making
Pierfrancesco La Mura 51

Dependence, Independence, Logic
Sebastian Link 51

Dependence and Independence in Social Choice
Eric Pacuit 52

Dependence logic
Jouko Väänänen 52

Uniform definability of connectives in propositional dependence logic
Fan Yang 52

Participants 54

3 Overview of Talks

3.1 Concurrency and (in)dependence

Julian Bradfield (University of Edinburgh, GB)

Joint work of Bradfield, Julian; Fröschle, Sibylle; Gutierrez, Julian; Kreutzer, Stephan

I review work by myself and colleagues over the last 20 years, which considers logics for concurrent systems, and how such logics relate to independence-friendly logic, and thus to dependence logic.

3.2 Extended Conditional Independence

Panayiota Constantinou (University of Cambridge, GB)

The notion of Conditional Independence can be extended to encompass stochastic and nonstochastic variables simultaneously. This extended language can express various notions in statistics, like sufficiency, causal concepts etc. Formalizing the extended language we study conditions that allow us to deduce the axioms of conditional independence (classical properties of stochastic conditional independence).

3.3 Conditional Independence and Irrelevance

A. Philip Dawid (University of Cambridge, GB)

Main reference A.P. Dawid, "Separoids: A mathematical framework for conditional independence and irrelevance," Ann. Math. Artificial Intelligence, Vol. 32, Issue 1–4, pp. 335-372, 2001.
URL http://dx.doi.org/10.1023/A:1016734104787

Probabilistic independence and conditional independence play a major role in statistical theory. Probabilistic conditional independence can be shown to enjoy certain fundamental general properties, which can then be used as an independent axiomatic system. A further step towards abstraction produces a mathematical object, the "separoid", which can be interpreted as embodying the informal concept of "irrelevance", and has many applications beyond, or totally removed from, the initial probabilistic framework. In particular, the logical relation of "variation independence" defines a separoid. Furthermore, by building connexions with other mathematical models of separoids, in particular undirected and directed acyclic graphs, we can streamline the analysis of a given separoid structure.

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3.4 Definability Issues in Team Semantics

Pietro Galliani (University of Helsinki, FI)

I will present a number of extensions and variants of Dependence Logic and discuss a number of known results (plus a couple of new ones) concerning interdefinability and expressivity.

Furthermore, I will discuss how these results can be integrated into a general theory of definability in team semantics.

3.5 Robust Constraint Satisfaction and hidden variable detection in quantum mechanics

Georg Gottlob (University of Oxford, GB)

Joint work of Abramsky, Samson; Gottlob, Georg; Kolaitis, Phokion

Motivated by considerations in quantum mechanics, we introduce the class of robust constraint satisfaction problems in which the question is whether every partial assignment of a certain length can be extended to a solution, provided the partial assignment does not violate any of the constraints of the given instance. We explore the complexity of specific robust colorability and robust satisfiability problems, and show that they are NP complete. We then use these results to establish the computational intractability of detecting local hidden-variable models in quantum mechanics.

3.6 Axiomatizing first-order consequences in independence logic

Miika Hannula (University of Helsinki, FI)

Independence logic cannot be effectively axiomatized. However, first-order consequences of independence logic sentences can be axiomatized. Here we give an explicit axiomatization and sketch a proof of it being complete in this sense.

3.7 Compositionality: its history and formalism

Wilfrid Hodges (Okehampton, Devon)

Main reference W. Hodges, "Formalizing the relationship between meaning and syntax," in The Oxford Handbook of Compositionality, ed. M. Werning, W. Hinzen and E. Machery, Oxford University Press, pp. 245–261, 2012.
URL http://wilfridhodges.co.uk/semantics13.pdf

A tutorial talk, covering the history of the idea of compositionality from its origins to its role in the discovery of the team semantics.

3.8 A double-slit experiment for non-classical dependencies in decision-making

Pierfrancesco La Mura (HHL Leipzig, DE)

Main reference To appear in Topics in Cognitive Science, special issue on Quantum Cognition, 2013.

We discuss the possible nature and role of non-physical entanglement, and the classical vs. non-classical interface, in models of human decision-making. We also introduce an experimental setting designed after the double-slit experiment in physics, and discuss how it could be used to discriminate between classical and non-classical interference effects in human decisions.

3.9 Dependence, Independence, Logic

Sebastian Link (University of Auckland, NZ)

Joint work of Hartmann, Sven; Link, Sebastian
Main reference S. Hartmann, S. Link, "The implication problem of data dependencies over SQL table definitions: Axiomatic, algorithmic and logic characterizations," ACM Trans. Datab. Syst. 37(2), Article 13, May 2012.
URL http://dx.doi.org/10.1145/2188349.2188355

Data dependencies enforce meaningful properties of a given application domain within a database system. Dependencies are essential for the design of databases, and facilitate many data processing tasks. Conditional independencies capture structural aspects of probability distributions, deal with knowledge in artificial intelligence, and help with learning and reasoning in intelligent systems. Reasoning about data dependencies or about conditional independencies is infeasible in general. However, expressive yet efficient subclasses have been identified in both cases, for examples, multivalued dependencies and saturated conditional independencies. These findings are based on the classic assumption that the underlying data are complete. In practice, data are missing or unknown, and structural or sampling zeros occur. In this seminar expressive and efficient notions of multivalued dependencies and saturated conditional independencies are presented in the presence of incomplete data. It is demonstrated that the implication problem for multivalued dependencies, for saturated conditional independencies, and for a propositional fragment of S-3 logic coincide. The results show that reasoning in the presence of incomplete data soundly approximates reasoning in the presence of complete data; and that reasoning can be done in almost linear time in the input.

3.10 Dependence and Independence in Social Choice

Eric Pacuit (Tilburg University, NL)

I surveyed a number of key results in social choice theory (e.g., Arrow's Impossibility Theorem, May's Characterization of Majority Rule). My goal was to highlight the notions of independence and dependence found in this literature.

3.11 Dependence logic

Jouko Väänänen (University of Helsinki, FI)

Main reference J. Väänänen, "Dependence Logic – A New Approach to Independence Friendly Logic," London Mathematical Society Student Texts, No. 70, Cambridge University Press, ISBN 9780521876599, 2007.
URL http://www.cambridge.org/gb/knowledge/isbn/item1174541

This is an opening introductory tutorial on the basic ideas of dependence and independence logic. I review team semantics, the main driving force behind dependence logic. I emphasise the ubiquitousness and potential applications of dependence and independence concepts throughout science and humanities.

3.12 Uniform definability of connectives in propositional dependence logic

Fan Yang (University of Helsinki, FI)

Propositional dependence logic is the propositional variant of first-order dependence logic [4]. Intuitionistic implication and intuitionistic disjunction in the setting of team semantics were introduced in [1]. Propositional dependence logic extended with intuitionistic implication and intuitionistic disjunction, called propositional intuitionistic dependence logic, is essentially equivalent to inquisitive logic [2]. Huuskonen (2012) showed that propositional intuitionistic dependence logic is equivalent to propositional dependence logic. It follows that every formula with intuitionistic disjunction and intuitionistic implication can be translated into a formula without these two connectives. In this talk, we show that although such a non-uniform translation exists, neither of intuitionistic disjunction and intuitionistic implication is uniformly definable in propositional dependence logic. This work was inspired by [3].

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Figure 1 Afternoon walk on Wednesday.

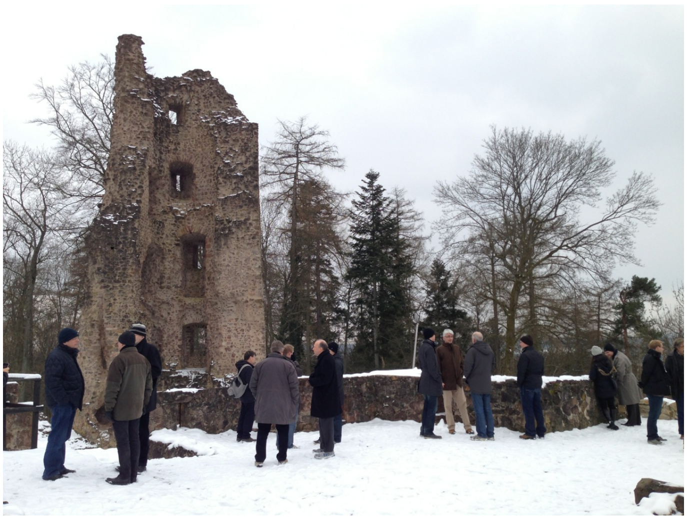

Figure 2 The tower at Dagstuhl Castle.

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