10061 Abstracts Collection
Circuits, Logic, and Games
— Dagstuhl Seminar —

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Abstract. From 07/02/10 to 12/02/10, the Dagstuhl Seminar 10061 "Circuits, Logic, and Games" was held in Schloss Dagstuhl – Leibniz Center for Informatics. During the seminar, several participants presented their current research, and ongoing work and open problems were discussed. Abstracts of the presentations given during the seminar as well as abstracts of seminar results and ideas are put together in this paper. The first section describes the seminar topics and goals in general. Links to extended abstracts or full papers are provided, if available.

Keywords. Computational complexity theory, Finite model theory, Boolean circuits, Regular languages, Finite monoids, Ehrenfeucht-Fraïssé-games

10061 Executive Summary – Circuits, Logic, and Games

In the same way as during the first seminar on "Circuits, Logic, and Games" (Nov. 2006, 06451), the organizers aimed to bring together researchers from the areas of finite model theory and computational complexity theory, since they felt that perhaps not all developments in circuit theory and in logic had been explored fully in the context of lower bounds. In fact, the interaction between the areas has flourished a lot in the past 2-3 years, as can be exemplified by the following lines of research.

Keywords: Computational complexity theory, finite model theory, Boolean circuits, regular languages, finite monoids, Ehrenfeucht-Fraïssé-games

Joint work of: Rossman, Benjamin; Schwentick, Thomas; Thérien, Denis; Vollmer, Heribert

Extended Abstract: http://drops.dagstuhl.de/opus/volltexte/2010/2527

Proof Complexity of Propositional Default Logic

Olaf Beyersdorff (Leibniz Universität Hannover, DE)

Default logic is one of the most popular and successful formalisms for non-monotonic reasoning. In 2002, Bonatti and Olivetti introduced several sequent calculi for credulous and skeptical reasoning in propositional default logic. In this paper we examine these calculi from a proof-complexity perspective. In particular, we show that the calculus for credulous reasoning obeys almost the same bounds on the proof size as Gentzen's system LK. Hence proving lower bounds for credulous reasoning will be as hard as proving lower bounds for LK. On the other hand, we show an exponential lower bound to the proof size in Bonatti and Olivetti's enhanced calculus for skeptical default reasoning.

Keywords: Proof complexity, default logic, sequent calculus

Joint work of: Beyersdorff, Olaf; Meier, Arne; Müller, Sebastian; Thomas, Michael; Vollmer, Heribert

Full Paper: http://drops.dagstuhl.de/opus/volltexte/2010/2526

Hardness of Parameterized Resolution

Nicola Galesi (University of Rome "La Sapienza", IT)

Parameterized Resolution and, moreover, a general framework for parameterized proof complexity was introduced by Dantchev, Martin, and Szeider (FOCS'07). In that paper, Dantchev et al. show a complexity gap in tree-like Parameterized Resolution for propositional formulas arising from translations of first-order principles.

We broadly investigate Parameterized Resolution obtaining the following main results:

1. We introduce a purely combinatorial approach to obtain lower bounds to the proof size in tree-like Parameterized Resolution. For this we devise a new asymmetric Prover-Delayer game which characterizes proofs in (parameterized) tree-like Resolution. By exhibiting good Delayer strategies we then show lower bounds for the pigeonhole principle as well as the order principle.
2. Interpreting a well-known FPT algorithm for vertex cover as a DPLL procedure for Parameterized Resolution, we devise a proof search algorithm for Parameterized Resolution and show that tree-like Parameterized Resolution allows short refutations of all parameterized contradictions given as bounded-width CNF's.
3. We answer a question posed by Dantchev, Martin, and Szeider showing that dag-like Parameterized Resolution is not fpt-bounded. We obtain this result by proving that the pigeonhole principle requires proofs of size $n^{\Omega(k)}$ in dag-like Parameterized Resolution. For this lower bound we use a different Prover-Delayer game which was developed for Resolution by Pudlák.

Keywords: Proof complexity, parameterized complexity, Resolution, Prover-Delayer Games

Joint work of: Beyersdorff, Olaf; Galesi, Nicola; Lauria, Massimo

Full Paper: http://drops.dagstuhl.de/opus/volltexte/2010/2525

Exact Threshold Circuits

Kristoffer Arnsfelt Hansen (Aarhus University, DK)

We initiate a systematic study of constant depth Boolean circuits built using exact threshold gates. We consider both unweighted and weighted exact threshold gates and introduce corresponding circuit classes. We next show that this gives a hierarchy of classes that seamlessly interleave with the well–studied corresponding hierarchies defined using ordinary threshold gates.

A major open problem in Boolean circuit complexity is to provide an explicit super–polynomial lower bound for depth two threshold circuits. We identify the class of depth two exact threshold circuits as a natural subclass of these where also no explicit lower bounds are known. Many of our results can be seen as evidence that this class is a strict subclass of depth two threshold circuits — thus we argue that efforts in proving lower bounds should be directed towards this class.

Joint work of: Hansen, Kristoffer Arnsfelt; Podolskii, Vladimir V.

Regular representations of uniform TC^0

Lauri Hella (University of Tampere, FI)

The complexity class DLOGTIME-uniform AC^0 is known to be a modest subclass of DLOGTIME-uniform TC^0. The weakness of AC^0 is due, put in logical terms, to the fact that the logics corresponding to AC^0 do not have the relativization property and hence they are not regular. This weakness of AC^0 has been elaborated in the line of research on the Crane Beach Conjecture. In this talk we show that DLOGTIME-uniform TC^0 can be logically characterized in terms of quantifier logics with cardinality quantifiers $\mathrm{FO}_<(C_S)$, where S is the range of some polynomial of degree at least two. Then we adapt the key properties of abstract logics to accomodate built-in relations and define the regular interior R-int(L) and regular closure R-cl(L) of a logic L. Finally we show that the Crane Beach Conjecture is closely related to the regular interior of a logic, and that the regular closure of AC^0 is TC^0.

Joint work of: Hella, Lauri; Kontinen, Juha; Luosto, Kerkko

Definability in dependence logic

Juha Kontinen (University of Helsinki, FI)

In this talk we consider dependence logic which incorporates the concept of dependence into first-order logic. For sentences, the expressive power of dependence logic coincides with that of existential second-order logic. As formulas of dependence logic express properties of sets of assignments, not properties of individual assignments, this result does not directly extend to open formulas. We show that open formulas of dependence logic correspond to the negative fragment (downwards monotone) of existential second-order logic.

We also show that the negation of dependence logic is not a semantic operation, that is, knowing the class of models that satisfy a formula does not completely determine the class of models of its negation. This is joint work with Jouko Väänänen.

Keywords: Dependence logic, team

Joint work of: Kontinen, Juha; Väänänen, Jouko

A new characterization of ACC^0 and probabilistic CC^0.

Michal Koucky (Academy of Sciences - Prague, CZ)

Barrington, Straubing and Thérien (1990) conjectured that the Boolean AND function can not be computed by polynomial size constant depth circuits built from modular counting gates, i.e., by CC^0 circuits. In this work we show that the AND function can be computed by uniform probabilistic CC^0 circuits that use only $O(\log n)$ random bits. This may be viewed as evidence contrary to the conjecture.

As a consequence of our construction we get that all of ACC^0 can be computed by probabilistic CC^0 circuits that use only O(log n) random bits. Thus, if one were able to derandomize such circuits, we would obtain a collapse of circuit classes giving $\mathrm{ACC}^0 = \mathrm{CC}^0$. We present a derandomization of probabilistic CC^0 circuits using AND and OR gates to obtain $\mathrm{ACC}^0 = \text{AND-OR-CC}^0 = \text{OR-AND-CC}^0$. AND and OR gates of sublinear fan-in suffice.

Both these results hold for uniform as well as non-uniform circuit classes. For non-uniform circuits we obtain the stronger conclusion that $\mathrm{ACC}^0 = \text{rand-ACC}^0 = \text{rand-CC}^0 = \text{rand}(\log n)\text{-CC}^0$, i.e., probabilistic ACC^0 circuits can be simulated by probabilistic CC^0 circuits using only $O(\log n)$ random bits.

As an application of our results we obtain a characterization of ACC^0 by constant width planar nondeterministic branching programs, improving a previous characterization for the quasi-polynomial size setting.

Joint work of: Arnsfelt Hansen,Kristoffer; Koucky, Michal

Two Variable Majority Logic

Andreas Krebs (Universität Tübingen, DE)

Following recent works connecting two-variable logic to circuits and monoids, we establish, for numerical predicate sets P satisfying a certain closure property, a one-to-one correspondence between $\mathrm{FO}[<, P]$-uniform linear circuits, two-variable formulae with P predicates, and weak block products of monoids.

In particular, we consider the case of linear TC^0, majority quantifiers, and finitely typed monoids.

This correspondence will hold for any numerical predicate set which is $\mathrm{FO}[<]$-closed and whose predicates do not depend on the input length.

We present a geometric method which is used to show that a given regular language cannot be defined by such formulas.

Complexity Results for Modal Dependence Logic

Peter Lohmann (Leibniz Universität Hannover, DE)

Modal dependence logic was introduced very recently by Väänänen. It enhances the basic modal language by an operator dep. For propositional variables $p_1, \ldots, p_n$, $\mathrm{dep}(p_1, \ldots, p_{n-1}; p_n)$ intuitively states that the value of p_n only depends on those of $p_1, \ldots, p_{n-1}$. Sevenster (J. Logic and Computation, 2009) showed that satisfiability for modal dependence logic is complete for nondeterministic exponential time.

In this paper we consider fragments of modal dependence logic obtained by restricting the set of allowed propositional connectives. We show that satisfibility for poor man's dependence logic, the language consisting of formulas built from literals and dependence atoms using conjunction, necessity and possibility (i.e., disallowing disjunction), remains NEXPTIME-complete. If we only allow monotone formulas (without negation, but with disjunction), the complexity drops to PSPACE-completeness. We also extend Väänänen's language by allowing classical disjunction besides dependence disjunction and show that the satisfiability problem remains NEXPTIME-complete. If we then disallow both negation and dependence disjunction, satistiability is complete for the second level of the polynomial hierarchy.

In this way we completely classify the computational complexity of the satisfiability problem for all restrictions of propositional and dependence operators considered by Väänänen and Sevenster.

Keywords: Dependence logic, satisfiability problem, computational complexity, poor man's logic

Joint work of: Lohmann, Peter; Vollmer, Heribert

Full Paper: http://drops.dagstuhl.de/opus/volltexte/2010/2524

Addition-invariant FO and regularity

Nicole Schweikardt (Universität Frankfurt, DE)

We consider first-order formulas which, in addition to the symbols in the vocabulary, may use two designated symbols $<$ and $+$ that must be interpreted as a linear order and its associated addition. Such a formula is called addition-invariant if, for each fixed interpretation of the initial vocabulary, its result is independent of the particular interpretation of $<$ and $+$.

We study the expressive power of addition-invariant first-order logic, $+$-inv-FO, on the class of finite strings. Our first main result gives a characterization of the regular languages definable in $+$-inv-FO: we show that these are exactly the languages definable in FO with extra predicates, denoted by "lm" for short, for testing the length of the string modulo some fixed number.

Our second main result shows that every language definable in $+$-inv-FO, that is bounded or commutative or deterministic context-free, is regular.

As an immediate consequence of these two main results, we obtain that $+$-inv-FO is equivalent to FO(lm) on the class of finite colored sets.

Our proof methods involve Ehrenfeucht-Fraissé games, tools from algebraic automata theory, and reasoning about semi-linear sets.

Joint work of: Schweikardt, Nicole; Segoufin, Luc

The Dynamic Complexity of Formal Languages

Thomas Schwentick (TU Dortmund, DE)

The paper investigates the power of the dynamic complexity classes DynFO, DynQF and DynPROP over string languages. The latter two classes contain problems that can be maintained using quantifier-free first-order updates, with and without auxiliary functions, respectively. It is shown that the languages maintainable in DynPROP are exactly the regular languages, even when allowing arbitrary precomputation. This enables lower bounds for DynPROP and separates DynPROP from DynQF and DynFO. Further, it is shown that any context-free language can be maintained in DynFO and a number of specific context-free languages, for example all Dyck-languages, are maintainable in DynQF.

Keywords: Dynamic complexity, Regular languages, context-free languages

Joint work of: Gelade, Wouter; Marquardt, Marcel; Schwentick, Thomas

The Help functions problem

Srikanth Srinivasan (The Institute of Mathematical Sciences - Chennai, IN)

We consider the Help functions problem for constant-depth boolean circuits. We show that this problem has applications to separating Exponential-time from the polynomial-time many one closure of AC^0. We also demonstrate an approach that might help solve this problem: we show that if one can solve the Remote Point Problem – introduced by Alon, Panigrahy, and Yekhanin in 2008 – then one can solve the Help functions problem. Finally, we show partial solutions to restricted subcases of this problem.

Keywords: Constant-depth circuits, Remote Point Problem, Sign representations

Joint work of: Arvind, V; Srinivasan, Srikanth

Full Paper:
http://arxiv.org/abs/0911.4337

See also: Vikraman Arvind, Srikanth Srinivasan: Circuit Lower Bounds, Help Functions, and the Remote Point Problem. ICS 2010.

The Complexity of Reasoning for Fragments of Autoepistemic Logic

Michael Thomas (Leibniz Universität Hannover, DE)

Autoepistemic logic extends propositional logic by the modal operator L. A formula that is preceded by an L is said to be "believed". The logic was introduced by Moore 1985 for modeling an ideally rational agent's behavior and reasoning about his own beliefs. In this paper we analyze all Boolean fragments of autoepistemic logic with respect to the computational complexity of the three most common decision problems expansion existence, brave reasoning and cautious reasoning. As a second contribution we classify the computational complexity of counting the number of stable expansions of a given knowledge base. To the best of our knowledge this is the first paper analyzing the counting problem for autoepistemic logic.

Keywords: Autoepistemic logic, computational complexity, nonmonotonic reasoning, Post's lattice

Joint work of: Creignou, Nadia; Meier, Arne; Thomas, Michael; Vollmer, Heribert

Full Paper: http://drops.dagstuhl.de/opus/volltexte/2010/2523

Expressiveness questions in the calculus of relations

Jan Van den Bussche (Hasselt University - Diepenbeek, BE)

The calculus of relations provides a natural algebraic query language for querying binary relational structures. Its operations consist of the identity and the diversity relations which are provided as constants; and the operations union, set difference, intersection, composition, and converse. The resulting query language is denoted here by RA. The expressive power of RA is well known to be equal to that of first-order logic with three variables. In this work we study the 14 different fragments of RA (and thus of FO^3) that can be obtained by taking always the operations union, intersection, composition, and identity, and taking a selection of the operations difference, converse, projection, coprojection, and diversity. (Projection and coprojection are derived operations.) We describe variants of the 3-pebble game for FO^3, in the form of similarity and bisimilarity relations on pairs of elements, that characterise indistinguishability for all these fragments.

Joint work of: Fletcher, George H.L.; Gyssens, Marc; Gucht, Dirk Van; Vansummeren, Stijn; Wu, Yuqing