The Ackermann Award 2014

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Abstract

Report of the Jury for the 2014 Ackermann Award.

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Ackermann Award

The tenth Ackermann Award is presented at CSL-LICS 2014, held in Vienna, Austria. This year, as for the previous four years, the EACSL Ackermann Award is generously sponsored by the Kurt Gödel Society. The Society provides financial support for the Ackermann award and invites the recipient of the award to present a lecture to the Society.

The 2014 Ackermann Award was open to PhD dissertations in topics specified by the CSL and LICS conferences, which were formally accepted as theses for the award of a PhD degree at a university or equivalent institution between 1 January 2012 and 31 December 2013. The Jury received seventeen nominations for the Ackermann Award 2014, a record number. The candidates came from a number of different countries across the world. The institutions at which the nominees obtained their doctorates represent eleven countries in Europe, North America, South America and the Middle East.

The topics covered the full range of Logic and Computer Science as represented by the LICS and CSL Conferences. All submissions were of a very high standard and contained remarkable contributions to their particular fields. The Jury wishes to extend its congratulations to all nominated candidates for their outstanding work. The Jury encourages them to continue their scientific careers and hopes to see more of their work in the future.

With such an outstanding field of nominees, the task of the jury was difficult. In the end, after much discussion, the decision converged on one thesis. The **2014 Ackermann Award** winner is:

> Michael Elberfeld from Germany, for his thesis
>
> *Space and Circuit Complexity of Monadic Second-Order Definable Problems on Tree-Decomposable Structures*
>
> approved by the University of Lübeck, Germany, in 2012, supervised by Till Tantau.

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Michael Elberfeld

Citation Michael Elberfeld receives the *2014 Ackermann Award* of the European Association of Computer Science Logic (EACSL) for his thesis

> *Space and Circuit Complexity of Monadic Second-Order Definable Problems on Tree-Decomposable Structures*

His thesis establishes that every property definable in monadic second-order logic can be evaluated on structures of bounded tree-width in logarithmic space. It pins down the exact structural complexity of constructing a tree-decomposition of given width. The results yield optimal complexity characterizations of a variety of widely-studied decision, counting and optimization problems in terms of space and circuit complexity.

Background of the Thesis Courcelle established that for every sentence ϕ of monadic second-order logic (MSO) and every positive integer k, the class of models of ϕ of tree-width at most k is decidable by a *linear-time* algorithm (Courcelle 1990). This theorem has proved highly influential for a number of reasons. It extends the close connection between MSO and finite automata, which has proved so fruitful in the case of words and trees, to a much wider variety of structures. It relates MSO definability to the notion of tree-width, a parameter that emerged from graph structure theory and has assumed great importance in recent years. It provides efficient algorithms (in the important case of bounded tree-width classes) for a number of otherwise intractable problems. It had an impact on the explosion of interest in fixed-parameter and multivariate algorithmics among the algorithms research community.

While linear-time algorithms cannot be asymptotically improved, Courcelle's theorem leaves open the exact structural complexity of the problems that are definable in MSO on bounded tree-width classes. It places them in the class P, but could they be in any lower class? Bodlaender (Bodlaender 1989) showed that all such problems are, in fact, in the class NC and this was improved by Wanke (Wanke 1994), who showed that they are in LOGCFL. In the time since then, there were no further improvements and it was widely assumed that the result was optimal, until the results in Elberfeld's thesis were established.

Elberfeld's Thesis The first main result in the thesis establishes that for every MSO sentence ϕ and positive integer k, the class of structures of tree-width at most k that satisfy ϕ is decidable in logarithmic space. Since there is a corresponding hardness result (i.e. there are ϕ and k for which the problem is L-hard), this is the definitive answer to a question that has been around for over two decades, fixing the precise computational complexity of this class of problems. And, the answer runs contrary to expectations. This result is further extended to counting and optimization problems that can be expressed in MSO. In each of these cases, it is shown that there are deterministic algorithms that can perform the related counting and optimization tasks within logarithmic space.

The main result is composed of two parts. In the first part, Elberfeld establishes the algorithmic result showing that, for a fixed k, there is a logarithmic-space algorithm that can compute a small-width tree decomposition, given a structure of tree-width at most k. This is in itself a significant contribution to the study of the complexity of a well-studied graph-theoretic parameter, improving the bounds of Bodlaender, of Wanke and of Gottlob et al. (Gottlob et al. 2002).

The second part of the main result is about the complexity of evaluating an MSO formula ϕ on a structure $\mathcal{A}$, *given* a tree-decomposition of $\mathcal{A}$ of width at most k. For this, Elberfeld turns to classification in terms of circuit complexity and shows that the problem can be solved by logarithmic-depth, bounded fan-in Boolean circuits. The result is extended to counting problems by considering arithmetic circuits in place of Boolean circuits. The heart of the proof is overcoming the difficulty that arises from the fact that the tree-decomposition of $\mathcal{A}$ may be a tree of height linear in the size of $\mathcal{A}$. Elberfeld tackles this with a clever re-balancing construction, which turns the decomposition into one that is of logarithmic height and shows that this itself can be achieved by small-depth circuits.

The proof establishes a relationship between the height of a tree-decomposition of $\mathcal{A}$ and the depth of the circuit that evaluates ϕ on $\mathcal{A}$. This focuses attention on those structures which admit decompositions of height bounded by a constant d. These are the structures of *bounded tree-depth*. The thesis shows that on such structures, an MSO formula ϕ can be evaluated by a family of constant-depth circuits. It is well-known that any problem defined by a uniform constant-depth family of circuits can also be defined by a first-order formula with additional numerical predicates. Elberfeld shows that these additional numerical predicates are not necessary in the case when the family is obtained from an MSO formula interpreted on structures of bounded tree-depth. This shows that on such classes of structures, any formula of MSO can be translated to first-order logic. What's more, Elberfeld shows that these are essentially the only classes of structures where this happens.

Monadic second-order logic is of central interest in applications of logic to computer science. This is partly due to the close connection between MSO and finite automata. Elberfeld's thesis adds small-depth Boolean and arithmetic circuits to the toolkit available to the logician studying MSO. Moreover, his thesis suggests that MSO is also a valuable addition to the complexity theorist's toolkit. As a consequence of Elberfeld's central results about MSO definable problems, we obtain the exact complexity of a number of specific problems. For instance, it is established that the directed reachability problem for graphs of bounded tree-width is in L; that the problem of determining whether an undirected graph contains an even-cycle is in L; and there is (for each k) a logarithmic-space algorithm that counts the number of perfect matchings in a graph of tree-width at most k.

It is often said that finite model theory provides a bridge between the study of logical definability on the one hand and computational complexity on the other. It has also been noted that the traffic across the bridge is mostly one way, with results on complexity being used to establish consequences about definability. A rare example going in the other direction is Immerman's award-winning proof of the closure under complementation of nondeterministic space complexity classes. To this, we should now add the consequences of Elberfeld's results.

Biographical Sketch. Michael Elberfeld was born on 23 November, 1981 at Friesoythe, Germany. From 2002, he was a student of computer science (with a minor in media studies) at the University of Lübeck where, in 2007, he completed a Diploma in the area of bioinformatics. He continued his doctoral studies at the same university, defending his PhD in July 2012. During 2012-13 he held a grant from the DAAD enabling him to carry out postdoctoral research at the International Computer Science Institute in Berkeley, USA and at the National Institute of Informatics in Tokyo, Japan. Since 2013 he is a postdoctoral fellow at RWTH Aachen University in Germany.

Jury

The Jury for the **Ackermann Award 2014** consisted of eight members, three of them *ex officio*, namely, the president and the vice-president of EACSL and one member of the LICS organising committee.

The members of the jury were:

- Thierry Coquand (Chalmers University of Gothenburg),
- Anuj Dawar (University of Cambridge), the president of EACSL,
- Thomas A. Henzinger (IST Austria),
- Daniel Leivant (Indiana University, Bloomington),
- Damian Niwiński (University of Warsaw),
- Luke Ong (University of Oxford), LICS representative
- Simona Ronchi della Rocca (University of Torino), the vice-president of EACSL,
- Wolfgang Thomas (RWTH, Aachen).

Previous winners

Previous winners of the Ackermann Award were

2005, Oxford:
Mikołaj Bojańczyk from Poland,
Konstantin Korovin from Russia, and
Nathan Segerlind from the USA.

2006, Szeged:
Balder ten Cate from The Netherlands, and
Stefan Milius from Germany.

2007, Lausanne:
Dietmar Berwanger from Germany and Romania,
Stéphane Lengrand from France, and
Ting Zhang from the People's Republic of China.

2008, Bertinoro:
Krishnendu Chatterjee from India.

2009, Coimbra:
Jakob Nordström from Sweden.

2010, Brno:
no award given.

2011, Bergen:
Benjamin Rossman from USA.

2012, Fontainebleau:
Andrew Polonsky from Ukraine, and
Szymon Toruńczyk from Poland.

2013, Turin:
Matteo Mio from Italy.

Detailed reports on their work appeared in the CSL proceedings and are also available on the EACSL homepage.

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