The Ackermann Award 2009

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Members of EACSL Jury for the Ackermann Award

The fifth **Ackermann Award** is presented at this CSL'09, held in Coimbra, Portugal. This is the third year in which the EACSL Ackermann Award is generously sponsored. Our sponsor is the world's leading provider of personal peripherals, Logitech S.A., situated in Romanel, Switzerland[1].

Eligible for the 2009 **Ackermann Award** were PhD dissertations in topics specified by the EACSL and LICS conferences, which were formally accepted as PhD theses at a university or equivalent institution between 1.1. 2007 and 31.12. 2008. The Jury received 12 nominations for the **Ackermann Award 2009**. The candidates came from 10 different nationalities from Europe, North America and Asia and received their PhDs in 9 different countries in Europe and North America.

The topics covered the full range of Logic and Computer Science as represented by the LICS and CSL Conferences. All the submissions were of very high standard and contained outstanding results in their particular domain. In the past the Jury reached a consensus to give more than one award. This time, in spite of the extreme high quality of the nominated theses, the Jury decided finally, to give for the year 2009 **only one** award. The 2009 **Ackermann Award** winner is

Jakob Nordström

for his thesis *Short Proofs May Be Spacious: Understanding Space in Resolution* issued by the Royal Institute of Technology, Stockholm, Sweden, May 2008, supervised by Prof. Johan Håstad.

The Jury wishes to congratulate the recipient of the Ackermann Award for his outstanding work and wishes him a successful continuation of his career.

The Jury wishes also to congratulate all the remaining 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.

Jakob Nordström

Citation. Jakob Nordström receives the *2009 Ackermann Award* of the European Association of Computer Science Logic (EACSL) for his thesis

Short Proofs May Be Spacious: Understanding Space in Resolution.

The thesis greatly advances our understanding of space-related measures in proof complexity. It completely fills the last remaining gap in the picture of most basic relations between space and other fundamental complexity measures like length or width for the system of propositional resolution. The result confirms that space is indeed an inherently independent measure by exhibiting natural contradictions possessing very short and narrow refutations but no low-space refutation. This solution of a well-known open problem complements and contrasts with previously known simulations in the opposite direction.

Background of the thesis. There are many good reasons that make the system of propositional resolution (formally introduced by Robinson in 1965) one of the most popular and widely studied propositional proof systems, both by theoreticians and practitioners.

On the automated theorem proving side, propositional resolution makes the core of one of the most known technique in the field, first-order resolution. As exemplified by the work of several previous Ackermann Award winners, the presence of unification does bring about a new level of interesting and difficult complexity questions. But all the same, the apparent simplicity of the propositional case is very deluding, and many fundamental problems here still remain unresolved.

It is worth noting that resolution often appears in automated theorem proving without invitation. For example, the famous DPLL algorithm developed by Davis, Putnam (1960) and Davis, Putnam, Logemann, Loveland (1962) *before* Robinson's work, still forms the basis for may efficient SAT solvers, as well as for many implementations of first-order theorem provers. The proof-search heuristic in this algorithm is represented by the choice of the branching literal, and, abstracting from the issue of *finding* the best heuristics, we arrive at the proof system that is nowadays called *tree-like resolution* (more modern versions of this algorithm result in unrestricted resolution). Any lower bounds proved for this system automatically translate into ultimate (i.e., regardless of the effort invested into making good branching choices) limitations of any DPLL-like algorithm.

On the theoretical side, propositional resolution had been considered in Proof Complexity (Tseitin 1968) well before the formal inauguration of the subject (Cook 1975). Tseitin worked with (and proved conclusive lower bounds for) its weaker version that has become known as regular resolution. The most natural problem of extending his result by removing the assumption of regularity had to wait for yet another 10 years to be solved (Haken 1985). Since the work of Haken, various methods of analyzing minimal refutation size in resolution (that essentially amount to inherent limitations on the running time of DPLL-like

procedures) have been developed (Ben-Sasson and Wigderson 2000; Raz 2001; Razborov 2001-2004), and by now the program of understanding resolution proof complexity for the most frequently used "benchmark" contradictions (pigeon-hole-principle, Tseitin tautologies, random 3-CNFs) is more or less complete.

This reasonably satisfactory situation pertains only to the size (aka length) of resolution proofs. From both practical and theoretical perspective, in many situations more elaborate complexity measures capture the essence of the problem better.

The first "non-standard" measure for resolution was considered by Ben-Sasson and Wigderson in 2000: this is refutation *width* defined as the maximal number of literals in a clause appearing in the given refutation. They proved a surprising simulation stating that any short proof can be made (somewhat) narrow.

While running-time is the ultimate measure of interest, running-space is arguably more restrictive constraint in practice with direct fatal effects on time. Theoretically, running-space is captured by the model of *space complexity* (Esteban and Torán 2001; Alekhnovich, Ben-Sasson, Razborov, Wigderson 2001). Assume that we download our axioms to RAM only as we need them, and, in order to free memory, we may also discard those intermediate theorems that are no longer needed. In the space model we measure the maximal amount of "information" (details vary in different versions) we should keep in memory at any particular moment.

Atserias and Dalmau proved in 2003 another surprising simulation: every low-space proof can be made narrow and hence (for certain trivial reasons) short. An intriguing problem left open by this research was whether any form of the converse is true, and if good upper bounds on length or width imply at least some non-trivial information about minimal space. This question was discussed in many previous papers, but there was no consensus on what the right answer should be. These papers, however, identified a prominent family of candidate contradictions for separating space from length, so-called *pebbling contradictions*. It is worth noting that although space lower bounds were proved already in the original papers by Esteban et. al, Alekhnovich et. al, all of them dealt with tautologies that were known to be complex also in terms of resolution length. In particular, previously known methods did not seem to work for the pebbling contradictions.

Nordström's thesis. The main contribution of the thesis consists in the ultimate solution of this open problem. But before supplying a few more details, let us make one technical remark.

As the author himself admits, the thesis represents work in progress, and it was written in the midst of intensive research. This fact is reflected by the ascending stricture of the text: different chapters prove increasingly strong versions of the main result. In particular, its final version in Chapter 11 was found roughly at the time the thesis went to press, and the proofs are rather sketchy. But since it is very plausible that it is this version that will make its way to textbooks, we will focuss on it nonetheless.

The main result was already informally formulated in the previous section. Numerically, there exist explicit families of 3-CNF contradictions with $O(n)$ clauses that possess a resolution refutation of constant width and linear length $O(n)$ (both are optimal), but such that the clause space of any refutation of this contradiction is $\Omega(n/\log n)$ (which is also best possible). It rules out any hope to gain information about space from the existence of short and/or narrow resolution refutations. In a sense, it is only this result that firmly established our belief that space complexity is really an independent complexity measure that can not be derived from the others. This fills the last remaining gap in the picture of basic relations between length, width and space.

In his proof Jakob Nordström significantly develops and enhances techniques based upon an important concept of pebbling. These techniques go back to the 197th, and it was very insightful and surprising to see that their modification can be helpful for solving this prominent open problem. The proof, however, contains many elements that are entirely new and are likely to be used elsewhere. In particular, the concept of an *XOR-pebbling contradiction* introduced in the thesis readily generalizes to arbitrary k-CNFs, thereby yielding an useful structural result whose potential importance stretches well beyond pebbling-related contradictions.

Another contribution of the thesis establishes a trade-off between the complexity measures in question. Nordström exhibits explicit contradictions that possess *either* length-efficient *or* space-efficient refutations, but these two requirements can not be fulfilled simultaneously.

The thesis is based upon papers published in STOC06 (Best Student Paper Award, submitted to *SIAM Journal on Computing*), STOC08 and FOCS08. Parts of this research are co-authored with his advisor Johan Håstad (Royal Institute of Technology, Stockholm), as well as Eli Ben-Sasson (Technion–Israel Institute of Technology, Haifa).

Biographic Sketch. Karl Jakob Nordström was born April 11, 1972, in Sweden. He currently is a postdoctoral fellow at the Massachusetts Institute of Technology (MIT). He received his Master of Science in Computer Science and Mathematics at Stockholm University in 2001, and his PhD in Computer Science at the Royal Institute of Technology (KTH) in 2008, while being a research assistant sponsored by the President of KTH. In 2006 he received the best student paper award at 38th ACM Symposium on Theory of Computing (STOC'06).

1997-1998 he served as a military interpreter at the Swedish Armed Forces Language Institute, where he graduated as the best student of the 1998 class. He still works as an interpreter and translator between Russian and Swedish/English, and was engaged as interpreter for among others His Majesty the King of Sweden, the Prime Minister of Sweden, the Speaker of the Swedish Parliament and the Supreme Commander of the Swedish Armed Forces. 2001-2002 he was the Secretary of the Swedish Association of Military Interpreters, and 2002-2005 served as its President.

In 1992 he received his Diploma in Choir Conducting with extended Music Theory from Tallinn Music Upper Secondary School, Estonia, and in 1994 he founded the vocal ensemble *Collegium Vocale Stockholm*, which he led till 1999. Throughout the 90s, the ensemble gave a number of concerts presenting mainly Renaissance and Baroque music.

The Ackermann Award

The EACSL Board decided in November 2004 to launch the EACSL Outstanding Dissertation Award for Logic in Computer Science, the **Ackermann Award**, The award[2]. is named after the eminent logician Wilhelm Ackermann (1896-1962), mostly known for the Ackermann function, a landmark contribution in early complexity theory and the study of the rate of growth of recursive functions, and for his coauthorship with D. Hilbert of the classic *Grundzüge der Theoretischen Logik*, first published in 1928. Translated early into several languages, this monograph was the most influential book in the formative years of mathematical logic. In fact, Gödel's completeness theorem proves the completeness of the system presented and proved sound by Hilbert and Ackermann. As one of the pioneers of logic, W. Ackermann left his mark in shaping logic and the theory of computation.

The **Ackermann Award** is presented to the recipients at the annual conference of the EACSL. The Jury is entitled to give more than one award per year. The award consists of a diploma, an invitation to present the thesis at the CSL conference, the publication of the abstract of the thesis and the citation in the CSL proceedings, and travel support to attend the conference.

The Jury for the **Ackermann Award** consists of eight members, three of them ex officio, namely the president and the vice-president of EACSL, and one member of the LICS organizing committee. The current jury consists of R. Alur (Philadelphia, USA) J. van Benthem (Amsterdam, The Netherlands), P.-L. Curien (Paris, France) A. Dawar (Cambridge, U.K., Member of the EACSL Board) A. Durand (Paris, France) M. Grohe (Berlin, Germany), M. Hyland (Cambridge, U.K.), J.A. Makowsky (Haifa, Israel, President of EACSL), G. Plotkin (Edinburgh, U.K., LICS Organizing Committee) and A. Razborov (Chicago, USA).

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.

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[2] Details concerning the Ackermann Award and a biographic sketch of W. Ackermann was published in the CSL'05 proceedings and can also be found at `http://www.eacsl.org/award.html`.

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.

Detailed reports on their work appeared in the CSL'05, CSL'06, CSL'07 and CSL'08 proceedings, and are also available via the EACSL homepage.