The Ackermann Award 2007

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Members of EACSL Jury for the Ackermann Award*

The third **Ackermann Award** is presented at this CSL'07. This is the first year in which the EACSL Ackermann Award is generously sponsored. Our sponsor for the next three years is the worlds leading provider of personal peripherals, Logitech S.A., situated in Romanel, Switzerland[1].

Eligible for the 2007 **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. 2005 and 31.12. 2006. The Jury received 7 nominations for the **Ackermann Award 2007**. The candidates came from 7 different nationalities from Europe, the Middle East and Asia and received their PhDs in 8 different[2] countries in Europe, North America and Australia.

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. The Jury decided finally, to give for the year 2007 three awards, one for work in *game logics*, one for work in *proof theory*, one for work in *automated theorem proving.* The 2007 **Ackermann Award** winners are, in alphabetical order,

- Dietmar Berwanger from Germany, for his thesis
  Games and logical expressiveness,
  issued by the Rheinisch-Westphälische Technische Hochschule Aachen, Germany, in 2005, supervised by Erich Grädel.

- Stephane Lengrand from France, for his thesis
  Normalisation and Equivalence in Proof Theory and Type Theory,
  issued by the University of St Andrews, Scotland and the University Paris VII, France, 2006, jointly supervised by Roy Dyckhoff and Delia Kesner.

- Ting Zhang from China, for his thesis
  Arithmetic Integration of Decision Procedures,
  issued by Stanford University, USA, 2006, jointly supervised by Zohar Manna and Henny Sipma.

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[1] We would like to thank Daniel Borel, Co-founder and Chairman of the Board of Logitech S.A, for his generous support of the Ackermann Award for the years 2007-2009. For a history of the company, founded in 1981 in Switzerland, consult `http://www.logitech.com`.

[2] Some of the candidates got their degree from two European institutions.

The Jury wishes to congratulate the recipients of the Ackermann Award for their outstanding work and wishes them a successful continuation of their career.

The Jury wishes also to encourage all the remaining candidates to continue their excellent work and hopes to see more of their work in the future.

Dietmar Berwanger

Citation. Dietmar Berwanger receives the *2007 Ackermann Award* of the European Association of Computer Science Logic (EACSL) for his thesis

Games and Logical Expressiveness

in which he substantially advanced our understanding of the connections between infinite games and logical definability and solved a long standing open problem by separating Parikh's dynamic game logic from the modal μ-calculus.

Background of the thesis. Close connections between mathematical logic and infinite strategic games have been established long ago, but they are still a topic of active research and bear some deep open problems. The determinacy of infinite two-person games, that is, the question of whether there is always a player who has a winning strategy, has been intensely studied in descriptive set theory. In computer science, a combination of infinite games, logic, and automata forms the theoretical basis for the synthesis and verification of reactive systems. The strategic interaction in two-person games can be used as a simple and elegant model of the interaction between a system and its potentially adverse environment, or the choices of a designer in building a system that reacts to its environment as specified.

The *modal μ-calculus* is a logic that plays a central role in the theory of synthesis and verification. Many other logics that are used as specification languages for reactive systems can be translated into the μ-calculus. A special class of infinite two-person games that is closely related to the μ-calculus is the class of *parity games*. More precisely, the evaluation of a μ-calculus formula on a transition system can be reduced to a parity game and, conversely, the winning regions in parity games are definable in the μ-calculus. It is an important, and still open, question whether these two problems can be solved in polynomial time. While much is understood about this elegant system, many questions remain open, especially concerning the fine-structure that its language provides for analyzing particular types of recursion.

Dynamic game logic was proposed by Parikh as an extension of propositional dynamic logic to the game setting. Dynamic logic is a modal logic where modalities are not just single actions but regular expressions over actions standing for complex games formed using operations of choice, sequential composition, and iteration. In game logic, modalities describe players' powers over sets of outcomes that can be achieved by following different strategies available to them. In particular, there is a special dualisation operator, which can be used to describe alternation between players in complex games. This duality operator is fundamental for a complete and symmetric treatment of game theoretic statements. Dynamic game logic is intimately related to game-theoretic notions of strategy and equilibrium, which have a mathematical fixed-point character, and hence a comparison with the *modal μ-calculus* is a natural and timely topic of research.

Berwanger's thesis. The core results of the thesis *Games and Logical Expressiveness* are concerned with the expressive power of fragments of the modal μ-calculus and game logic. These results are proved in a very innovative and sometimes surprising way. A notable by-product of the proof of the main theorem is the introduction of a new directed-graph invariant called entanglement, which turned out to be of independent interest. The thesis is written in a concise and elegant style.

The technical part of the thesis begins with an investigation of the expressive power of game logic in the framework of the μ-calculus. Berwanger observes that, as many other modal and temporal logics studied in this context, for example CTL* or PDL, game logic can be translated into the two-variable fragment of the μ-calculus. Surprisingly, he then proves that game logic is nevertheless expressive enough to define the winning regions in parity games, which makes it much more expressive than the other modal and temporal logics mentioned above. This also implies that the model checking problem for game logic is algorithmically as hard as that for the full μ-calculus. Thus, understanding essential aspects of multi-player interaction seems as hard as understanding unlimited recursion.

The main result of the thesis states that the variable hierarchy of the modal μ-calculus is strict, that is, more variables induce more expressive fragments of the logic. As game logic can be embedded into the two-variable fragment, this implies that the μ-calculus is more expressive than game logic, answering an open question asked by Parikh in 1985. But also as a stand-alone result, Berwanger's theorem provides key new insights into the fine-structure of general fixed-point logics, of which the following is an example.

An important and innovative step in the proof of the hierarchy theorem is to "measure" the combinatorial essence of the expressive power of the bounded variable fragments of the μ-calculus by a new directed-graph invariant called *entanglement*. Every finite graph is bisimilar to a tree with back edges. The entanglement of such a tree measures the number of "open" back edges that a node in such a tree can have. The entanglement of a structure is the minimal entanglement of a bisimilar tree with back edges. The notion has a natural characterisation in terms of a search game on directed graphs; similar games are known to characterise other measures for the "tree-likeness" of graphs and directed graphs. Besides applying it in the proof of the main result, Berwanger exploited the connection between entanglement and the μ-calculus in a different way by proving that the model checking problem for the μ-calculus is in polynomial time on structures of bounded entanglement.

The thesis contains a number of further nice results, in particular about the positional determinacy and complexity of *path games*, another family of infinite two-person games related to the classical Banach-Mazur games.

The results on game logic and the variable hierarchy are lasting results in the theory of fixed point logics. The notion of entanglement, introduced as a technical tool in the proof of the hierarchy result, has already turned out to be of independent interest. The thesis introduces a wealth of new ideas and is a pleasure to read.

Biographic Sketch. Dietmar Berwanger was born Lugoj, Romania in 1972. He studied computer science at the RWTH Aachen and Universitá di Roma "La Sapienza" and received his "Diplom" in Aachen in 2000. He wrote his PhD thesis under the supervision of Erich Grädel in Aachen and received his Ph.D. in May 2005. Currently, he is a postdoctoral fellow at the EPFL Lausanne.

Stéphane Lengrand

Citation. Stéphane Lengrand receives the *2007 Ackermann Award* of the European Association of Computer Science Logic (EACSL) for his thesis

Normalisation and Equivalence in Proof Theory and Type Theory

in which he profoundly advanced our understanding of the logical under-pinnings of proof search and programming language semantics.

Background of the thesis. Interactions between logic and computer science provide formal methods for the development of proof assistant software, automated reasoning, high-level programming languages and certified software. Research in this area is concerned with the following key concepts:

- mathematical objects that can formalise the notion of proof,
- computational features of these objects, with notions of *normalisation*,
- equational theories about these objects, i.e. notions of *equivalence*, related to their computational features.

Intellectual direction comes from the *Curry-Howard correspondence*, relating proofs to programs and propositions to types. For a logical system, one attempts first to design an accurate proof-term calculus, and then uses techniques from rewriting theory to establish the desired proof-theoretic properties. Lengrand's wide ranging thesis successfully deploys these ideas in new directions: to versions of the *sequent calculus* appealing for *proof-search*; to powerful type theories; and to the case of classical reasoning.

Stéphane Lengrand's thesis. The thesis lies on the boundary between proof theory, type theory, λ-calculus and term rewriting. It provides a range of new results relating to normalization, confluence, consistency and equivalence. Several major contributions of the thesis stand out:

- The thesis answers a long-standing challenge arising from the well-known Melliès' counterexample by presenting a calculus with *explicit substitutions*, *erasure* and *duplication* constructors, which refines λ-calculus with an explicit handling of resources. Improving on results of David and Guillaume (in particular with the simulation of β-reduction), such a calculus allows the combination of a **full notion of *composition* of substitutions** with the property of ***Preservation of Strong Normalisation***. In its typed version, the calculus establishes a Curry-Howard correspondence for *multiplicative natural deduction* (with explicit rules of *weakening* and *contraction*).
- A sequent calculus framework, giving a clear and natural theoretical basis to **proof-search in type theory**, is given. This comes from a formalism, *Pure Type Sequent Calculi* (PTCS) yielding for each type theory expressed in Barendregt's natural deduction style *Pure Type Systems*, a corresponding sequent calculus. Optimised versions of PTSC express, in a natural fashion, proof-search mechanisms found in proof assistants like Coq, in *logic programming*, and in algorithms that enumerate the programs of a given type (i.e. satisfying a given specification).
- The Vorob'ev–Hudelmaier–Dyckhoff sequent calculus G4ip (in which the proofs of every sequent are bounded in depth) is another long-standing issue addressed in the thesis. Lengrand gives the first complete analysis of the **computational content** of this calculus. This uses rewriting techniques: an internal cut-elimination process, of which the (strong) termination is shown, is expressed as a calculus of proof-terms and rewriting rules. Its semantics is subtle, and capable of eliminating redundancies in proofs to produce proofs of small depth (below the bound).
- The thesis contains a very careful study of the intuitionistic sequent calculus **LJQ** (distinguished by a syntactic restriction on the left rule for implication) and its relation to call-by-value semantics. The main result is an equational correspondence with a slight but delicate modification of Moggi's call-by-value λ-calculus
- A classical version of the system F_ω is shown to be strongly normalising and consistent; this is achieved in an elegant fashion by allowing a purely intuitionistic upper layer of types but a lower, classical, layer of terms.

In general terms, the work on PTSC initiates a particularly promising line of research, in which concepts related to proof-search and logic programming can fruitfully interact with the expressivity of type theories.

The thesis contains many other ideas: a constructive theory of (weak and strong) normalisation; extensions of the simulation technique for proving strong normalisation; notions of proof equality in classical logic relating to computational representations within the framework of *Deep Inference*. It is clearly written, with its many diverse contributions expressed within a general, uniform and abstract framework. Being unusual both in range and in depth, it shows creativity and maturity, and gives a high-level view of fields in logic and computer science.

Biographical Sketch. Stéphane Lengrand was born in 1980 in Paris. He entered the École Normale Supérieure de Lyon in 2000. He took an M.Sc. in Mathematics and the Foundations of Computer Science at Oxford University in 2002. He took his D.E.A. in 2003 and in the same year completed a Licence d'Anglais in Medieval English at the Sorbonne.

Stéphane Lengrand studied for his PhD under cotutelle arrangements at the Université Paris VII and the University of St. Andrews, being supervised jointly by Delia Kesner (Paris VII) and Roy Dyckhoff (St. Andrews). He received his doctorate in December 2006. This year he has been teaching at St. Andrews where he is a Visiting Scholar, and he has been attending the Royal Scottish Academy of Music and Drama in Glasgow from which he hopes to graduate with the Postgraduate Diploma in Cello (Performance).

Ting Zhang

Citation. Ting Zhang receives the *2007 Ackermann Award* of the European Association of Computer Science Logic (EACSL) for his thesis

Arithmetic Integration of Decision Procedures.

His thesis constitutes a *tour de force* in decidability of structures with limited arithmetic capability, and in particular establishes decidability of the first-order theory of Knuth-Bendix order, thus solving a long-standing open problem.

Background of the thesis. Algorithmic decidability of formalized mathematical theories was first studied by Tarski and his students, who discovered that, in spite of general undecidability of mathematics, several basic structures enjoy decidable theories, as, e.g., reals, or integers with just addition (Presburger arithmetics). Whenever it exists, a decision procedure gives us a deeper insight into the structure.

The search for decision procedures remains an active topic in computer science, especially in logic-based verification of programs, where decidable theories underline the fully automatic methods. Computer science has its own menagerie of abstract structures, like words, trees (terms), graphs..., and much effort has been put into understanding decidability issues of these structures. But number-theoretic domains are also needed whenever quantitative questions arrive.

Integration of various discrete structures with arithmetics is a non-trivial task, appearing in many contexts, as, e.g., verification of memory safety properties. The thesis of Ting Zhang meets this challenge by developing a series of decision procedures for first-order theories of algebraic structures integrated with Presburger arithmetics via some functions of measurement. By an ingenious refinement of his method, the author also establishes decidability of the first-order theory of the Knuth-Bendix ordering of terms, thus solving a long-standing open problem in term-rewriting.

Deciding combined theories was previously addressed by Nelson and Oppen (in 1979). These authors proposed a modular combination method under restriction to quantifier-free theories with disjoint signatures. In spite of subsequent attempts by several researchers, these assumptions are hard to remove in general, so the method fails for theories involving measurement functions. In his thesis, rather than searching for general combination scheme, Zhang focuses on specific problems and exploits the algebraic properties of the combined domain.

The idea of a well-ordering of first-order terms originated in Don Knuth's work on "completion procedure" for algebraic theories in early 1970s. Knuth's ideas regarding term inference were subsequently extended by Dershowitz and others, and applied in design and implementation of automated theorem provers. Here the order underlines a rewriting strategy, and the inference rules include side conditions that involve quantified inequalities between terms. The two orderings mainly used in this context are recursive path ordering and Knuth-Bendix ordering. Solving quantified constraints based on the former is however generally undecidable.

The analogous question for the Knuth-Bendix ordering has been believed a difficult open problem. First positive results were given by Korovin and Voronkov, who established NP-completeness of the quantifier-free fragment over arbitrary signature, and decidability of the first-order fragment restricted to unary functions. The proof of Korovin–Voronkov used a reduction to WS2S, and was hard to extend to general case. Let us recall that Konstantin Korovin was among the winners of the Ackermann Award in 2005.

The Knuth-Bendix ordering is of hybrid nature, as it combines a syntactic precedence of function symbols with a linear weight function in a recursive way. It has turned out that the methods developed by Ting Zhang for deciding theories of hybrid structures were powerful enough to establish decidability of the full first-order theory of Knuth-Bendix ordering. As the author remarks: *It is interesting that the combination of term algebra with integer arithmetic can help an open problem in another quite different field.*

Zhang's thesis. The starting point is integration of term algebra and Presburger arithmetic into a one combined structure, additionally equipped with the length-of-term function (which can be replaced by another weight function). The fundamental construction extracts complete integer constraints from term constraints, thus transferring the decision task into arithmetics. This construction is subsequently refined throughout the thesis, yielding the more and more powerful decidability results.

The main contributions are as follows.

- NP-completeness of the quantifier-free fragment and decidability of the full theory of the aforementioned combination of term algebra and Presburger arithmetic. The quantifier elimination procedure involves a block-wise reduction of term quantifiers to integer quantifiers, and eliminates a block of quantifiers of the same kind in one step. This makes the algorithm k-fold exponential for formulas with k quantifier alternations, regardless of the

number of quantifiers, which also improves elimination procedure for the pure theory of term algebras.
- Application of the above method to decidability of a theory of term algebra with two integer functions which capture precisely the properties of red-black trees.
- Decision procedure for the first-order theory of queues combined with Presburger arithmetic, and NP-completeness of the quantifier-free fragment extended with prefix predicate.
- Decidability of the first-order theory of Knuth-Bendix order. This is most brilliant achievement of the thesis, based on an extremely sophisticated argument (80 pages), involving many conceptual innovations. The key step is introduction of boundary functions going in the opposite direction: from integers to terms, which helps one to bound the terms being quantified over.

The thesis is based on a number of articles presented to IJCAR'04 (*Best Paper Award*), TPHOLs'04, FSTTCS'05, CADE'05, LFCS'07, and an article in Information & Computation (joint with H.B.Sipma and Z.Manna).

Biographic Sketch. Ting Zhang received his B.Sc. degree in computer science from Peking University, Beijing, China, in 1996, and M.Sc. degree in computer science from the Stanford University, CA, in 2001. He wrote his Ph.D. thesis under the supervision of professor Zohar Manna (the co-advisor being professor Henny Sipma) and obtained the Ph.D. degree in computer science from the Stanford University, in 2006. He is currently a researcher at Microsoft Research Asia in Beijing, China. He also teaches at Tsinghua University.

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[3]. 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

[3] 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.dimi.uniud.it/eacsl/award.html`.

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 S. Abramsky (Oxford, LICS Organizing Committee), J. van Benthem (Amsterdam), B. Courcelle (Bordeaux), M. Grohe (Berlin), M. Hyland (Cambridge), J.A. Makowsky (Haifa, President of EACSL), D. Niwinski (Warsaw, Vice President of EACSL), and A. Razborov (Moscow and Princeton).

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

A detailed report on their work appeared in the CSL'05 and CSL'06 proceedings, and is also available via the EACSL homepage.