The Ackermann Award 2013

Anuj Dawar, Thomas A. Henzinger, and Damian Niwiński

Members of EACSL Jury of the Ackermann Award

The ninth Ackermann Award is presented at CSL'13, held in Turin, Italy. This year, as in the previous three years, the EACSL Ackermann Award is generously sponsored by the Kurt Gödel Society. Besides providing financial support for the Ackermann Award, the Kurt Gödel Society has also committed to inviting the recipient of the Award for a special lecture to be given to the Society in Vienna.

The 2013 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 2011 and 31 December 2012. The Jury received fifteen nominations for the Ackermann Award 2013. The candidates came from a number of different countries across the world. The institutions at which the nominees obtained their doctorates represent nine countries in Europe, North America, and the Middle East.

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, one thesis stood out. The **2013 Ackermann Award** winner is:

- Matteo Mio from Italy, for his thesis
  Game Semantics for Probabilistic Modal μ-Calculi
  approved by the University of Edinburgh, UK, in 2012,
  supervised by Alex Simpson.

Matteo Mio

Citation. Matteo Mio receives the *2013 Ackermann Award* of the European Association of Computer Science Logic (EACSL) for his thesis

Game Semantics for Probabilistic Modal μ-Calculi.

His thesis builds an extension of the modal μ-calculus suitable for reasoning about non-deterministic probabilistic systems. It advances previous approaches, and adds a quantitative dimension to the game semantics of fixed-point logics, via a novel concept of a tree game, integrating randomness and concurrency.

Background of the Thesis. The modal μ-calculus lies at the very heart of logics and algorithms for computer-aided verification: it provides a powerful framework for comparing specification formalisms and devising model-checking algorithms for discrete dynamical systems, such as hardware and software systems. In order to model uncertainty in the behavior of such systems, it is natural to extend both state transition models and property specification languages with probabilistic aspects; the first such probabilistic temporal logic was introduced by Hansson and Jonsson in the early 1990s, and probabilistic extensions of the modal μ-calculus followed quickly. The resulting field of "probabilistic verification" has received much attention in the past two decades, which saw the solution of many probabilistic model-checking problems, the development of corresponding verification tools, and their application to case studies ranging from networking to systems biology. Yet the field still lacks

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a convincing canonical and foundational framework for specifying and comparing probabilistic properties. The thesis by Mio presents a promising step in this direction.

Mio's Thesis. In his thesis, Matteo Mio adopts a quantitative approach to temporal logics over probabilistic transition systems, introduced by Huth and Kwiatkowska, and independently by Morgan and McIver, where a formula holds in a state with some probability. An interpretation of a formula is therefore a mapping from the set of states to $[0,1]$. In the probabilistic μ-calculus pLμ introduced by Morgan and McIver, conjunction and disjunction are interpreted as min and max over reals, respectively. The first contribution of the thesis extends to all models the equivalence between denotational and game semantics of the logic pLμ, established previously by Morgan and McIver for finite models. The logic pLμ, however, is not a completely satisfactory generalization of its classical counterpart to the probabilistic setting. Indeed, in contrast to the propositional μ-calculus Lμ, which subsumes most of the temporal logics known in the literature, pLμ fails to contain the probabilistic version of the most basic temporal logic CTL as its sublogic. A remedy proposed by Mio consists in using different real extensions of the Boolean operators *and* and *or* and combining them in a single logic. These interpretations have been already considered by Huth and Kwiatkowska as alternatives: in addition to min and max used in pLμ, also product $x\dot{y}$ (for *and*), and its dual co-product

$$x \odot y \quad = \quad x + y - xy$$

(for *or*), as well as the strong conjunction and disjunction of the Łukasiewicz logic

$$\begin{aligned} x \ominus y &= \max(0, x + y - 1) \\ x \oplus y &= \min(1, x + y). \end{aligned}$$

Mio shows that with all these operators one can express the probabilistic version of CTL, whereas the first two suffice for the qualitative fragment of this logic. Thus a new powerful fixed-point logic has emerged, whose expressive power and algorithmic properties are not yet completely understood. This will likely be the subject of active research in future years. What Matteo Mio contributes in his thesis is the game semantics for the new logic.

A known feature of μ-calculi is that, in contrast to, e.g., first-order logic or temporal logic, they did not arise as a formalization of natural language constructs, but rather as equational systems. As a result, fixed-point formulas are relatively hard to understand by humans. This difficulty only increases for a probabilistic version of the logic involving three variants of conjunction and disjunction. In the classical case, a helpful way of understanding the μ-calculus formulas is via games. More specifically, a formula φ of Lμ and a model M induce a perfect-information two-person game of possibly infinite duration, a so-called parity game, such that the satisfaction $M \models \varphi$ is equivalent to the existence of a winning strategy for the proponent in this game. This characterization is also at the basis of many model-checking algorithms, which thus boil down to solving games. As we have already mentioned, the thesis settles a similar characterization for the probabilistic μ-calculus pLμ. However, the main contribution of the thesis consists in establishing the game semantics for the full probabilistic μ-calculus pL$\mu^{\odot}_{\oplus}$ described above. *A priori* it is not obvious that this is possible, as the real functions used in this μ-calculus do not have any apparent game interpretation. Now Matteo Mio makes an unexpected twist in the very paradigm of game playing. He admits that a play need not be a linear process, but can instead split in several threads, which form of a tree. This tree can serve as an arena of a new (inner) game, and the payoff of the original (outer) game is defined in terms of winning the inner game. Here, the outer game is usually stochastic, whereas the inner game is a perfect-information game. This construction, referred to by the author as a *tree game*, leads to the concept of meta games, parametrized by the class of inner games. The game semantics of the extended probabilistic μ-calculus is provided by meta parity games.

Mio also discovers a number of remarkable properties of tree games, which make this concept interesting in its own right. In particular, the tree games turn out to comprise (under suitable encoding) the Blackwell games, which is a class of infinite stochastic games with imperfect information that is well-studied in game theory. The determinacy of Blackwell games established by Donald Martin in 1998 is considered to be one of the strongest determinacy results provable in ZFC. Another feature of tree games is that they can be derandomized; i.e., the stochastic player *Nature* can be eliminated, its role taken by the concurrent branching mechanism.

The game semantics of the μ-calculus $\mathrm{pL}\mu_{\oplus}^{\odot}$ relies on the determinacy result for the meta parity games. This is the most technically difficult part of the thesis. Indeed, the argument requires some properties of sets in $\boldsymbol{\Delta_1^2}$, which do not, in general, hold in ZFC. Therefore, the author proves his results in ZFC extended by the Martin axiom for the first uncountable cardinal, $\mathrm{MA}_{\aleph_1}$.

Biographical Sketch. Matteo Mio was born on 5 July 1983. He was a student at the University of Udine in Italy during the period 2002-2007, studying for the *Laurea Triennale* and *Laurea Specialistica* in Computer Science. In 2007 he joined the University of Edinburgh in Scotland to pursue a PhD degree, which he completed in February 2012. Since then, he has spent a year as a postdoctoral researcher at the École Polytechnique in Paris and is currently a postdoctoral researcher at the Centrum Wiskunde & Informatica (CWI) in Amsterdam, funded by an ERCIM Alain Bensoussan fellowship.

Jury

The Jury for the **Ackermann Award 2013** consisted of eight members, two of them *ex officio*, namely, the president and the vice-president of EACSL. A member of the LICS organising committee is also normally a member of the jury. On this occasion, this member withdrew owing to a conflict of interest and a replacement was named.

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),
- Catuscia Palamidessi (École Polytechnique, Paris),
- 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.

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