Susanne Graf
Wenhui Zhang (Eds.)

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Susanne Graf
VERIMAG
Centre Equation - 2, Avenue de Vignate
F-38610 Gieres, France
E-mail: Susanne.Graf@imag.fr

Wenhui Zhang
Chinese Academy of Sciences
Institute of Software
P.O. Box 8718, Beijing, China
E-mail: zwh@ios.ac.cn

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Preface

The Automated Technology for Verification and Analysis (ATVA) international symposium series was initiated in 2003, responding to a growing interest in formal verification spurred by the booming IT industry, particularly hardware design and manufacturing in East Asia. Its purpose is to promote research on automated verification and analysis in the region by providing a forum for interaction between the regional and the international research/industrial communities of the field. ATVA 2006, the fourth of the ATVA series, was held in Beijing, China, October 23-26, 2006. The main topics of the symposium include theories useful for providing designers with automated support for obtaining correct software or hardware systems, as well as the implementation of such theories in tools or their application.

This year, we received a record number of papers: a total of 137 submissions from 27 countries. Each submission was assigned to three Program Committee members, who could request help from subreviewers, for rigorous and fair evaluation. The final deliberation by the Program Committee was conducted through Springer's Online Conference Service for a duration of about 10 days after nearly all review reports had been collected. In the end, 35 papers were selected for inclusion in the program.

ATVA 2006 had three keynote speeches given respectively by Thomas Ball, Jin Yang, and Mihalis Yannakakis. The main symposium was preceded by a tutorial day, consisting of three two-hour lectures given by the keynote speakers.

ATVA 2006 was supported by the National Natural Science Foundation of China and the Institute of Software of the Chinese Academy of Sciences. Their generous sponsorships are gratefully acknowledged. We would like to thank the Program Committee members and their subreviewers for their hard work in evaluating the submissions and selecting the program. We thank the keynote speakers for their extra effort in delivering the tutorials. We thank the Steering Committee for their advice, particularly Farn Wang, who also served as program chair of the first two ATVA symposia, for providing valuable suggestions.

For the administrative support, we thank the Laboratory of Computer Science at the Institute of Software of the Chinese Academy of Sciences. We also thank Martin Karusseit from Metaframe for his help with the online conference server.

October 2006

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Regular Papers

Analysis of Recursive Probabilistic Models

Mihalis Yannakakis

Department of Computer Science, Columbia University
mihalis@cs.columbia.edu

In this talk we will discuss recent work on the modeling and analysis of systems that involve recursion and probability. Both, recursion and probability, are fundamental constructs that arise in a wide variety of settings in computer science and other disciplines.

There has been extensive work over the years in the verification community on the algorithmic analysis of finite state probabilistic models and their properties (eg. [10,11,13,30,33,36,43]). *Markov chains* serve as the standard basic model for systems that evolve probabilistically in a wide variety of domains, including in particular, as a model for (finite-state abstractions of) probabilistic programs. The probabilities of the transitions may either reflect randomizing steps of the program or the system under study; or they may reflect statistical assumptions on the branching of the program or the evolution of the system. *Markov Decision Processes* (MDP) and *Stochastic Games* (SG) model systems that contain both probabilistic and nonprobabilistic actions that are controlled by one agent (entity) or by two (or more) agents respectively; these models serve in particular to capture open systems that interact with their environment. In the case of games (among two or more agents), a distinction is usually made between *turn-based* (or *simple*) games where the agents take turns, i.e. only one agent acts at a time, and the more general case of *concurrent* games where several agents may act at the same time.

Another line of verification research has extended finite-state model checking methods to models that correspond to (abstractions of) recursive programs with procedures ([2,3,14]. *Recursive State Machines* (RSM) and *Pushdown Systems* (PDS) are two equivalent models for this purpose. Informally, a RSM is a finite collection of finite-state machines that can call each other in a potentially recursive manner (similar to a recursive program); a PDS is a machine with a finite control equipped with a pushdown store (a stack). The two models are expressively and computationally equivalent, but they represent somewhat different views as modeling formalisms. Their relation is analogous to the relation between a program that is written as a set of procedures that call each other, and a nonrecursive (single-procedure) program that uses a stack to perform an equivalent computation. *Hierarchical State Machines* (HSM) form a subclass of Recursive State Machines, in which the calling relation between the component machines is acyclic (hierarchical); they are useful in modularizing and representing succinctly larger finite state systems.

In the last few years there has been a lot of activity in the study of systems that involve both recursion and probability [4,5,6,15,16,17,18,19,20,21,22].

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The primary motivation comes from the analysis of probabilistic programs with procedures, but such systems have arisen also in various other domains. In the presence of recursive procedures, a natural model for (purely) probabilistic programs is *Recursive Markov Chains* (RMCs): Informally, a RMC consists of a collection of finite state component Markov chains that can call each other in a potentially recursive manner [17]. An equivalent model is *Probabilistic Pushdown Automata* (pPDA) [15]. These models are essentially a succinct, finite representation of an infinite state Markov chain, which captures the global evolution of the system.

More generally, if some steps of the program/system are probabilistic while other steps are not, but rather are controllable by the system or the environment, then such a system can be naturally modeled by a *Recursive Markov Decision Process* (RMDP) or a *Recursive Stochastic Game* (RSG)[19,22]. In a RMDP all the nonprobabilistic actions are controlled by the same agent (the controller, or the environment), while in a RSG (simple or concurrent), different nonprobabilistic actions are controlled by two opposing agents (eg. some by the designer and some by the environment).

Recursive Markov chains encompass as special cases several other basic stochastic models that have been studied in various other domains. *Branching processes* are an important class of stochastic processes [29], introduced first by Galton and Watson in the 19th century to study population dynamics, and generalized later on in the mid 20th century to the multitype case by Kolmogorov and Sevastyanov [32,40]. A branching process specifies the probability distributions of the set of offsprings of each species (type) from one generation to the next. They have been applied in a wide variety of contexts such as population genetics [28], biology[31], and nuclear chain reactions [23]. Another related model is that of *stochastic context-free grammars* which have been studied extensively since the 1970's especially in the Natural Language Processing community (see eg. [34]), and in other contexts (for example, RNA modeling [39]). In a certain formal sense, (multitype) branching processes and stochastic context-free grammars correspond to a subclass of recursive Markov chains, namely the class of "1-exit RMCs", where each component Markov chain has a single exit state where it can terminate and return control to the component that called it. Another example that is also included in the subclass of 1-exit RMCS is a model of web-surfing, called "Markov chain with back-button", that was introduced and analyzed thoroughly by [24].

Recursive Markov chains, and their extension to Recursive Markov Decision Processes and Stochastic Games, have a rich theory and pose a lot of challenging problems. Even in the 1-exit case, recursive Markov chains introduce several difficulties not encountered in the case of standard finite Markov chains. For example, in the case of standard Markov chains, *qualitative questions* concerning events holding with probability 1 or 0, such as, "starting at state s will we reach state t almost surely?', or "does a given temporal logic property hold a.s. in an execution?" do not depend on the actual values of the probabilities on the edges, but only on which transitions are present (have nonzero probability). This

is not true anymore in the case of recursive Markov chains: the actual values of the probabilities matter. Furthermore, in a finite Markov chain with rational transition probabilities, the probabilities of the events that we are interested in (for example, the probability that a trajectory satisfies a given LTL property) are also rational, and moreover have polynomially bounded complexity in the size of the Markov chain and can be computed efficiently. In recursive Markov chains this is not true any more: the probability of simple events (eg. termination, reachability) can be irrational and thus cannot be computed exactly.

The analysis of recursive probabilistic models involves combinatorial, algebraic, and numerical aspects. There are connections to various areas, such as the existential theory of the reals [8,38,7], multidimensional Newton's method, matrix theory, and many others. There are connections also with several well-known open problems, such as the square root sum problem [27,42] (a 30-year old intriguing, simple problem that arises often in the numerical complexity of geometric computations, and which is known to be in PSPACE, but it is not known even whether it is in NP), and the value of simple stochastic games [9] and related games (parity game etc.), which are in NP∩coNP, but it is not known whether they are in P.

In this talk we will present some of this theory, and the related algorithmic results and methods.

Acknowledgement. Work partially supported by NSF Grant CCF-04-30946.

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