SOFTWARE systems are expected to meet a multitude of quantitative constraints, such as timely response, performance, and efficient use of energy and other resources. Quantitative evaluation of systems refers to a set of techniques which can be applied to analyze such systems and obtain a range of quantitative characteristics of their performance, for example, the probability of satisfying a request within a given time or the appropriate number of replicas in a quorum air traffic control system.

In this special issue, we publish a diverse range of novel research work which contributes to the development of quantitative evaluation of computer systems from a number of perspectives. These include theoretical foundations, models and modeling languages, analysis methods, simulation, verification, and software tools.

Queueing networks have long been used for performance analysis of computer systems. This issue includes two papers related to queueing networks. In the first, “Enhanced Modeling and Solution of Layered Queueing Networks,” the layered queueing networks modeling formalism is presented. This modeling language allows a structured, hierarchical queueing network to be built up representing the resource usage and contention within a system. Analysis techniques which make use of the hierarchical structure allow complex models to be analyzed to address questions about the performance and dependability of the system. The second queueing paper, “CoMoM: Efficient Class-Oriented Evaluation of Multiclass Performance Models,” describes an improved solution technique for multiclass queueing network models. For more than 25 years, mean value analysis (MVA) has been one of the most frequently applied analysis methods of these models. This paper proposes an efficient rearrangement of recursive computational steps (referred to as the CoMoM method) such that it minimizes the number of recursive steps needed to solve the model. The CoMoM method makes possible the approximate analysis of much larger queueing network models, with tens of classes and thousands of nodes.

Another well-established quantitative modeling technique is based on timed and stochastic extensions of Petri nets. In “State-Density Functions over DBM Domains in the Analysis of Non-Markovian Models,” a solution technique for such a Petri net extension is considered. The analysis of stochastic Petri nets with exponentially distributed firing times is well-developed and widely applied in software systems modeling. In contrast, the case of stochastic Petri nets with nonexponentially distributed firing times is far less advanced. The paper presents a computational approach for the stationary analysis based on stochastic state classes (sets of markings and associated elapsed firing times). It presents a closed-form calculus for the derivation of state-density functions over stochastic state classes for models where all transitions have exponential distributions. This class of distributions includes common basic distributions (e.g., uniform, exponential, Erlang, gamma) and enables close approximation of other general distributions.

Simulation remains a widely used and often valuable tool for investigating the behavior of systems, particularly from a quantitative perspective. In “Automated Trace Analysis of Discrete-Event Systems Models,” the authors present a novel technique which assists a modeler in gaining insight from the trace produced by a stochastic discrete event simulation model. Many simulation tools offer the facility to output a trace, or event-by-event account of the behavior of the model. However, such traces are usually long and repetitious. The technique proposed here is based on algorithms to distinguish progressive behavior from repetitive behavior, resulting in a minimal progressive fragment of the trace, which is much more amenable to inspection. Such traces can help the modeler recognize problems and identify their causes.

Quantitative verification, in which techniques originating from the formal verification of correctness of systems are enhanced with information such as probability, resource usage, and time, has been a growing area for the last decade. In this special issue, we include a number of papers originating from this area. In “Model Checking Probabilistic and Stochastic Extensions of the π-Calculus,” the authors develop quantitative verification techniques based on extensions of the well-established modeling formalism, the π-calculus. The π-calculus is a process algebra which supports concurrency and mobility and its probabilistic extensions are well-suited to modeling network protocols.
probabilistic security protocols and biological pathways. Model checking is an automated procedure to deduce whether a formal model satisfies a property expressed in an appropriate logic. In this paper, the authors describe their work on tools for model checking probabilistic and stochastic extensions of the \( \pi \)-calculus, through judicious adaptation and reuse of existing tools. Furthermore, they demonstrate how a compositional approach to model checking may be applicable to some models with particular structure.

Model checking is also at the core of the paper “Model Checking Timed and Stochastic Properties with CSL\(^{TA}\).” Here, the issue considered is how best to express the quantitative logical properties against which a model should be verified. In this paper, the Continuous Stochastic Logic (CSL), which has been successfully used for model checking continuous time Markov chains for a number of years, is enriched with timed automata, giving more expressiveness to the properties to be checked. The extension, incorporating timed automata to capture conditions of interest, is motivated not only by expressibility, but also a desire to make the technique more accessible, as CSL\(^{TA}\) may be more intuitive to use than CSL.

Continuing on the topic of model checking, the paper “Counterexample Generation in Probabilistic Model Checking” concerns the theoretical and algorithmic formulations for the generation of refutations of probabilistic temporal logic properties. In conventional model checking, counterexamples provide essential diagnostic information about property violation and are used in abstraction-refinement schemes. This paper is the first to generalize counterexamples to probabilistic model checking. This is achieved for discrete time Markov chain models using the notion of strongest evidences. It turns out that variants of shortest-path algorithms can be applied to obtain counterexamples. The techniques have already been applied to generate counterexamples for continuous Markov chains and probabilistic abstraction refinement.

The paper “Linear and Branching System Metrics” considers a quantitative semantic framework for establishing whether the system meets its specification. In contrast to the classical approach which yields Boolean yes/no answers, the approach formulated here uses metric spaces and particularly an appropriate notion of a distance that measures the extent to which the system meets the specification. The paper proposes quantitative generalizations of process equivalence relations and offers logical characterizations of the distances in terms of quantitative temporal logic.

Finally, the paper “Compositional Dependability Evaluation for STATEMATE” introduces a toolset for the analysis of quantitative dependability properties at design time. The techniques are developed for STATEMATE, allowing the designers to work directly with state chart models and permit time-bounded properties such as the probability of a safety violation within specified mission time is bounded by 0.01. The approach is formulated for continuous time Markov decision processes and uses model checking, which yields detailed and exact results as opposed to those obtainable using simulation. The toolset is evaluated on a nontrivial case study of a high-speed train and is applicable to similar avionics/automotive designs.

This volume was assembled from 34 papers submitted in response to an open call, including several invited papers from the Fourth International Conference on the Quantitative Evaluation of SysTems (QEST 2007). Based on the reviews, the editors selected nine papers from those submitted.

We thank the reviewers for their timely and rigorous reviews, and are grateful to the TSE editors and journal staff for their help in finalizing the issue.

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Guest Editors

Jane Hillston received the BA and MSc degrees in mathematics from the University of York (UK) and Lehigh University (USA), respectively. After a brief period working in industry, she joined the Department of Computer Science at the University of Edinburgh as a research assistant in 1989. She received the PhD degree in computer science from that university in 1994. She is a professor of quantitative modeling in the School of Informatics at the University of Edinburgh and holds an Advanced Research Fellowship from the Engineering and Physical Sciences Research Council. She is a fellow of the Royal Society of Edinburgh. Her work on the stochastic process algebra PEPA (www.dcs.ed.ac.uk/pepa) was recognized by the British Computer Society in 2004, which awarded her the first Roger Needham Award. Currently, her principal research interests are in the use of stochastic process algebras to model and analyze computer systems and biological systems and the development of efficient solution techniques for such models.

Marta Kwiatkowska holds the BSc/MSc degree in computer science from the Jagiellonian University, the MA degree from Oxford University, and the PhD degree from the University of Leicester. She is a professor of computing systems and a fellow of Trinity College, University of Oxford. Her main research focus is on modeling and quantitative verification of probabilistic systems, which includes both theoretical investigation leading to new models and efficient verification algorithms, as well as practical implementation. The PRISM model checker (www.prismmodelchecker.org) implemented under her leadership is the leading software tool in the area and is widely used for research and teaching. Applications of probabilistic model checking have spanned communication and security protocols, nanotechnology designs, power management, and systems biology. Dr. Kwiatkowska was invited speaker at the LICS 2003 and ESEC/FSE 2007 conferences and lead organizer of the Royal Society Discussion Meeting “From Computers to Ubiquitous Computing, by 2020” (Phil. Trans. R. Soc. A, vol. 366).
Miklós Telek graduated as an electrical engineer from the Faculty of Electrical Engineering, Technical University of Budapest, in 1987. He received the candidate of science and the MTA doctor degree from the Hungarian Academy of Science in 1995 and 2004, respectively. He received the habilitation degree in technical sciences from the Technical University of Budapest in 2003. In 1987, he joined the Hungarian Post Research Institute, where he studied the modeling, analysis, and planning aspects of communication networks. Since 1990, he has been with the Department of Telecommunications at the Technical University of Budapest, where he is now a professor. He took part in the development of various communication network and computer system planning and/or analysis tools. He spent research visits at universities (Torino, Catania, Erlangen, Berlin, Dortmund, Duke, UNC, Trento) and research institutes (Avaya research, INRIA Rennes, Istituto Galileo Ferraris). Since 1997, he has been the head of the stochastic modeling laboratory of the department, which participates in international research projects and cooperates with industry on traffic modeling of mobile telecommunication networks. His current research interests include various aspects of stochastic performance modeling and analysis of computer and communication systems.