Report from Dagstuhl Seminar 14041

Quantitative Models: Expressiveness, Analysis, and New Applications

Edited by

Manfred Droste[1], Paul Gastin[2], Kim Guldstrand Larsen[3], and Axel Legay[4]

1 **Universität Leipzig, DE,** droste@informatik.uni-leipzig.de
2 **ENS – Cachan, FR,** Paul.Gastin@lsv.ens-cachan.fr
3 **Aalborg University, DK,** kgl@cs.aau.dk
4 **INRIA – Rennes, FR,** alegay@irisa.fr

Abstract

From Jan. 19 to Jan. 24, 2014, "Quantitative Models: Expressiveness, Analysis, and New Applications " was held in Schloss Dagstuhl – Leibniz Center for Informatics. During the seminar, several participants presented their current research, and ongoing work and open problems were discussed. Abstracts of the presentations given during the seminar as well as abstracts of seminar results and ideas are put together in this paper. The first section describes the seminar topics and goals in general. Links to extended abstracts or full papers are provided, if available.

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1 Executive Summary

Manfred Droste
Paul Gastin
Kim Guldstrand Larsen
Axel Legay

Quantitative models and quantitative analysis in Computer Science is receiving increased attention in order to meet the challenges from application areas such as Cyber Physical Systems. What is aimed at is a revision of the foundation of Computer Science where Boolean models and analyses are replaced by quantitative models and analyses in order that more detailed and practically useful answers can be provided. Recently, a large number of new models, toolsets, and new application domains have emerged. The theory of weighted automata has also developed, introducing extensions of the models which are motivated by the quantitative analysis of systems.

The first objective of the seminar was to bring the quantitative model checking and weighted automata communities together with the goal of discussing the latest developments

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in those areas. The second objective of this workshop was to go one major step further. In fact, it has been recently observed an increasing usage (and demand) of quantitative models in a wide range of new application domains. This includes, e.g., systems biology and energy grid. However, these different communities are often not aware of each other. This seminar had the major objective to put those various communities in contact with the hope of creating fruitful long term collaborations.

Quantitative model checking covers extended automata-based models that permit to reason on quantities. The model of timed automata introduced by Alur and Dill in 1989 has by now established itself as a universal formalism for describing real-time systems. The notion of zone has led to a number of tools – e.g. BIP, Kronos, UPPAAL – which support efficient analysis (reachability and model checking) of timed automata. Later the more expressive formalism of hybrid automata was introduced and popularized by Henzinger et al and the introduction of the tool HyTech provided a semi-decision algorithm for analyzing so-called linear hybrid systems. Whereas in timed automata the continuous part of a model is restricted to be clocks (which always evolve with rate 1), linear hybrid automata allow more general continuous variables with evolution rates in arbitrary intervals. The notion of priced (or weighted) timed automata was introduced independently by Alur et al and Larsen et al in 2001, with the surprising result that cost optimal reachability is decidable. Since these initial results, efficient tools were developed and a number of more challenging questions have been considered including multi-priced timed automata, optimal infinite scheduling (both with respect to mean pay-off and discounting), priced timed games and model checking for priced timed automata.

Driven by new needs in areas such as cyber physical systems, a series of recent work have tried to combine real-time with stochastic aspects, leading to new models such as timed stochastic automata. One of the main objectives of the seminar was to study those new models and put them in perspective with similar results in weighted automata. The new notion of energy automata (Larsen, Markey, Bouyer, ...) that extends price timed automata and permits to reason on energy problems was also discussed and put in perspective with similar work done at the weighted automata level.

Weighted automata on finite words were already investigated in seminal work of Schützenberger (1961) and Chomsky and Schützenberger (1963). They consist of classical finite automata in which the transitions carry weights which may model, e.g., the cost, the consumption of resources, or the reliability or probability of the successful execution of the transitions. This concept soon developed a flourishing theory. Recently, motivated by practical examples of energy consumption, new quantitative automata models have been introduced and investigated in which the weights of finite or infinite paths are computed e.g. by the average weights or by the accumulation points of the average weights of their transitions. Colcombet (2009) studied regular cost functions which permit a quantitative extension of classical equivalence results relating automata, expressions, algebraic recognizability, and variants of monadic second-order logic. Gastin et al (2010) introduced weighted pebble automata in order to capture the expressive power of weighted extensions of Xpath for XML documents, or temporal logics for linear behaviors. All these concepts provide totally new models for which weighted automata-theoretic methods can often be applied successfully. It was very profitable therefore to bring these different communities together.

Another main theme of the seminar was to create interaction with researchers working in areas where the theoretical models and techniques may have potential applications. In systems biology, the challenge is not only to find mathematical models, but also to define new efficient quantitative analysis techniques capable of coping with very large size complex

systems. Two promising applications are 1) using SMC-based techniques to monitor complex properties that cannot be expressed in classical temporal logic (e.g., oscillation properties), and 2) using interface theories as a formal characterization of phenomena in the area of synthetic biology. As another application area, the challenge of smart electricity grids is to balance the behavior of all participants (suppliers and consumers) to improve efficiency and stability. Again, quantitative models such as energy automata and analysis are emerging as potential key techniques.

In the seminar, 40 researchers from 13 countries discussed their recent research results and developments for quantitative models and their analysis. Five survey lectures, including two lectures covering the application domains, and 32 talks were organized in eight sessions with centralized themes. From the beginning, all lectures and talks raised questions of members from the other fields, and lively discussions followed. In particular, the surveys presented the fields of weighted automata, formal model checking and simulation methods adopted by industry, programmable single-cell biocomputers, models for smart grid balancing, and asymptotic analysis of weighted automata. The lectures and talks dealt with, e.g., quantitative logics and their semantics, expressiveness of models including quantitative measures for infinite behavior (like discounting, mean payoff, long-run averages), and statistical model checking of stochastic hybrid systems, to name only a few topics.

There are a number of open problems concerning the interplay between these fields. For instance, there are many interesting open questions about the connection between energy automata, energy functions and weighted automata, on weighted specification languages used in more algebraic settings, on energy games, and on the combination of real-time and probabilism. The interplay between priced timed automata and weighted automata also demands further investigation. Due to these open challenges, several researchers decided to meet again later in the year, e.g. during the international workshop in Leipzig on "Weighted Automata: Theory and Applications (WATA 2014)".

During the seminar, there was very much interaction between the participants. In particular, the seminar was successful in attracting academic researchers with contacts to industry; this was felt very positive and should definitely be continued. Generally, it was expressed that a future research collaboration between the different present groups should be highly fruitful and would therefore be very desirable. A Dagstuhl seminar would provide an ideal and unique opportunity for this. The successful collaboration in the present seminar was felt to be due in particular to the superb facilities and excellent organization provided by the Dagstuhl center and its team.

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3 Overview of Talks

3.1 Computing Behavioral Distances, Compositionally

Giorgio Bacci (Aalborg University, DK)

Joint work of Bacci, Giorgio; Bacci, Giovanni; Larsen, Kim G., Mardare, Radu;
Main reference G. Bacci, G. Bacci, K. G. Larsen, R. Mardare, "Computing Behavioral Distances, Compositionally" in Proc. of the 38th Int'l Symp. on Mathematical Foundations of Computer Science (MFCS'13), LCNCs, Vol. 8087, pp. 74–85, Springer, 2013.
URL http://dx.doi.org/10.1007/978-3-642-40313-2_9

In the last years, behavioral metrics have received an increased attention as a theoretical tool for approximate reasoning on quantitative models. Realistic models are usually specified compositionally by means of operators that describe the interactions between the subcomponents. These specifications may suffer from an exponential growth of the state space making their analysis difficult to perform in practice. We show recent work on the practical benefits of the compositional reasoning for computing the bisimilarity distance of Ferns et al. between Markov Decision Processes with rewards (MDPs). We identified a well behaved class of operators, called safe, that are guaranteed to be non-extensive w.r.t. the bisimilarity distance on MDPs and we will show that, for MDPs built using safe/non-extensive operators, it is possible to exploit the structure of the system improving the performance on state of the art methods for (exactly) computing such distance.

3.2 On-the-Fly Exact Computation of Bisimilarity Distances

Giovanni Bacci (Aalborg University, DK)

Joint work of Bacci, Giorgio; Bacci, Giovanni; Larsen, Kim G.; Mardare, Radu;
Main reference G. Bacci, G. Bacci, K. G. Larsen, R. Madare, "On-the-Fly Exact Computation of Bisimilarity Distances," in Proc. of the 19th Int'l Conf. on Tools and Algorithms for the Construction and Analysis of Systems (TACAS'13), LNCS, Vol. 7795, pp. 1–15, Springer, 2013.
URL http://dx.doi.org/10.1007/978-3-642-36742-7_1

We describe recent work on an efficient on-the-fly algorithm for exact computation of bisimilarity distances between discrete-time Markov chains. Unlike other existing solutions, our method is able to exactly compute the distances between given states avoiding an exhaustive exploration of the state space. Given a set of target states, our technique successively refines over- approximations of the distance using a greedy strategy which ensures that the state space is further explored only when this is actually needed for improving the current approximation on the given target. Tests performed on a consistent set of (pseudo)randomly generated Markov chains shows that our algorithm improves, on average, the efficiency of the corresponding iterative algorithms with orders of magnitude.

3.3 Fundamental Problems of Fuzzy Automata Theory

Miroslav Ćirić (University of Niš – Serbia)

Joint work of Ćirić, Miroslav; Ignjatovic, Jelena;

In this talk we will present the main ideas and methodology used in dealing with certain fundamental problems of the theory of fuzzy automata, such as equivalence, simulation and bisimulation, state reduction, determinism and determinization, etc. We have found that fuzzy automata can be successfully studied using a fuzzy relational calculus. In particular, it turned out that the basic problems in the study of simulation, bisimulation and state reduction can be reduced to the problems of solving some particular systems of fuzzy relation equations and inequalities. A key role in solving these systems play residuals of fuzzy relations, which naturally generalize residuals of ordinary Boolean relations introduced by Birkhoff in the 1940s. In order to ensure the existence of residuals it is needed that the structure of truth values is a complete residuated lattice, or a quantale (a complete residuated lattice which might lack commutativity). We will also show that some of the obtained results concerning simulation, bisimulation and state reduction can be extended to weighted automata over some types of semirings which allow residuation (max-plus algebras or min-plus algebras – tropical semirings) or relative residuation (additively idempotent semirings), whereas the results concerning determinization can be extended to weighted automata over arbitrary semirings, and even to weighted automata over strong-bimonoids (semirings which might lack distributivity). Finally, we will show how these results of fuzzy automata theory influenced the development of general methods for solving systems of fuzzy relation equations and inequalities, or even more generally, the development of methods for solving systems of equations and inequalities defined by residuated functions. We will also demonstrate how our methodology can be applied in other fields, such as social network analysis and formal concept analysis.

3.4 Approximations of Difficult Problems for Tropical Automata

Thomas Colcombet (CNRS / Université Paris-Diderot)

In this presentation I will consider the problem of comparing tropical automata (min-plus or max-plus, with non-negative weights). This problem is undecidable [1]. In this talk I will present three decidable approximations of this question:

- regular cost function, in which only the relative boundedness is considered, yielding a robust theory extending regular languages.
- the epsilon-approximation of the comparison of min-plus automata, in which the exact comparison of min-plus automata is decided up to an epsilon-multiplicative margin of error epsilon (collaboration with Laure Daviaud).
- the asymptotic analysis of max-plus automata, in which the asymptotic worst-case behaviour of a max-plus automaton is analysed, with an application to the analysis of the termination time of algorithms under the Size-Change-Abstraction (collaboration with Laure Daviaud and Florian Zuleger).

These research received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under grant agreement No. 259454 (project GALE).

References

1 Daniel Krob. The equality problem for rational series with multiplicities in the tropical semiring is undecidable. Internat. J. Algebra Comput., 4(3):405–425, 1994

3.5 Equilibria in Multiplayer Cost Games

Julie De Pril (University of Mons, BE)

Main reference J. De Pril, "Equilibria in Multiplayer Cost Games," PhD thesis, Université de Mons, 2013.
URL http://math.umons.ac.be/perso/DePril.Julie/thesis_Julie_DePril.pdf

In order to model complex interactive computer systems with more than two components, and with quantitative objectives that are not necessarily antagonist, we resort to multiplayer non zero-sum quantitative games played on graphs (also called multiplayer cost games). Many parameters appear when studying cost games: the graph can be enriched with prices on edges or not; there can be two or more players; the objectives of the players can be very various and also complicated; different kinds of rational behaviour can be considered for the players, leading to different concepts of equilibria; ... In this talk, we define different kinds of equilibria in these games. For each kind, we present some existence results and state some open questions.

3.6 Quantitative Languages: Weighted Automata and Beyond

Laurent Doyen (ENS – Cachan, FR)

Quantitative generalizations of classical languages, which assign to each word a real number instead of a boolean value, have applications in modeling resource-constrained computation. We use nondeterministic weighted automata (finite automata with transition weights) to define classes of quantitative languages over infinite words. We study the natural generalization of decision problems and closure properties from automata theory: threshold-emptiness, threshold-universality, language inclusion, language equivalence, and closure under the pointwise operations $\max(L, L')$, $\min(L, L')$, $1 - L$ (which generalize the boolean operations), and sum $L + L'$ where L, L' are quantitative languages. In this survey, we give an overview of the results and open questions about decidability, expressiveness (including determinization), and closure properties of the various classes of quantitative languages defined by weighted automata. As none of these classes enjoys both full decidability and positive closure properties (even if we consider an extension to alternating automata), we present mean-payoff automaton expressions, a new syntax to specify quantitative languages with limit-average value. We show that this class of quantitative languages is robust and decidable: it is closed under the four pointwise operations, and we show that all decision problems are decidable.

3.7 Weighted Automata and Quantitative Logics

Manfred Droste (Universität Leipzig)

Joint work of Paul Gastin resp. Ingmar Meinecke;

We investigate weighted automata and their relationship to weighted logics. For this, we present syntax and semantics of a quantitative logic; the semantics counts "how often" a formula is true in a given word. Our main result, extending the classical result of Büchi, shows that if the weights are taken from an arbitrary semiring, then weighted automata and a syntactically defined fragment of our weighted logic are expressively equivalent. A corresponding result holds for infinite words. Moreover, this extends to quantitative automata investigated by Henzinger et al. with (non-semiring) average-type behaviors, or with discounting or limit average objectives for infinite words.

3.8 Some Algebraic Structures for the Behavior of Quantitative Systems

Zoltán Ésik (University of Szeged)

I will discuss algebraic structures for the behavior of quantitative systems including Conway and iteration semirings, hemirings, semimodules, etc. Some open problems will be presented.

3.9 Kleene Algebras and Semimodules for Energy Problems

Ulrich Fahrenberg (INRIA Bretagne Atlantique – Rennes)

Joint work of Ésik, Zoltán; Fahrenberg, Ulrich; Legay, Axel; Quaas, Karin;

With the purpose of unifying a number of approaches to energy problems found in the literature, we introduce generalized energy automata. These are finite automata whose edges are labeled with energy functions that define how energy levels evolve during transitions. Uncovering a close connection between energy problems and reachability and Büchi acceptance for semiring-weighted automata, we show that these generalized energy problems are decidable. We also provide complexity results for important special cases.

3.10 Functional Weighted Automata

Emmanuel Filiot (Université Libre de Bruxelles, BE)

Joint work of Filiot, Emmanuel; Gentilini, Raffaella; Raskin, Jean-François;
Main reference E. Filiot, R. Gentilini, J.-F. Raskin, "Quantitative Languages Defined by Functional Automata," in Proc. of the 23rd Int'l Conf. on Concurrency Theory, LNCS, Vol. 7454, pp. 132–146, Springer, 2012; pre-print available as arXiv:1111.0862v2 [cs.FL].
URL http://dx.doi.org/10.1007/978-3-642-32940-1_11
URL http://arxiv.org/abs/1111.0862v2

We study several decision problems for functional weighted automata. To associate values with runs, we consider four different measure functions: the sum, the mean, the discounted sum of weights along edges and the ratio between rewards and costs. On the positive side, we show that the existential and universal threshold problems, the language inclusion problem and the equivalence problem are all decidable for the class of functional weighted automata and the four measure functions that we consider. On the negative side, we also study the quantitative extension of the realizability problem and show that it is undecidable for sum, mean and ratio. We show how to decide if the quantitative language defined by a functional weighted discounted sum automaton can be defined with a deterministic automata (it was already known for sum and mean). Finally, we discuss some extension to k-valued weighted automata.

3.11 Probabilistic Regular Expressions

Paul Gastin (ENS – Cachan)

We provide a Kleene Theorem for (Rabin) probabilistic automata over finite words. Probabilistic automata generalize deterministic finite automata and assign to a word an acceptance probability. We provide probabilistic expressions with probabilistic choice, guarded choice, concatenation, and a star operator. We prove that probabilistic expressions and probabilistic automata are expressively equivalent. Our result actually extends to two-way probabilistic automata with pebbles and corresponding expressions.

3.12 Compositional Metric Reasoning with Probabilistic Process Calculi

Daniel Gebler (Free University of Amsterdam, NL)

Joint work of Gebler, Daniel; Larsen, Kim G.; Tini, Simone;
Main reference D. Gebler, S. Tini, "Compositionality of Approximate Bisimulation for Probabilistic Systems," in Proc. of the Combined 20th Int'l Workshop on Expressiveness in Concurrency and 10th Workshop on Structural Operational Semantics (EXPRESS/SOS'13), EPTCS, Vol. 120, pp. 32–46, 2013.
URL http://dx.doi.org/10.4204/EPTCS.120.4

Probabilistic process calculi are algebraic theories to specify and verify probabilistic concurrent systems. Bisimulation metric is a fundamental semantic notion that defines the behavioral distance between probabilistic processes. We study which operators of probabilistic process calculi allow for compositional reasoning with respect to bisimulation metric semantics. We

propose continuity as property of process combinators that capture the essential nature of compositional reasoning for both non-recursive and recursive probabilistic processes. Moreover, we characterize the distance between probabilistic processes composed by standard process algebra operators.

3.13 Important Splitting for Statistical Model Checking

Cyrille Jegourel (INRIA Bretagne Atlantique – Rennes)

Statistical model checking avoids the intractable growth of states associated with probabilistic model checking by estimating the probability of a property from simulations. Rare properties are often important, but pose a challenge for simulation-based approaches: the relative error of the estimate is unbounded. A key objective for statistical model checking rare events is thus to reduce the variance of the estimator. Importance splitting achieves this by estimating a sequence of conditional probabilities, whose product is the required result. To apply this idea to model checking it is necessary to define a score function based on logical properties, and a set of levels that delimit the conditional probabilities.

In this talk we motivate the use of importance splitting for statistical model checking and describe the necessary and desirable properties of score functions and levels. We illustrate how a score function may be derived from a property and present an (adaptive) importance splitting algorithm that discovers optimal levels adaptively.

3.14 Inferring Partially Observed Markov Chains in Biology

Heinz Koeppl (ETH Zürich)

I will discuss the problem specifics of working with biochemical stochastic models to describe experimental single-cell data. In particular, this involves the incorporation of cellular heterogeneity into the mathematical formalism and I will show how to overcome the computational burden related to the inference of resulting models. Moreover, I will explain our work and ideas related to estimation of molecular states and its relation to conditional Markov processes and statistical model checking.

3.15 Assume-Guarantee Reasoning in Continuous-Time

Jan Křetínský (TU München, DE)

Joint work of Brázdil, Tomáš; Hermanns, Holger; Krčál, Jan; Křetínský, Jan; Řehák, Vojtěch;
Main reference H. Hermanns, J. Krčál, J. Křetínský, "Compositional Verification and Optimization of Interactive Markov Chains," in Proc. of the 24th Int'l Conf. on Concurrency Theory, LNCS, Vol. 8052, pp. 364–379, Springer, 2013.
URL http://dx.doi.org/10.1007/978-3-642-40184-8_26

We discuss assume-guarantee reasoning for and compositional verification of interactive Markov chains (a model with non-determinism and stochastic continuous-time). We discuss

several ways to interpret this task and some ideas for solutions specific for continuous-time. We also provide a specification formalism for these systems, namely a continuous and modal extension of timed automata.

References

1 Tomáš Brázdil, Holger Hermanns, Jan Krčál, Jan Křetínský, Vojtěch Řehák: Verification of Open Interactive Markov Chains. FSTTCS 2012.
2 Holger Hermanns, Jan Krčál, Jan Křetínský: Compositional Verification and Optimization of Interactive Markov Chains. CONCUR 2013.

3.16 Patroling Games

Antonín Kučera (Masaryk University – Brno)

Joint work of Brázdil, Tomáš; Hliněný, Petr; Řehák, Vojtěch;

Patrolling is one of the central problems in operational security. Formally, a patrolling problem is specified by a set U of vulnerable targets and a function d which to every target u assigns the (integer) time $d(u)$ needed to complete an intrusion at u. The goal is to design an optimal strategy for a defender who is moving from target to target and aims at detecting possible intrusions. The defender can detect an intrusion at u only by visiting u before the intrusion is completed. The goal of the attacker is to maximize the probability of a successful attack. We assume that the attacker is adversarial, i.e., he knows the strategy of the defender and can observe her moves. We prove that the defender has an optimal strategy for every patrolling problem and every environment, and we show how to construct an optimal strategy efficiently.

3.17 Formal Analysis of Resource Contention in Multicore Architectures

Kai Lampka (Uppsala University, SE)

Joint work of Lampka, Kai; Georgia Giannopoulou; Nikolay Stoimenov; LotharThiele;
Main reference G. Giannopoulou, K. Lampka, N. Stoimenov, L. Thiele, "Timed Model Checking with Abstractions: Towards Worst-Case Response Time Analysis in Resource-Sharing Manycore Systems," in Proc. of the 10th ACM Int'l Conf. on Embedded Software (EMSOFT'12), pp. 63–72, ACM, 2012.
URL http://dx.doi.org/10.1145/2380356.2380372

The talk is concerned with the analysis of real-time constrained software executing on multicore processors with shared resources like caches, memory and inter-core connections. The presented results have been developed as part of the EU FP-7 STREP CERTAINTY [1]. The challenge inherent to the design of mixed-critical real-time system deployed on multi-core architectures is to organize the system in such a way, that the system behaviour can be analyzed precisely. This precision will help to avoid over- provisioning of the architecture and in turn reduces the waste of resources. This talk focus on the structuring of software systems to achieve time predictability, i.e, to reduce the non-determinism of occurrence of

events. Based on the proposed model of computation, the talk introduces an analysis scheme based on Timed Automata and model checking which is described in [2].

References

1 EU FP 7 STREP: CERTAINTY (Certification of Real Time Applications designed for mixed criticality) http://www.certainty-project.eu
2 Georgia Giannopoulou, Kai Lampka, Nikolay Stoimenov and LotharThiele: Timed Model Checking with Abstractions: Towards Worst-Case Response Time Analysis in Resource-Sharing Manycore Systems. Proc. International Conference on Embedded Software (EMSOFT) 2012. pp. 63–72, ACM 2012.

3.18 Statistical Model Checking of Stochastic Hybrid Systems

Kim Guldstrand Larsen (Aalborg University, DK)

Timed automata, priced timed automata and energy automata have emerged as useful formalisms for modeling a real-time and energy-aware systems as found in several embedded and cyber-physical systems. Whereas the real-time model checker UPPAAL allows for efficient verification of hard timing constraints of timed automata, model checking of priced timed automata and energy automata are in general undecidable – notable exception being cost-optimal reachability for priced timed automata as supported by the branch UPPAAL Cora. These obstacles are overcome by UPPAAL-SMC, the new highly scalable engine of UPPAAL, which supports (distributed) statistical model checking of stochastic hybrid systems with respect to weighted metric temporal logic. The talk will review UPPAAL-SMC and some of its applications, e.g. to the domains of energy-harvesting wireless sensor networks, schedulability analysis for mixed criticality systems, as well as smart grids. In the talk I will also contemplate on how other branches of UPPAAL may benefit from the new scalable simulation engine of UPPAAL-SMC in order to improve their performance as well as scope in terms of the models that they are supporting. This includes application of UPPAAL-SMC to counter example generation, refinement checking, controller synthesis, optimization, testing and meta-analysis.

3.19 Timing Analysis of Parallel Software Using Abstract Execution

Björn Lisper (Mälardalen University – Västerås, SE)

Joint work of Gustavsson, Andreas; Gustafsson, Jan; Lisper, Björn;
Main reference A. Gustavsson, J. Gustafsson, B. Lisper , "Timing Analysis of Parallel Software Using Abstract Execution," in Proc. of the 15th Int'l Conf. on Verification, Model Checking, and Abstract Interpretation (VMCAI'14), LNCS, Vol. 8318, pp. 59–77, Springer, 2014.
URL http://dx.doi.org/10.1007/978-3-642-54013-4_4

A major trend in computer architecture is multi-core processors. To fully exploit this type of parallel processor chip, programs running on it will have to be parallel as well. This means that even hard real-time embedded systems will be parallel. Therefore, it is of utmost importance that methods to analyze the timing properties of parallel real-time systems are

developed. We present an algorithm that is founded on abstract interpretation and derives safe approximations of the execution times of parallel programs. The algorithm is formulated and proven correct for a simple parallel language with parallel threads, shared memory and synchronization via locks.

3.20 Definition of Star and Epsilon-Removal in Weighted Automata

Sylvain Lombardy (Université Bordeaux)

The removal of epsilon-transitions in weighted automata requires, except in some particular cases, to deal with a definition of a star operator in the semiring of weights. This operator must allow both a sound definition of validity of weighted automata and the computation of the epsilon-removal. Different approachs exist; the axiomatique method states axioms on semirings that guarantee the validity of weighted automata and the sound definition of the star operator. We present here another method based on the topology of the semiring, that allows to define the star as a sum; the semirings that can be handled this way includes all the common semirings, but in this framework, weighted automata may be not valid and decision algorithms must be designed.

3.21 Robustness of Timed Models

Nicolas Markey (ENS – Cachan, FR)

Joint work of Markey, Nicolas; Bouyer, Patricia; Sankur, Ocan; Reynier, Pierre-Alain; Fang, Erwin;

Timed automata are governed by an "idealized" semantics, assuming zero-delay transitions and infinite precision in the measure of time. This is not compatible with real-life systems, and small clock drifts can have important impact on the correctness of real-time systems, even when their abstract model has been proven correct. In this talk, I present several recent attempts that have been proposed to overcome this problem, taking into account perturbations in the semantics. I conclude with general perspectives for robust model checking of real-time systems.

3.22 Weighted Hybrid Logics

Benjamin Monmege (Université Libre de Bruxelles, BE)

Joint work of Bollig, Benedikt; Gastin, Paul; Monmege, Benjamin; Zeitoun, Marc;

The link between weighted automata and weighted logic has been investigated since several years. At first, a weighted extension of monadic second order logic (wMSO) has been introduced by Droste and Gastin, which appears to be much too powerful with respect to

weighted automata. However, a fragment of this logic appears to match the expressive power of weighted automata. In this talk, we will consider a weighted hybrid logic which combines the features of weighted regular expressions and weighted first-order logic (a fragment of wMSO). We show an efficient translation from this weighted hybrid logic to weighted pebble automata, an extension of weighted automata with two-way navigation and pebbles. This translation works over general classes of graphs, like words, trees, nested words, pictures, ... Moreover, weighted pebble automata can be evaluated efficiently. In the overall, this permits an efficient processing of quantitative specifications over general classes of graphs, with possible applications to language processing, speech recognition, or XML querying, e.g. Finally, notice that the expressive power of our weighted hybrid logic meets the one of pebble weighted automata, proving the robustness of our models.

3.23 Multi-weighted Automata and MSO Logic

Vitaly Perevoshchikov (Universität Leipzig, DE)

Joint work of Droste, Manfred; Perevoshchikov, Vitaly;
Main reference M. Droste, V. Perevoshchikov, "Multi-weighted automata and MSO logic," in Proc. of the 8th Int'l Computer Science Symposium in Russia (CSR'13), LNCS, Vol. 7913, pp. 418–430, Springer, 2013.
URL http://dx.doi.org/10.1007/978-3-642-38536-0_36

Weighted automata are non-deterministic automata where the transitions are equipped with weights. They can model quantitative aspects of systems like costs or energy consumption. The value of a run can be computed, for example, as the maximum, limit average, or discounted sum of transition weights. In multi-weighted automata, transitions carry several weights and can model, for example, the ratio between rewards and costs, or the efficiency of use of a primary resource under some upper bound constraint on a secondary resource. Here, we introduce a general model for multi-weighted automata as well as a multi-weighted MSO logic. In our main results, we show that this multi-weighted MSO logic and multi-weighted automata are expressively equivalent both for finite and infinite words. The translation process is effective, leading to decidability results for our multi-weighted MSO logic.

3.24 Formal Reductions of Stochastic Rule-based Models of Biochemical Systems

Tatjana Petrov (IST Austria – Klosterneuburg, AT)

Joint work of Petrov, Tatjana; Koeppl, Heinz; Feret, Jerome; Henzinger, Tom; Ganguly, Arnab;
Main reference A. Ganguly, T. Petrov, H. Koeppl , "Markov chain aggregation and its applications to combinatorial reaction networks," Journal of Mathematical Biology, Nov. 2013 (online).
URL http://dx.doi.org/10.1007/s00285-013-0738-7

Intuitively, bisimulation is a measure of behavioural similarity between two transition systems. The classical probabilistic bisimulation on transition systems running in continous-time, on discrete state space, coincides with the concept of lumpability in Markov chain theory. We show that such probabilistic bisimulation can be effectively constructed for models of

biochemical networks written in a rule-based language, and, hence, it can provide a significant state space reduction. Then, we discuss possible further directions in this application domain.

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3.25 Verification of Timed One-Counter Automata

Karin Quaas (Universität Leipzig, DE)

A timed one-counter automaton is a timed automaton extended with a counter ranging over the natural numbers. During the execution of a transition, the counter can be incremented or decremented. In this way, a timed one-counter automaton can also be regarded as an extension of a one-dimensional vector addition system with states extended with clocks. By an easy extension of the classical region graph construction for timed automata, one can prove that the reachability problem for timed one-counter nets is decidable. I present some results and open questions about typical verification problems like Metric Temporal Logic-model checking and language inclusion for timed one-counter automata and related models.

3.26 Topological RNA Structures

Christian M. Reidys (University of Southern Denmark – Odense, DK)

Joint work of Reidys, Christian M.; Fenix Huang;
Main reference F. Huang, C. Reidys, "Shapes of topological RNA structures," submitted.

In this talk I discuss topological RNA structures. The particular topologization method is quite generic and applicable to other discrete structures, like graphs when additional information is given. Topological RNA structures are fatgraphs, a natural enrichment of the concept of undirected graphs and equivalent to cell-complexes of orientable surfaces. In this talk we describe the model and discuss main results and new perspectives.

3.27 Using LARES in Order to Tackle Hierarchically Structured Dependable Systems

Martin Riedl (Universität der Bundeswehr – München, DE)

In order to bridge the gap between high-level dependability modelling formalisms and formal modelling languages the LAnguage for REconfigurable dependable Systems (LARES) has been defined. It can serve as both an intermediate language as well as a stand-alone modelling approach. LARES provides means for hierarchical modelling, i.e. it separates between definition of structure and behaviour. Furthermore, it introduces scopes in order to restrict visibility of definitions and named statements, which leads to structured model descriptions. Specific language elements are provided which allow asserting questions on states of subinstances in order to imply a specific reaction. The semantics is defined by means of stochastic process algebra and labelled transition systems. LARES has meanwhile been extended by rewards and non-deterministic decisions. It is still an open question how hierarchical structures can be exploited for improving the analysis and which additional extensions would be useful in order to increase the expressiveness of LARES, thus its field of application.

3.28 Decidable Properties for Subfragments of Quantitative Monadic Second-Order Logic

Cristian Riveros (Pontificia Universidad Catolica de Chile, CL)

Joint work of Riveros, Cristian; Kreutzer, Stephan;
Main reference S. Kreutzer, C. Riveros, "Quantitative Monadic Second-Order Logic ," in Proc. of the 28th IEEE/ACM Symp. on Logic in Computer Science (LICS'13), pp. 113–122, IEEE, 2013.
URL http://dx.doi.org/10.1109/LICS.2013.16

What is a good logic to define quantitative properties? Quantitative monadic second order logic (i.e. Weighted monadic second order logic, Droste and Gastin 2005) is a good alternative for defining quantitative properties that captures the expressiveness of weighted automata. Unfortunately, this equivalence implies that many interesting problems (e.g. containment or emptyness of formulas) of this logic become undecidable. To avoid these undesirable features of QMSO, one is forced to look at its subfragments and sacrifices expressiveness in favor of decidability. Towards this goal, we show that, by refining the analysis of QMSO, one can obtain subfragments that characterize exactly subclasses of weighted automata defined by the level of ambiguity allowed in the automata. This gives us a starting point in order to find a quantitative logic with good decidability properties while being reasonably expressive. In this talk, I will give a summary of the connection of between subfragments of QMSO and the ambiguity of weighted automata. Towards the end, I will show how this is connected with their decidability properties for different semirings.

3.29 Basics of Weighted Automata Theory: An Algebraic Perspective

Jacques Sakarovitch (Telecom ParisTech, FR)

In this lecture, I shall try to give a comprehensive introduction to the study of weighted automata along the line I have developed in the chapter I wrote in the Handbook of Weighted Automata edited by Droste, Kuich and Vogler and in more recent works achieved with Sylvain Lombardy. The notions of rationality and recognisability will be distinguished, in particular for the purpose of dealing with weighted transducers. The questions of reduction and morphisms of weighted automata will be tackled with the notion of conjugacy of automata. Reduction is the problem of finding an equivalent automaton of smaller size, hopefully of minimal size. Reduction is effective when the weight semiring is a (subsemiring of a) skew field, and yields the decidability of equivalence in these cases, with a cubic complexity. As established by Harju and Karhumäki, this decision result extends to unambiguous transducers via Malcev-Neumann theorem. The notion of morphisms for weighted automata proves to be equivalent to the notion of bisimulation developed in other contexts.

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3.30 Energy-Autonomous Smart Micro-Grids

Gerard J. M. Smit (University of Twente)

URL http://www.dagstuhl.de/mat/Files/14/14041/14041.SmitGerard.ExtAbstract.pdf

When enough (renewable) generation like PV panels, biomass installations and wind-turbines in combination with storage assets are installed, it may be possible to create a self-supplying (autonomous) neighbourhood in a so- called energy autonomous smart micro-grid. The main objective of our work is: to develop methods and techniques to support the development of energy-autonomous smart micro-grids. This broad main objective can be decomposed in a number of detailed research questions:

- In an energy-autonomous smart micro-grid demand/supply matching (DSM) has to be done on a local level. How to find local balance of demand/supply/storage. A related research question is: How (and for how long) can a micro-grid continue autonomously without a connection to the main electricity grid?
- What distributed energy management systems can be used for a local micro-grid and a cluster of micro-grids (systems of systems) attached to the smart grid.

- Find and use the flexibility of appliances in a micro-grid e.g. storage, charging time of EV, starting time of dishwashers.
- What kind of (wireless) communication networks will support reliable, real-time and efficient communication in a micro-grid?

3.31 Probabilistic Rectangular Hybrid Automata

Jeremy Sproston (University of Turin, IT)

Main reference J. Sproston, "Discrete-Time Verification and Control for Probabilistic Rectangular Hybrid Automata," in Proc. of the 8th Int'l Conf. on Quantitative Evaluation of Systems (QEST'11), pp. 79–88, IEEE, 2011.
URL http://dx.doi.org/10.1109/QEST.2011.18

Hybrid automata provide a modeling formalism for systems characterized by a combination of discrete and continuous components. Probabilistic rectangular hybrid automata generalize the class of rectangular hybrid automata with the possibility of representing random behavior of the discrete components of the system. We consider verification and control problems for probabilistic rectangular hybrid automata. When restricting to the case of a semantics in which discrete control transitions can occur only at integer points in time, both the verification and control problems are decidable. We also consider positive and negative results and open problems with regard to the standard continuous-time semantics of probabilistic rectangular hybrid automata.

3.32 Model Checking meets Simulation-Based Analysis – Getting Formal Methods Adopted by Industry

Bart Theelen (Embedded Systems Institute – Eindhoven, NL)

Joint work of Theelen, Bart; Geilen, Marc; Voeten, Jeroen;

In our mission to advance innovation by industrial adoption of academic results, TNO-ESI performs projects with high-tech industries such as ASML, Océ Technologies, Thales, NXP Semiconductors, Philips Healthcare and TP Vision. Favoring formal methods, we observe a gap between industrial needs in analyzing quantitative properties and the capabilities of formal methods for this goal. After highlighting a few aspects of this gap, we briefly identify some relevant deficiencies of state-of-the-art quantitative analysis techniques (focusing on model checking and simulation). As an ingredient to bridging the gap, we indicate the formal link between our model checking and simulation-based analysis approaches. Although concentrating on infinite horizon properties (i.e., complex forms of long-run averages), our techniques also serve best/worst case and (probabilistic/expected) reachability properties. We illustrate our approaches with an example from the domain of dynamic Digital Signal Processing (DSP) applications in high-tech (embedded / cyber-physical) systems. Based on ingredients of our work, we conclude with some technical thoughts to initiate a discussion on advancing model checking based quantitative analysis to improve its adoption by industry.

3.33 Probabilistic Logic and Regular Expressions on Infinite Words

Thomas Weidner (Universität Leipzig, DE)

We introduce a probabilistic extension to MSO logic on infinite words. This extended logic adds an expected-value operator to classical MSO. We also provide probabilistic omega-regular expressions, which are based on probabilistic regular expressions introduced by Bollig, Gastin, Monmege, Zeitoun. Both formalisms prove to be expressively equivalent to probabilistic Muller-automata. To obtain better decidability results we restrict probabilistic automata and probabilistic expressions such that probabilistic choices occur almost surely only finitely often. The image of such restricted automata, resp. expressions, can be approximated by a finite, computable set.

3.34 Models and Control for Smart Grid Balancing

Rafael Wisniewski (Aalborg University, DK)

Joint work of Luminita C. Totu, Rafael Wisniewski, John Leth;

This presentation addresses the problem of maintaining the balance between consumption and production in the electricity grid when volatile resources, such as wind and sun, account for a large percentage of the power generation. I will consider a participant in the energy market, who manages a portfolio composed of different units. Specifically, the portfolio includes consumption units with flexible consumption. The units in the portfolio are distributed across geographical areas, and the number of units in the portfolio can make the portfolio very large. Consequently, both collecting and distributing data across the portfolio, as well as optimizing individual power schedules in a centralized manner, may become cumbersome. During the talk, I will address two approaches:

1. deterministic, where distributed optimisation techniques are applied,
2. stochastic, where Forward Kolmogorov equations is used to capture the power consumption behavior at the population level.

Participants

- Giorgio Bacci
Aalborg University, DK
- Giovanni Bacci
Aalborg University, DK
- Benedikt Bollig
ENS – Cachan, FR
- Miroslav Ćirić
University of Niš – Serbia, RS
- Thomas Colcombet
CNRS / Université Paris-Diderot, FR
- Julie De Pril
University of Mons, BE
- Laurent Doyen
ENS – Cachan, FR
- Manfred Droste
Universität Leipzig, DE
- Zoltán Ésik
University of Szeged, HU
- Javier Esparza
TU München, DE
- Ulrich Fahrenberg
INRIA Rennes – Bretagne Atlantique, FR
- Emmanuel Filiot
Université Libre de Bruxelles, BE
- Paul Gastin
ENS – Cachan, FR
- Daniel Gebler
Free Univ. of Amsterdam, NL
- Cyrille Jegourel
INRIA Rennes – Bretagne Atlantique, FR
- Heinz Koeppl
ETH Zürich, CH
- Jan Křetínský
TU München, DE
- Antonín Kučera
Masaryk University – Brno, CZ
- Dietrich Kuske
TU Ilmenau, DE
- Kai Lampka
Uppsala University, SE
- Kim Guldstrand Larsen
Aalborg University, DK
- Axel Legay
INRIA Rennes – Bretagne Atlantique, FR
- Björn Lisper
Mälardalen University – Västerås, SE
- Sylvain Lombardy
Université Bordeaux, FR
- Jan Madsen
Technical Univ. of Denmark – Lyngby, DK
- Nicolas Markey
ENS – Cachan, FR
- Benjamin Monmege
Université Libre de Bruxelles, BE
- Vitaly Perevoshchikov
Universität Leipzig, DE
- Tatjana Petrov
IST Austria – Klosterneuburg, AT
- Karin Quaas
Universität Leipzig, DE
- Christian M. Reidys
University of Southern Denmark – Odense, DK
- Martin Riedl
Universität der Bundeswehr – München, DE
- Cristian Riveros
Pontificia Universidad Catolica de Chile, CL
- Jacques Sakarovitch
Telecom ParisTech, FR
- Sean Sedwards
INRIA Rennes – Bretagne Atlantique, FR
- Gerard J. M. Smit
University of Twente, NL
- Jeremy Sproston
University of Turin, IT
- Bart Theelen
Embedded Systems Institute – Eindhoven, NL
- Thomas Weidner
Universität Leipzig, DE
- Rafael Wisniewski
Aalborg University, DK