05241 Abstracts Collection
Synthesis and Planning
— Dagstuhl Seminar —

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Abstract. From 12.06.05 to 17.06.2005 the Dagstuhl Seminar 05241 "Synthesis and Planning" was held in the International Conference and Research Center (IBFI), Schloss Dagstuhl. 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.

Keywords. AI planning, controller synthesis, partially observed domains, reactive computation, program analysis, games, model checking, satisfiability, Markov decision processes

05241 Executive Summary – Synthesis and Planning

This seminar has brought together researchers working in two complementary fields: automatic synthesis of (control) programs, and methods for devising planning algorithms in artifical intelligence (AI). This combines a strong thread of current research in automata theory with an area of possible but so far unexplored applications.

Keywords: Synthesis, planning

Joint work of: Kautz, Henry; Thomas, Wolfgang; Vardi, Moshe

Full Paper: http://drops.dagstuhl.de/opus/volltexte/2006/452

Planning for Partially Observable, Non-Deterministic Domains

Piergiorgio Bertoli (IRST - Trento, I)

The problem of planning for partially observable, nondeterministic domains has lately attracted considerable interest, due to its relevance and complexity. It is relevant since it allows tackling the wide variety of realistic situations where only limited sensing is available, and where (some) actions may have uncertain outcomes. The problem has shown to be extremely complex, both theoretically and in practice, posing a serious scalability challenge.

In this talk, I will present a general framework for partially observable planning; in such framework, I will focus on describing a forward-chaining approach to the problem, and its implementation based on symbolic representation techniques; finally, I will draw relationships with other state-of-the-art approaches that tackle the same problem.

Keywords: Planning, nondeterminism, partial observability

External Exploration in Planning and Model Checking Practice

Stefan Edelkamp (Universität Dortmund, D)

Guided or heuristic search includes information on the distance to the set of terminal states into the exploration process and external search has shown to be important option to bypass limitations to main memory that are present when storing states for duplicate detection. The combination of both search approaches, denoted as External A*, is effective in solving challenging action planning and in model checking problems. The partition of sets of states into buckets indexed by the generating path costs and the heuristic estimates of the remaining costs reduces the number of external accesses to a theoretical optimum, namely to $O(scan(v)+sort(e))$ I/Os, where v and e are the vertices and edges of the explored state space subgraph. In the talk we further address how to integrate symbolic BDD-based representation especially for the automated generation of search heuristics.

Keywords: Model checking, action planning, external search, symbolic search, automated heurstics, pattern databases, abstraction

Analysis of Recursive Markov Chains, Recursive Markov Decision Processes, and Recursive Stochastic Games

Kousha Etessami (University of Edinburgh, GB)

Recursive Markov Chains (RMCs) ([Etessami-Yannakakis'05a]) are a natural abstract model of procedural probabilistic programs and related systems involving recursion and probability. RMCs define a class of denumerable Markov chains with a rich theory generalizing that of multi-type Branching (stochastic) Processes and Stochastic Context-Free Grammars, and are intimately related to probabilistic Pushdown Systems. Recursive Markov Decision Processes (RMDPs) and Recursive Simple Stochastic Games (RSSGs) extend RMCs with a controller and two adversarial players, respectively.

In a series of recent papers with Mihalis Yannakakis, we have studied central algorithmic analysis and verification questions for RMCs, RMDPs, and RSSGs, providing some strong upper and lower bounds on the complexity of key algorithmic problems.

In this talk I will provide a broad survey of this work, indicating some of the main techniques involved in our analyses.

Joint work of: Kousha Etessami; Mihalis Yannakakis (Columbia U.)

Keywords: Recursive Markov chains, rekursiv decision processes, recursive stochastig games

Planning and Controller Synthesis for Hard Real-Time

Robert P. Goldman (SIFT - Minneapolis, USA)

Timed automata give a theoretical framework for controller synthesis and planning for hard real-time systems. We are particularly interested in controller synthesis/planning for the case of closed-loop control over looping state spaces. We survey three approaches to timed automaton controller synthesis, an abstract symbolic framework [Asarin, Maler & Pneuli; Maler, Pneuli & Sifakis], a system based on graph search over time-abstract systems [Tripakis & Altisen], and a system based on artificial intelligence planning [Musliner,Durfee & Shin; Goldman, Musliner & Pelican]. Even in these closely-related approaches, we see substantial differences in framing assumptions that lead to quite different algorithms.

Keywords: Planning, controller synthesis, real-time systems

Path Games

Erich Grädel (RWTH Aachen, D)

Path games are two-player games on finite or infinite graphs, where the players, in each move, take a token not just along an edge (as in the common form of graph games), but along a path of any finite length.

Path games have been studied in descriptive set theory, in the form of Banach-Mazur games. An important issue in this context is determinacy (does one of the players have a winning strategy?) and its dependency on the topological properties of the winning condition. In a quite different setting, path games have been used for task planning in nondeterministic domains.

Rather than determinacy (which is obvious for winning conditions in such applications), the main concern there are algorithmic questions. It turns out that planning problems modeled by path games can be solved by automata-based methods.

Here we survey path games in a general, abstract setting, but with emphasis on definability and complexity issues. After a brief review on Banach-Mazur games, we discuss path games that are positionally determined, i.e., admit winning strategies that only depend on the current position, not on the history of the play. This can be used to determine the complexity of deciding the winner of path games with LTL winning conditions. Finally we discuss definability issues. We are interested in the question how the logical complexity of defining the winning condition (a property of infinite paths) is related to the logical complexity of defining who wins the associated game (a property of game graphs).

In particular, it turns outthat the winner of path games with LTL winning conditions is definable in CTL*.

Keywords: Planning in nondeterministic domains, Banach-Mazur games, logical definability

Joint work of: Grädel, Erich; Berwanger, Dietmar; Kreutzer, Stephan

Discrete Distributed Games And Tree Automata

David Janin (LaBRI Bordeaux, F)

Distributed games is a recent multiplayer extension of discrete two player infinite games. The main motivation for their introduction is that they provide an abstract framework for distributed synthesis problems, in which most known decidable cases can be encoded and solved uniformly.

In this talk, we show that this unifying approach allows as well a better understanding of the role played by classical results from tree automata theory (as opposed to adhoc automata constructions) in distributed synthesis problems.

More precisely, we use alternating tree automata composition, and simulation of an alternating automaton by a non-deterministic one, as two central tools for giving a simple proof of known decidable cases.

Keywords: Distributed games, tree automata, synthesis

Decentralized Supervisory Control of Discrete-Event Systems

Stéphane Lafortune (University of Michigan, USA)

Decentralized control architectures where a set of local controllers jointly control a given distributed system by fusion of their respective control actions are considered.

These control architectures arise for instance in the study of networked systems. The framework adopted is that of discrete-event systems, i.e., systems with discrete state spaces and event-driven dynamics. The controllers (or supervisors) observe and control subsets of the events executed by the system. Attention will be focused on the necessary and sufficient "coobservability" requirements in order for a set of supervisors to achieve a given desired controlled behavior. Different complementary versions of "coobservability" will be discussed, as the amount of inferencing done by the supervisors and the method of fusion of their respective control actions are varied.

Keywords: Discrete event systems, decentralized control, coobservability

Synthesis from Scenarios

Christof Löding (RWTH Aachen, D)

Scenarios provide an intuitive graphical way for writing specifications of reactive systems. The most popular formalism from the family of scenarios is the one of message sequence charts (MSCs).

To overcome weaknesses of MSCs Damm and Harel proposed in 1999 an extension called live sequence charts (LSCs) with a clearly defined semantics. We propose here a subset of these LSCs as specification formalism for the synthesis of centralised open systems. We analyse the expressive power of this formalism in comparison to automata and temporal logic and provide a game based algorithm that solves the aforementioned synthesis problem in exponential time.

Keywords: Scenarios, reactive systems, live sequence charts

Counterexample-guided Planning

Rupak Majumdar (Univ. California - Los Angeles, USA)

Counterexample-guided abstraction refinement is an extremely successful paradigm in software and hardware verification. In counterexample-guided abstraction refinement, we start analyzing a coarse abstraction of a system, and automatically refine the abstraction by analyzing abstract counterexamples produced by a model checker. We discuss, in a tutorial setting, counterexample-guided refinement algorithms for transition systems and (deterministic and stochastic) games. Along the way, we point out how the same algorithms can be used in corresponding planning problems.

Keywords: Counterexample-guided abstraction refinement

Full Paper:
http://www.cs.ucla.edu/~rupak/Papers/CounterexampleGuidedPlanning.ps

See also: Rupak Majumdar is an assistant professor in computer science at the University of California at Los Angeles. He obtained his PhD from the University of California at Berkeley in 2003. His research interests are verification and control of hardware and software systems.

On Optimal and Sub-optimal Control in the Presence of Adversaries

Oded Maler (VERIMAG - IMPG, F)

This paper constitutes a sketch of a unified framework for posing and solving problems of optimal control in the presence of uncontrolled disturbances. After laying down the general framework we look closely at a concrete instance where the controller is a scheduler and the disturbances are related to uncertainties in task durations.

Keywords: Special theory of everything

See also: WODES'04

Synthesis for concurrent models

Anca Muscholl (LIAFA - Université Paris VII, F)

The talk surveys main results on the synthesis problem for closed concurrent models, where finite-state processes cooperate either through shared variables (Zielonka automata) or through unbounded channels (communicating finite-state machines). We focuss on CFM synthesis for MSC-based specifications, for which we show solutions assuming strong/weak channel bounds. We also address the question of deadlock-free synthesis.

Keywords: Synthesis, concurrent models, Zielonka automata, communicating finite-state machines

Synthesis in analysis of systems

Madhusudan Parthasarathy (Univ. of Illinois - Urbana, USA)

While synthesis of systems and controllers is well understood in theory, not much practical synthesis has been demonstrated. We give two applications of synthesis in the domain of analysis of systems.

We propose that learning algorithms for finite automata are useful for solving games, and hence in solving the synthesis problem. We detail the learning approach, and present two applications: one for synthesizing dynamic interfaces for Java classes that capture usage of a class, and the other that synthesizes symbolic interfaces to do compositional verification of hardware.

Keywords: Analysis of systems, dynamic interfaces, Java, compositional verification

Second-order Quantification of Temporal Logics and their Application to Supervisory Control

Sophie Pinchinat (IRISA - Rennes, F)

We propose a general framework based on second-order quantifications of temporal formulas for the specification of an extremely large family of control problems of sequential (possibly non-deterministic) processes for branching-time control objectives.

After a brief explanation of the technical background based on the mu-calculus and its parity game semantics, we will give examples ranging from the easy case of centralized control with full observation to the complex case of decentralized control with architecture. At the end of the talk, we might have time to address decidability issues and explain some of our non trivial results.

Keywords: Mu-calculus, controller synthesis, maximal permissivity

Full Paper:
http://www.irisa.fr/prive/Sophie.Pinchinat/publications/mfcs03.ps.gz

See also:
http://www.irisa.fr/prive/Sophie.Pinchinat/publications/ipl2005.pdf

Automated Generation of Executable Compositions of Web Services

Marco Pistore (Università di Trento, I)

In the last years, automated composition of web services has become one of the key application domains for the AI planning research community. Given a set of services that are published on the Web, and given a composition goal, this task consists in the automatic generation of a composition of the available services that satisfies the goal.

This task is particularly challenging if the composition is supposed to be executable, i.e., to be expressed in terms of a process that can be executed on suitable engines in order to carry out the interactions with the existing services and to achieve the composition goal. Indeed, in this case can be seen as the synthesis of a reactive controller under the assumption of partial observability on the synthesis domain and automated composition requires advanced techniques for planning under uncertainty.

In this talk we describe the problem of generating web service compositions and we describe the challenges this problem issues to the AI planning and program synthesis communities.

Keywords: Web service composition, planning under uncertainty

Joint work of: Pistore, Marco; Traverso, Paolo; Bertoli, Piergiorgio

Design Synthesis in Action: Solving a Doubly Exponential hard problem in time N^3

Amir Pnueli (Courant Institute - New York, USA)

We consider the problem of synthesizing digital designs from their LTL specification. In spite of the theoretical double exponential lower bound, we show that for many expressive specifications of hardware designs the problem can be solved in time N^3. Technically, these are all the specifications which can be written as a generalized Reactivity(1) property.

We describe the context of the problem, as part of the Prosyd European Project which aims to provide a property-based development flow for hardware designs. Within this project, synthesis plays an important role, first in order to check whether a given specification is realizable, and then for synthesizing part of the developed system.

Keywords: Synthesis, generalized Street(1), reactivity properties

Merging Spatial and Temporal Logic for Discrete Event Control

William Rounds (University of Michigan, USA)

We introduce spatial deterministic CTL, a logic for deterministic transition systems with named transitions, augmented with two spatial connectives, one for the parallel composition of two formulas, and one for expressing "assume-guarantee" properties. We prove the finite model property for a fragment of this logic, the fragment being one in which the satisfiability of a formula expresses the existence of a finite controller, under partial observation, for a given plant, forcing the controlled system to obey a given specification. The satisfiability procedure yields a controller synthesis procedure requiring time exponential in the size of the specification. We show how to recast the work of Walukiewicz et al., and Pinchinat et al., in this framework.

Keywords: Spatial logic, temporal logic, discrete event systems

A Heuristic for Symbolic Strategy Synthesis for ATL* Games

Pierre-Yves Schobbens (University of Namur, B)

ATL* is a logic of games. It extends LTL by a modal operator that describes temporal properties that a coordinated coalition of agents can enforce. One can synthesize the implementing strategies by determinizing the automaton corresponding to the property using Safra's algorithm. However, it is computationnaly demanding even in simple cases. We propose here a simple incomplete algorithm, that can be implemented symbolically and give good results on practical examples.

Keywords: Strategy synthesis, games, Büchi winning condition, ATL*

Joint work of: Harding , Aidan; Ryan, Mark; Schobbens, Pierre-Yves

Full Paper:
http://www.cs.bham.ac.uk/~ath/thesis.pdf

See also: Strategy Synthesis in LTL Games, TACAS 2005, LNCS

The Achilles' Heel of QBF

Bart Selman (Cornell University, USA)

In recent years we have seen significant progress in the area of Boolean satisfiability (SAT) solving and its applications. As a new challenge, the community is now moving to investigate whether similar advances can be made in the use of Quantified Boolean Formulas (QBF).

QBF provides a natural framework for capturing problem solving and planning in multi-agent settings. However, contrarily to single-agent planning, which can be effectively formulated as SAT, we show that a QBF approach to planning in a multi-agent setting leads to significant unexpected computational difficulties.

We identify as a key difficulty of the QBF approach the fact that QBF solvers often end up exploring a much larger search space than the natural search space of the original problem.

This is in contrast to the experience with SAT approaches.

We also show how one can alleviate these problems by introducing two special QBF formulations and a new QBF solution strategy. We present experiments that show the effectiveness of our approach in terms of a significant improvement in performance compared to earlier work in this area. Our work also provides a general methodology for formulating adversarial scenarios in QBF.

Keywords: QBF, SAT, games, adversarial planning, multiagent planning

Joint work of: Ansotegui, Carlos; Gomes, Carla P.; Selman, Bart

Full Paper:
http://www.cs.cornell.edu/selman/papers/pdf/05.aaai.achilles-heel-qbf.pdf

See also: Proc. AAAI-05.

Backdoors To Typical Case Complexity

Bart Selman (Cornell University, USA)

There has been significant recent progress in reasoning and constraint processing methods. In areas such as planning and finite model-checking, current solution techniques can handle combinatorial problems with up to a million variables and five million constraints. The good scaling behavior of these methods appears to defy what one would expect based on a worst-case complexity analysis. In order to bridge this gap between theory and practice, we propose a new framework for studying the complexity of these techniques on practical problem instances. In particular, our approach incorporates general structural properties observed in practical problem instances into the formal complexity analysis. We introduce a notion of "backdoors", which are small sets of variables that capture the overall combinatorics of the problem instance. We provide empirical results showing the existence of such backdoors in real-world problems. We then present a series of complexity results that explain the good scaling behavior of current reasoning and constraint methods observed on practical problem instances.

Joint work of: Williams, Ryan; Gomes, Carla P.; Selman; Bart

See also: In Proc. 18th Intl. Joint Conf. on Artificial Intelligence (IJCAI-03), 2003

Supervisory Control Tutorial

John G. Thistle (University of Waterloo, CDN)

Complex automated systems pose control problems that are often naturally formulated in terms of abstract, discrete-event plant models. Supervisory control theory aims to synthesize control logic for discrete-event systems, managing complexity through modular synthesis and decentralized and hierarchical architectures. A finite-string formal language framework allows the formulation of some of the key system-theoretic properties that characterize solutions of control synthesis problems. We sketch some of the main outlines of the theory, and describe the extension of basic monolithic synthesis procedures to an infinite-string framework.

Automata-Theoretic Foundatios of Controller Synthesis

Wolfgang Thomas (RWTH Aachen, D)

In this tutorial, we give a synopsis of the automata-theoretic methods for synthesizing nonterminating finite-state controllers. The framework is that of infinite games, played between two agents (the controller and its environment), restricted here to the case of finite-state systems and regular specifications ("regular infinite games").

The task is to generate from the system description (a finite game graph) and a regular omega-language (as a "winning condition", defined e.g. in linear-time temporal logic or the logic S1S) a winning strategy for the controller which is executable by a finite-state machine. The existence and effective computability of such controllers was shown in classical works of Buechi, Landweber and Rabin in the beginning of the 1970s. We present a modula approach, using a sequence of "game simulations". This amounts to simplyfying the winning conditions, in particular, - from an LTL- or S1S-condition to a Muller condition, - from a Muller condition to a parity condition, after which a solution of the parity games is given. An essential ingredient of the last step is the notion of attractor, for solving simple reachability games. Finally, some topics for current research are outlined.

Keywords: Controller synthesis, regular infinite games, game simulations

Tree Automata in Program Synthesis

Moshe Y. Vardi (Rice University, USA)

The automata-theoretic framework to program synthesis is complementary to the game-theoretic framework. The basic idea is to start from the specifications and construct a tree automaton that accepts all winning strategies, viewed as labeled infinite trees. Then by checking the automaton for nonemptiness we find a winning strategy, which is a program that meets the specifications. To make the construction of the automaton easier, it is useful to have a powerful model of tree automata. In particular, alternating parity automata on infinite trees have proven to be particularly useful.

Keywords: Program synthesis, alternating parity automata

Full Paper:
http://www.cs.rice.edu/~vardi/papers/ictl97.ps.gz

See also: Kupferman, O., Vardi, M.Y.: Synthesis with incomplete informatio. In *Advances in Temporal Logic* (Proc. 2nd International Conference on Temporal Logic,1997), H. Barringer et al. (eds.), 1999, Kluwer Academic Publishers, pp. 109–127.

Controlled Linear Programming and Linear Complementarity for Some Infinite Games in NP ∩ coNP

Sergei Vorobyov (Uppsala University, S)

We argue that combinatorial linear programming provides a powerful, efficient, and simple algorithmic toolbox, useful for the unification and development of the new algorithms for solving infinite games. We present the Controlled Linear Programming Problem (CLPP), a new combinatorial optimization problem nicely merging linear programming with games. In a system of linear monotone constraints of the form $xi \leqslant p_i^j(\bar{x}) + w_i^j$, where p_i^j are linear homogeneous polynomials (linear forms) with nonnegative coefficients and $w_i^j \epsilon \mathbb{R}$, some variables are distinguished as controlled and we want to select exactly one constraint for each controlled variable to make $max \sum x_i$, subject to the remaining constraints, as large as possible (over all possible such selections). We suggest a number of iterative strategy improvement policies, simplex-like and interior-point. For many important cases we prove optimality conditions (when a local optimum is global), describe a number of combinatorial randomized subexponential algorithms, and show that the decision version of the problem is in NP ∩ coNP.

It turns out that the well-known mean payoff, discounted payoff, simple stochastic, and parity games, as well as the recent Longest-Shortest Paths (LSP, select exactly one edge out of each controlled vertex to make the shortest directed s - t-path as long as possible) problem [MFCS'2004] (all in NP ∩ coNP,

unknown to be in P) are easily reducible to the CLPP. This suggests a simplifying and unifying view of all these games as particular restricted instances of the CLPP, one of the "most general" problems in NP $\cap$ coNP to which all the known games in the class reduce (in certain sense "complete" in the class). We show that a slight generalization of the CLPP allowing for negative coefficients in the constraint polynomials p_i^j is NP-hard. So are the controlled versions of many other polynomial optimization problems, like MAXIMUM FLOW. We describe the full taxonomy of complexity results for different CLPP classes.

The simple algebraic and combinatorial structure of the CLPP unifies and gives insights into algo- rithmic and complexity-theoretic studies of infinite games, and is amenable to the powerful tools from combinatorial and polyhedral optimization, as well as linear programming. We investigate boundedness, CLPP duality, stability, optimality conditions, correctness of subexponential algorithms, and conditions for NP$\cap$coNP-membership. In particular, strong duality immediately implies NP $\cap$ coNP-membership, polynomial optimality conditions, and strongly subexponential algorithms.

We also describe new pseudopolynomial and subexponential algorithms for Mean Payoff Games (MPGs). The algorithms are based on representing the MPG decision problem in the forms of non- standard and standard Linear Complementarity Problems (LCPs):

find $w, z \geq 0$ satisfying $w = Mz + q$ and $w^T \cdot z = 0$,

and monotonic iterative propagation of slack updates. We extend the LCP-based approach to numerous subclasses of CLPPs.

Keywords: Infinite games, linear programming, randomized algorithms

Joint work of: Vorobyov, Sergei; Bjorklund, Henrik; Svensson, Ola

Synthesis from Knowledge-based Specifications

Thomas Wilke (Universität Kiel, D)

In program synthesis, one starts with a specification of a system and attempts to derive a program that implements this specification. This problem is particularly challenging in the context of open or reactive systems, which are required to respond appropriately to a sequence of inputs provided by an environment that is not under their full control.

In the talk we will consider the situation where the systems to be synthesized are distributed and specified in the "logic of knowledge and linear time". This is motivated by the fact that properties of distributed systems often refer to their temporal aspects and, in addition, the uncertainty that system components have about the global state of the system. For instance, a designer might make a statement such as "if process X knows that the transaction will be aborted, it should rollback its local contribution and terminate immediately." Such assertions can be made formal in the logic of knowledge and linear time.

Joint work of: Wilke, Thomas; van der Meyden, Ron