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Editorial

# Advances in automated plan generation

Planners have made significant advances in performance on classical planning domains in recent years. Anyone who has followed the series of International Planning Competitions will recognise this fact, but the extent to which performance has improved, and the dimensions of its improvement, are not so clear cut. In this special issue we bring together a collection of papers representing some of the most important recent trends in modern planning. These papers cover classical planning, temporal planning, and planning under uncertainty, showing how understanding has consolidated and developed and indicating current and future directions of research.

As planners have made advances in performance there has been a growing, and increasingly productive, interest in exploring the solution of problems in more expressive planning languages. Each of the papers in this special issue illustrates a way in which tried and tested classical techniques can be successfully combined and exploited in a more expressive setting. This includes the probabilistic and non-deterministic planning systems of Likhatchev and Stenz (PPCP), Buffet and Aberdeen (FPG), Sanner and Boutilier (FOALP) and Kuter, Nau, Traverso and Pistore (YoYo), as well as approaches to partial satisfaction planning and planning with temporally extended goals and preferences such as the Sapa$^{PS}$ and Yochan$^{PS}$ systems by Benton, Do and Kambhampati, and the HPlan-P system by Baier, Bacchus and McIlraith. The paper by Gerevini, Haslum, Long, Saetti and Dimopoulos describes constructs to support the modelling of trajectory constraints and preferences, resulting in the extended language PDDL3.0. They present results from the sixth international planning competition, demonstrating performance of some of the most recent planners while raising new challenges in planning with the language features of PDDL3.0.

All of the approaches described in this special issue address richer expressiveness than is available in the classical planning framework. However, what is of particular interest is that the undeniable advances that these planners represent are all built on fundamental techniques that were hot-housed in the development of classical planners and other core technologies in reinforcement learning, linear programming, model-checking and formal verification. The use of classical planning algorithms to solve problems of planning under uncertainty, including by direct compilation into classical planning, is one of the most promising avenues of research in current planning. The paper by Likhatchev and Stenz makes an important step in this direction. The authors identify an interesting and useful class of partially observable, decision-theoretic planning problems with the property that some unknowns in the environment are preferred over others. This property can be exploited to yield an efficient algorithm, based on a series of simple deterministic searches in an A* style, which returns optimal policies under certain conditions.

The Factored Policy Gradient (FPG) planner by Buffet and Aberdeen uses well-known Reinforcement Learning techniques that have been under-exploited by the planning community. In contrast with typical MDP algorithms for probabilistic planning, policy gradient approaches avoid the state space explosion by searching in the space of parameterised policies, sampling to estimate the gradient of the expected utility of the policy and moving the parameters in the direction of the gradient. The generality and simplicity of this approach makes it possible to generate approximate factored (parallel) policies for complex concurrent temporal probabilistic domains, with continuous or discrete distributions.

FOALP, by Sanner and Boutilier, addresses the very challenging problem of solving Markov Decision Problems represented in relational form. Traditional MDP algorithms ground the planning domain, leading to a complexity that is exponential in the number of domain objects. Relational MPDs, formalised in a situation calculus language, provide an opportunity to exploit the relational structure of the domain and generate generalised policies covering arbitrary numbers of objects. FOALP implements a first-order version of approximate linear programming and scales remarkably well in several of the probabilistic planning competition domains.

In their planner YoYo, Kuter, Nau, Traverso and Pistore explore the combination of the HTN decomposition-based approach of ND-SHOP2 with a BDD-based state space representation. This approach, which brings together two powerful – but not obviously compatible – ideas, produces an efficient hierarchical planner for solving non-deterministic STRIPS problems.

In Sapa$^{PS}$, Benton, Do and Kambhampati examine an important class of partial satisfaction planning problems where the objective is to balance the “net benefit” of action costs with the additive goal utilities. One of the contributions of the

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paper is the adaptation of classical heuristic search planning to this type of problem. Another contribution is the translation, implemented in the IPC6 planner Yochan$^{\mathcal{PS}}$, of PDDL 3.0 "simple preference" problems into partial satisfaction planning.

HPlan-P, by Baier, Bacchus and McIlraith, translates temporally extended STRIPS goals into parameterised automata expressing equivalent linear temporal logic formulae and enabling solution within a classical planning framework. The main contribution of this paper is the development of heuristics and a search strategy that guides the planner towards plans that satisfy the most preferences. HPlan-P exploits a range of relaxation-based heuristics that estimate the difficulty of achieving the specified preferences, coupled with a powerful pruning strategy, thereby building on a solid foundation of research into heuristic search control in classical planning.

New preprocessing techniques and automatically generated heuristics have been at the core of the most spectacular performance improvements in classical planning. Helmert's paper in this special issue provides a comprehensive description of the set of preprocessing techniques (domain normalisation, grounding, and reachability analysis) that originated in the Fast-Downward planner and are now used in a number of planning systems. These techniques exploit a more concise finite-domain representation of planning tasks, obtained by analysing invariants in the propositional PDDL representation. The same finite-domain representation typically reveals structure in planning domains that is often obscured by propositional representations, hence facilitating the automatic generation of heuristics that exploit this structure.

Helmert's work, the first-order MDP representation in the FOALP planner and the parameterisation of automata in HPlan-P, illustrate another current trend of planning research: exploiting problem structure by operating on increasingly concise representations.

The papers in this special issue demonstrate both consolidation and advancement in our understanding of representation and reasoning for planning. But are modern planning problems more challenging than they used to be, and are modern planners more capable of meeting these challenges? To help us evaluate the progress of research in automated planning, Roberts and Howe have performed an extensive empirical evaluation of more than 30 publicly available, PDDL-compatible, classical planners, over a diverse collection of over 5000 domains and problems. These problem sets include competition benchmarks, and other domains obtained from various sources, as well as domains specially designed to explore gaps in planner performance on the known problems. Using statistical techniques the authors confirm that problem sets are becoming increasingly challenging and that modern planners tend to out-perform older technology. However, there remain some interesting features of older planners that make them particularly suited to solving some types of problems that remain challenging to the best modern systems. Impressive progress is being made, but many important challenges remain.

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