A Modular Architecture for Hybrid Planning with Theories

Maria Fox

Dept. Informatics, King's College London, UK
maria.fox@kcl.ac.uk*

Planning technology has made huge strides, alongside other combinatorial optimisation solving technologies, over the past decade. Automated planning systems now exist for temporal and metric problems, including management of continuous time and concurrency, continuous numeric resources and action costs [3, 1, 2, 12, 7, 8, 11, 9]. There is an increasing interest in combining planners with specialised solvers, such as optimisation alogorithms, to achieve a hybrid form of planning. In this context, the relationship between planning and model-checking, planning and constraint-solving and planning and control are all being clarified.

Synergies between different optimisation modelling and solving paradigms can be exploited to achieve new capabilities and improved performance of solvers. An example of this is recent work exploiting the developments in SAT solving, SAT Modulo Theories, in which atoms can be built from predicates, functions and constants whose interpretations are provided through external theory modules [10, 5]. In planning, extension to support external modules allows a much richer expression of preconditions and state variables. A motivation for exploring this idea is that the increased expressiveness can allow planners to work with models of application domains using specialised solvers, necessary for reasoning within those applications, alongside the generic solving cores developed in the planning community. Since this is a common requirement of planning applications, it is important to provide clean and well-understood methods for linking planners to external libraries, choosing heuristics and exchanging constraints.

In this talk we present the Planning Modulo Theories paradigm, first proposed in 2012 [6], describing how the paradigm has been extended to incorporate the latest advances in temporal planning. We discuss how the use of constraint reasoning can provide an additional source of powerful solving capabilities within this framework. In general, constraint solvers prune choices from the search space by inference, while most modern planners focus on heuristic guidance of the search towards good choices. Complex interactions in resource-constrained models can be obscure, making heuristic evaluation of states much more difficult, while at the same time offering more opportunity for leverage

* Thanks to my generous collorators and co-authors who have contributed to this work.

from inference [13]. We consider, with reference to two real application domains, how constraint solving can contribute to making planners suitable for deployment in applications with demanding requirements.

One of the important challenges in extending the capabilities of planners is to continue to be able to efficiently validate plans and domain models. We will describe how the VAL system [4], developed incrementally over the last 10 years for validation of plans and domains in the mixed discrete-continuous expressiveness of PDDL+, is now being extended to cope with richer behaviours encountered in the PMT framework.

References

1. A. Coles, A. Coles, M. Fox, and D. Long. COLIN: Planning with continuous linear numeric change. *Journal of Art. Int. Research*, 44:1–96, 2012.
2. A. I. Coles, M. Fox, D. Long, and A. J. Smith. A Hybrid Relaxed Planning Graph-LP Heuristic for Numeric Planning Domains. In *Proc. 18th Int. Conf. on Automated Planning and Scheduling (ICAPS)*, 2008.
3. A. J. Coles, A. I. Coles, M. Fox, and D. Long. Forward-Chaining Partial-Order Planning. In *Proc. 20th Int. Conf. on Aut. Planning and Scheduling, ICAPS*, 2010.
4. Maria Fox, Richard Howey, and Derek Long. Validating plans in the context of processes and exogenous events. In Manuela M. Veloso and Subbarao Kambhampati, editors, *AAAI*, pages 1151–1156. AAAI Press / The MIT Press, 2005.
5. Sicun Gao, Soonho Kong, and Edmund Clarke. Satisfiability Modulo ODEs. In *Proc. Formal Methods in Computer-Aided Design, FMCAD*, 2013.
6. Peter Gregory, Derek Long, Maria Fox, and J. Christopher Beck. Planning Modulo Theories: Extending the Planning Paradigm. In *Proc. 22nd Int. Conf. on Automated Planning and Scheduling, ICAPS*, 2012.
7. Franc Ivankovic, Patrik Haslum, Sylvie Thiebaux, Vikas Shivashankar, and Dana Nau. "optimal planning with global numerical state constraints". In *Proceedings of 24th Int. Conf. on Aut. Planning and Scheduling, ICAPS*, 2014.
8. Nir Lipovetzky, Christina N. Burt, Adrian R. Pearce, and Peter J. Stuckey. Planning for Mining Operations with Time and Resource Constraints. In *Proceedings of 24th Int. Conf. on Aut. Planning and Scheduling, ICAPS*, 2014.
9. Johannes Löhr, Patrick Eyerich, Stefan Winkler, and Bernhard Nebel. Domain Predictive Control Under Uncertain Numerical State Information. In *Proc. 23rd Int. Conf. on Automated Planning and Scheduling (ICAPS)*, 2013.
10. Robert Nieuwenhuis, Albert Oliveras, and Cesare Tinelli. Solving SAT and SAT Modulo Theories: From an abstract Davis–Putnam–Logemann–Loveland procedure to DPLL(*T*). *J. ACM*, 53(6):937–977, 2006.
11. Masahiro Ono, Brian C. Williams, and Lars Blackmore. Probabilistic Planning for Continuous Dynamic Systems under Bounded Risk. *Journal of AI Research (JAIR)*, 46:511–577, 2013.
12. Giuseppe Della Penna, Benedetto Intrigila, Daniele Magazzeni, and Fabio Mercorio. Upmurphi: a tool for universal planning on pddl+ problems. In *Proc. 19th Int. Conf. on Automated Planning and Scheduling (ICAPS)*, pages 19–23, 2009.
13. Vincent Vidal and Hector Geffner. Branching and pruning: An optimal temporal pocl planner based on constraint programming. *Artif. Intell.*, 170(3):298–335, 2006.