Solution Diversity in Planning

Alexandra Coman

PhD Thesis Supervisor: Dr. Héctor Muñoz Avila

Department of Computer Science and Engineering, Lehigh University, Bethlehem, PA 18015

{alc308|hem4}@lehigh.edu

Abstract

Diverse planning consists of generating multiple different solutions for the same planning problem. I explore solution diversity, based on quantitative (domain independent) and qualitative (domain dependent) distance metrics, in deterministic and nondeterministic planning domains.

The Plan Diversity Problem

Planning consists of generating plans (sequences of actions) or policies (sets of state-action pairs) which solve a problem by transforming its initial state(s) into a goal state. Planning is conducted based on domain descriptions including available actions (with preconditions and effects). Deterministic planning (the solutions of which are plans) is carried out under the assumption that actions have a predefined outcome, while nondeterministic planning (which produces policies) allows for actions with multiple possible outcomes.

Diverse planning consists of generating multiple solutions for the same planning problem. Such solutions can represent varied strategies and approaches to achieving the goal, each reflecting different priorities (such as caution versus willingness to explore), thus catering to variation in circumstances, preferences and needs. Plan diversity is particularly useful when user preferences are assumed to exist, but are unknown to the planner (Nguyen *et al.*, 2011).

In my PhD thesis work, I have explored plan diversity in deterministic, as well as nondeterministic planning, using various planning techniques: forward state-space planning (Coman and Muñoz-Avila, 2011a), case-based planning (Coman and Muñoz-Avila, 2010 and 2011b), and strong cyclic planning for fully-observable nondeterministic problems, as described by Kuter *et al.*, 2008.

The diversity of a set of solutions is evaluated based on a solution-distance metric: a measure of the dissimilarity between two solutions. Distance metrics can be qualitative or quantitative (Coman and Muñoz-Avila, 2011a and 2011b). Quantitative distance metrics are domain-independent, while qualitative distance metrics incorporate domain-specific information.

The expected contribution of this work is a set of domain-independent diverse planning algorithms for various planning paradigms, all of them usable with both quantitative and qualitative distance metrics, and with no knowledge-engineering requirements in addition to the distance metrics.

Current and Future Work

In Coman and Muñoz-Avila (2010), we began investigating diversity in case-based planning, by comparing diversity based on the initial state of the problem with diversity based on the set of actions in the plan. In Coman and Muñoz-Avila (2011a, 2011b), we obtained quantitative and qualitative plan diversity in deterministic planning domains, using a forward state-space planner, and a case-based planner, respectively. In addition to synthetic domains, we tested our algorithms on a planning domain based on the real-time strategy game Wargus. For this domain, we assessed the diversity of the generated solution plans by running them in the game and analyzing the game-specific results obtained (score and battle duration). We showed that qualitatively-diverse plan sets (which we obtain using only a qualitative distance metric, as opposed to an entire domain metatheory, as previously required by Myers and Lee, 1999) produce greater in-game variation than quantitatively-diverse plans.

Our most recent work deals with diversity in nondeterministic planning. I have implemented DivNDP, an algorithm for generating diverse policies for fully-observable non-probabilistic nondeterministic planning prob-

lems. DivNDP is built upon NDP (Kuter *et al.*, 2008), a state-of-the-art nondeterministic planner, and generates *k* diverse policies as follows: first, it generates a policy using regular NDP; then, it generates (*k*-1) additional policies using a modified version of NDP which favors candidate partial policies that are evaluated as being more distant from previously-generated policies. Experimental results on synthetic nondeterministic planning domains show that DivNDP produces highly diverse solution sets without unreasonably inflating solution size (an indicator of solution quality, according to Kuter *et al.*, 2008).

Currently, I am conducting a comparison of our heuristic-search-based and case-based diverse deterministic planning methods, with regard to the diversity of generated plans, as well as to planning speed. I expect this work to be completed by the time of the Doctoral Consortium.

In the final year of my PhD studies, I plan to work on generating qualitatively-diverse policies with DivNDP: while the algorithm can be used with any distance metric, we have so far only tested it with a quantitative one. I would also like to extend the range of test domains so as to include compelling non-synthetic nondeterministic domains (such as computer games), which allow the diversity of generated policies to be assessed by running them in their intended environment and evaluating the results (as we have already done in deterministic planning). I expect that such complex domains will introduce additional efficiency concerns, making it necessary to devise methods for enhancing planning performance.

Related Work

In deterministic planning, Srivastava *et al.* (2007), Nguyen *et al.* (2011), and Eiter *et al.* (2012) obtain quantitative plan diversity; Myers and Lee (1999) obtain qualitative plan diversity through the use of a domain metatheory providing high-level, domain-specific information. In all of the above-mentioned work, the test domains are synthetic, and diversity assessment is conducted solely by analyzing the sets of plans themselves. We obtain both quantitative and qualitative plan diversity without requiring a domain metatheory. Our test domains include a non-synthetic one (Wargus), the plans for which we evaluate by running them in the game environment, and assessing the diversity of the obtained results.

In probabilistic planning, Bryce, Cushing, and Kambhampati (2007) generate multi-option plans using a modified version of the LAO* algorithm. We address diversity in non-probabilistic nondeterministic planning,

therefore not assuming action-outcome probabilities and state-transition cost or reward information to be available. To our knowledge, our work is the first on diversity in non-probabilistic nondeterministic planning.

The related problem of plan similarity has been addressed by Fox *et al.* (2006).

Outside planning, solution diversity has been explored in case-based reasoning for analysis tasks (Smyth and McClave, 2001, and many others).

References

Bryce, D.; Cushing, W.; and Kambhampati, S. 2007. Model Lite Planning: Diverse Multi option Plans & Dynamic Objective Functions. *ICAPS 2007 Workshop on Planning and Plan Execution for Real World Systems*.

Coman, A., and Muñoz Avila, H. 2010. Case based Plan Diversity. In *Proceedings of ICCBR 2010*, 66 80. Springer.

Coman, A., and Muñoz Avila, H. 2011a. Generating Diverse Plans Using Quantitative and Qualitative Plan Distance Metrics. In *Proceedings of AAAI 2011*, 946 951. AAAI Press.

Coman, A., and Muñoz Avila, H. 2011b. Qualitative vs. Quantitative Plan Diversity in Case Based Planning. In *Proceedings of ICCBR 2011*, 32 46. Springer.

Eiter, T.; Erdem, E.; Erdogan, H.; and Fink, M. 2012. Finding Similar/Diverse Solutions in Answer Set Programming. *arXiv:1108.3260v1*. To appear in *Theory and Practice of Logic Programming*.

Fox, M.; Gerevini, A.; Long, D.; and Serina, I. 2006. Plan Stability: Replanning versus Plan Repair. In *Proceedings of ICAPS 2006*, 212 221. AAAI Press.

Kuter, U.; Nau, D. S.; Reisner, E.; and Goldman, R. P. 2008. Using Classical Planners to Solve Nondeterministic Planning Problems. In *Proceedings of ICAPS* 2008, 190 197. AAAI Press.

Myers, K. L., and Lee, T. J. 1999. Generating Qualitatively Different Plans through Metatheoretic Biases. In *Proceedings of AAAI 1999*, 570 576. AAAI Press/The MIT Press.

Nguyen, T.; Do, M.; Gerevini, A.; Serina, I.; Srivastava, B.; Kambhampati, S. 2011. Generating Diverse Plans to Handle Unknown and Partially Known User Preferences. *Technical report arxiv: 1101.2279*. To appear in *Artificial Intelligence*.

Smyth B., and McClave, P. 2001. Similarity vs. Diversity. In *Proceedings of ICCBR 2001*, 347 361. Springer.

Srivastava, B.; Kambhampati, S; Nguyen, T.; Do, M.; Gerevini, A.; and Serina, I. 2007. Domain Independent Approaches for Finding Diverse Plans. In *Proceedings of IJCAI 2007*, 2016 2022. AAAI Press/IJCAI.