Efficient lifting of symmetry breaking constraints for complex combinatorial problems: Extended Abstract*

Alice Tarzariol[1], Martin Gebser[1,2], Mark Law[3], and Konstantin Schekotihin[1]

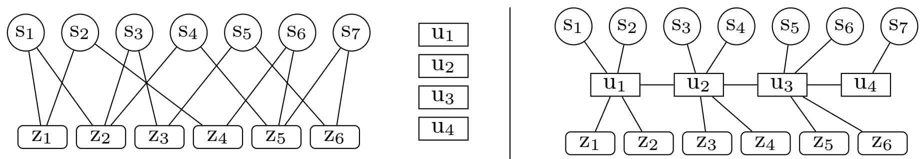
[1] University of Klagenfurt, Austria
[2] Graz University of Technology, Austria
[3] Imperial College London, UK

1 Introduction and Paper Contributions

Finding solutions to hard combinatorial problems is important for various applications, including configuration, scheduling, or planning. Modern declarative solving approaches allow programmers to easily encode various problems and then use domain-independent solvers to find solutions for given instances. The encoding quality highly influences the search performance; however, writing an efficient encoding remains a challenge that requires an experienced programmer to clearly understand the problem up to details. A possible way for simplifying the programming task consists of automatically extend a given encoding with constraints eliminating symmetric solution candidates, i.e., a set of candidates where each one can be obtained from another by renaming constants [10, 7, 15]. For Answer Set Programming (ASP) paradigm [6, 9], the works [11, 12] introduce a framework for learning first-order constraints to automatically improve the efficiency of a given encoding for instances of a target distribution. It applies SBASS [5] for identifying ground symmetries of small but representative instances, and then generalizes respective examples by means of Inductive Logic Programming (ILP) [3]. The main challenge in the application of this approach is that it must be able to access or generate instances that *(i)* comprise symmetries representative for the whole instance distribution, and *(ii)* are simple enough to allow the implementation to compute all of their solutions. Consider a small example of the well-studied *Partner Unit Problem* (PUP) [1, 14], which is an abstract representation of configuration problems occurring in railway safety or building security systems. The Fig. 1a shows the smallest instance representing a class of building security systems named *double* by [1]. Despite being the simplest instance, it has 145368 solutions, one of which is depicted in Fig. 1b. Applying SBASS to a naive encoding grounded with the instance in Fig. 1a, we can identify that 98.9% of the solutions are symmetric (for instance, by renaming the units of a solution). Therefore, the enumeration of symmetries for PUP instances is problematic, although the premises for applying the framework are promising.

In the work referred by this extended abstract [13], we extend the framework's applicability to combinatorial problems lacking trivial representative instances,

* This is an extended abstract of a paper presented at ICLP 2022 [13].



(a) PUP instance

(b) A solution for the instance

Fig. 1. Partner Unit Problem example

addressing the aforementioned limitations. In particular, the paper makes the following contributions: *(i)* we propose a new definition of the ILP learning task and a corresponding implementation for the input generation, which allow the approach to scale with respect to the number of answer sets of the analyzed instances, thus, learning efficient first-order constraints; *(ii)* we provide a novel conflict analysis method for the ILP system ILASP [8] that significantly improves the efficiency of the constraint learning; *(iii)* we present an extensive experimental study conducted on three kinds of PUP benchmarks shows that the new method clearly outperforms the legacy approach in terms of learning and solving performance.

2 Discussion of Results

We applied the revised framework to PUP instances supplied by [1], studying the *double*, *doublev*, and *triple* instance collections. Instances of the same type represent buildings of similar topology with scaling parameters that follow a common distribution. Although the benchmark instances are synthetic, they represent a relevant configuration problem; in addition, the scalable synthetic benchmarks are easy to generate and analyze. We executed the experiments using 120 different random seeds to counterbalance the impact of randomness and get more reliable estimates of the relative learning and solving performance. We compared the new version of the framework with respect to the previous one. The experiments showed that all the revisions proposed for defining the ILP task (including the conflict analysis method) either improve the learning time or lead to more efficient constraints.

Lastly, we select the most efficient learned constraints among those aggregated and compared the running time of CLINGO with: *(ENC1)* a basic PUP encoding, *(ENC1+C)* the same encoding extended with the learned constraints, and *(ENC2)* an advanced encoding [4], incorporating hand-crafted static symmetry breaking as well as an ordered representation [2] of assigned units. The results for the three different types of PUP lead to the same conclusion, i.e., *ENC1* produced the highest solving time, followed by *ENC2*, while *ENC1+C* obtained significantly better performance compared to the other encodings, particularly on the unsatisfiable instances.

Acknowledgments

This work was partially funded by KWF project 28472, cms electronics GmbH, FunderMax GmbH, Hirsch Armbänder GmbH, incubed IT GmbH, Infineon Technologies Austria AG, Isovolta AG, Kostwein Holding GmbH, and Privatstiftung Kärntner Sparkasse.

References

1. Aschinger, M., Drescher, C., Friedrich, G., Gottlob, G., Jeavons, P., Ryabokon, A., Thorstensen, E.: Optimization methods for the partner units problem. In: International Conference on Integration of Artificial Intelligence and Operations Research Techniques in Constraint Programming. Lecture Notes in Computer Science, vol. 6697, pp. 4–19. Springer (2011)
2. Crawford, J., Baker, A.: Experimental results on the application of satisfiability algorithms to scheduling problems. In: Hayes-Roth, B., Korf, R. (eds.) Proceedings of the Twelfth National Conference on Artificial Intelligence (AAAI'94). pp. 1092–1097. AAAI Press (1994)
3. Cropper, A., Dumančić, S.: Inductive logic programming at 30: a new introduction. Journal of Artificial Intelligence Research **74**, 765–850 (2022)
4. Dodaro, C., Gasteiger, P., Leone, N., Musitsch, B., Ricca, F., Schekotihin, K.: Combining answer set programming and domain heuristics for solving hard industrial problems. Theory and Practice of Logic Programming **16**(5-6), 653–669 (2016)
5. Drescher, C., Tifrea, O., Walsh, T.: Symmetry-breaking answer set solving. In: Balduccini, M., Woltran, S. (eds.) Proceedings of ICLP'10 Workshop on Answer Set Programming and Other Computing Paradigm (2010)
6. Gebser, M., Kaminski, R., Kaufmann, B., Schaub, T.: Answer Set Solving in Practice. Synthesis Lectures on Artificial Intelligence and Machine Learning, Morgan and Claypool Publishers (2012)
7. Katebi, H., Sakallah, K.A., Markov, I.L.: Symmetry and satisfiability: An update. In: International Conference on Theory and Applications of Satisfiability Testing. Lecture Notes in Computer Science, vol. 6175, pp. 113–127. Springer (2010)
8. Law, M., Russo, A., Broda, K.: The ILASP system for inductive learning of answer set programs (2020)
9. Lifschitz, V.: Answer Set Programming. Springer (2019)
10. Margot, F.: Symmetric ilp: Coloring and small integers. Discrete Optimization **4**(1), 40–62 (2007), mixed Integer Programming
11. Tarzariol, A., Gebser, M., Schekotihin, K.: Lifting symmetry breaking constraints with inductive logic programming. In: International Joint Conference on Artificial Intelligence. pp. 2062–2068. ijcai.org (2021)
12. Tarzariol, A., Gebser, M., Schekotihin, K.: Lifting symmetry breaking constraints with inductive logic programming. Machine Learning **111**(4), 1303–1326 (2022)
13. Tarzariol, A., Schekotihin, K., Gebser, M., Law, M.: Efficient lifting of symmetry breaking constraints for complex combinatorial problems. Theory and Practice of Logic Programming **22**(4), 606–622 (2022)
14. Teppan, E.C., Friedrich, G., Gottlob, G.: Tractability frontiers of the partner units configuration problem. Journal of Computer and System Sciences **82**(5), 739–755 (2016)
15. Walsh, T.: Symmetry breaking constraints: Recent results. In: 26th AAAI Conference on Artificial Intelligence. pp. 2192–2198. AAAI Press (2012)