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Meta-Optimization

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14. ABSTRACT

This grant sought to investigate the use of meta-optimization in tackling broader classes of optimization problems, and solving existing optimization problems more efficiently. The research teams ultimate goal is to build solvers that learn over time, that exploit the common features found in repeated optimization problems, and that take account of the rich structure found in real world optimization. They investigated a number of approaches to improving solving using meta-optimization by (a) making use of a sub-solver for particular class of important constraints (difference logic), (b) adding sub-problems that reason about objective bounds more effectively, (c) automating a logic-based Benders approach of problem decomposition and (d) exploiting the online nature of many natural resource allocation problems. They also tackled a number of important scheduling problems, and redefined the state-of-the-art for each of these problems. Their results have been presented in multiple peer-reviewed archival journals throughout the project duration.

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Meta-Optimization
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1 Overview

The aim of this grant was to investigate the use of meta-optimization in tackling broader classes of optimization problems, and solving existing optimization problems more efficiently. Our ultimate goal is to build solvers that learn over time, that exploit the common features found in repeated optimization problems, and that take account of the rich structure found in real world optimization. We investigated a number of approaches to improving solving using meta-optimization by (a) making use of a sub-solver for particular class of important constraints (difference logic), (b) adding sub-problems that reason about objective bounds more effectively, (c) automating a logic-based Benders approach of problem decomposition and (d) exploiting the online nature of many natural resource allocation problems. We also tackled a number of important scheduling problems, and redefined the state-of-the-art for each of these problems.

2 Archival Publications

- *Matin Aleksandrov and Toby Walsh. Pure Nash Equilibria in Online Fair Division.* Proceedings of International Joint Conference on Artificial Intelligence*, 2017.*
  We often want to allocate some resource efficiently and fairly. For instance, how do we share access to an expensive scientific instrument? Existing approaches typically treat this as an offline fixed problem. In this work, we view this as an online problem in which resources arrive over time to be allocated to different agents.
- *Nick Matteri, Abdallah Saffidine and Toby Walsh. Mechanisms for Online Organ Matching.* Proceedings of International Joint Conference on Artificial Intelligence, 2017.
  An important example of an online fair division problem is organ matching. Organs are donated over time and need to be matched shortly after they arrive. This matching problem has special features (for example, all patients have identical preferences for younger organs) that we show how to exploit.
- *Martin Aleksandrov and Toby Walsh. Expected Outcomes and Manipulations in Online Fair Division. Proceedings of 40th Annual German Conference on Artificial Intelligence (KI-2017), 2017.*
  Best Paper award. Building on the framework introduced in IJCAI 2017, we study the expected outcomes and strategic manipulations of randomized mechanisms for

online fair division. Such mechanisms have attractive axiomatic fairness properties. In addition, we demonstrate that computational intractability can be a barrier to agents gaining unfair advantage by acting strategically.

- *Nysret Musliu, Andreas Schutt, and Peter J. Stuckey. Solver independent rotating workforce scheduling. In Willen-Jan van Hoeve, editor,* Fifteenth International Conference on Integration of Artificial Intelligence and Operations Research techniques in Constraint Programming (CPAIOR2018)*, volume 10848 of* LNCS*, pages 429–445. Springer, 2018.*

  Rotating workforce scheduling is a challenging constraint satisfaction problem, that is critical to many businesses. In this paper we generate two solver-independent models for the problem, one high level model targeting constraint programming (CP) solvers, and a low-level linear model. Both models improve the state-of-the-art substantially. Surprisingly the high-level model is better for mixed integer programming solvers, while the lower level is better for CP. This demonstrates the importance of solver-independent modelling where we can use the same model with different solving technologies.

- *Stefan Kreter, Andreas Schutt, Peter J. Stuckey, and Jürgen Zimmermann. Mixed-integer linear programming and constraint programming formulations for solving resource availability cost problems.* European Journal of Operations Research*, 266(2):472–486, 2018.*

  Resource availability cost problems try to build schedules to minimize the maximum amount of resource used at any one time. In this paper we construct new mixed integer programming and constraint programming solutions for this class of problem and compare them. Our new CP solution redefines the state-of-the-art, closing all the open instances for two classes of the problem.

- *Stefan Kreter, Andreas Schutt, and Peter J. Stuckey. Using constraint programming for solving RCPSP/max-cal.* Constraints*, 22(3):432–462, 2017.*

  Scheduling with calendars frequently occurs, where some resources are not available in regular or irregular patterns. For example personnel may not be available on weekends, or machines not available during planned maintenance periods. This paper builds new technology to solve this class of problems, substantially improving the state of the art, and closing all the known problem instances except eight.

- *Toby Davies, Graeme Gange, and Peter J. Stuckey. Automatic logic-based Benders decomposition with minizinc. In* Proceedings of the 31st AAAI Conference on Artificial Intelligence (AAAI-17)*, pages 787–793. AAAI Press, 2017.*

  This paper uses meta-optimization to automatically construct a Benders decomposition of an arbtrary discrete optimization problem. Hence it can take advantage of the complementary strengths of Mixed Integer Programming and Constraint Programming solvers. Whereas previsouly generating a logic-based Benders decomposition required months of programming work, here it is achieved automatically, and for free.

- *Geoffrey Chu and Peter J. Stuckey. Lagrangian decomposition via subproblem search. In Claude-Guy Quimper, editor,* Thirteenth International Conference on Integration of Artificial Intelligence and Operations Research techniques in Constraint Programming*, number 9676 in LNCS, pages 6580, 2016.*

This approaches solves a standard optimization problem, using meta-optimization, by adding in, essentially, copies of the problem in order to reason more effectively over objective bounds. It creates a new approach to Lagrangian decomposition that takes advantage of the capabilities of CP solvers.

– *Andreas Schutt and Peter J. Stuckey. Explaining producer/consumer constraints. In Michel Rueher, editor,* Proceedings of the 22st International Conference on Principles and Practice of Constraint Programming*, LNCS 9892, pages 484-454. Springer, 2016.*

  Producer/consumer constraints model consumable resources, such as raw materials (e.g., water) money, in which event times relate to a production or consumption event. They are ubiqitious in discrete optimization problems, modelling reservoirs, or renewable resources. This paper defined the state of the art by using a meta-optimization approach where a nested difference logic solver reasons about interpendencies between event times.

Esteem measures

Martin Aleksandrov and Toby Walsh presented a paper describing work supported by the grant at the 40th Annual German Conference on AI, in Dortmund, Germany, September 2017. This publication won the Best Paper award for the conference.

At the end of 2016, Toby Walsh won the New South Wales Premier's Prize for Excellence in ICT and Engineering.

Toby Walsh gave numerous invited keynote talks during the course of this grant including at CeBIT (2017), the 5th International Conference on Algorithmic Decision Theory (ADT 2017), the 3rd Chinese Congress on AI, PyData 2017 in Berlin, and Data Natives 2017.

Pete Stuckey continues to develop Chuffed, a state of the art lazy clause solver for constraint solving based on insights gained from this research. As organizer of the MiniZinc annual competition, Stuckey's solver is unable to win medals. It would, for example, haven taken the Silver Medal in the finite domain constraint solving section of the competition, and Gold Medal in the free search section.