Review on the Doctoral Thesis

Author:	Libor Bukata, Czech Technical University in Prague
Title:	Parallel Algorithms for Optimization of Production Systems
Reviewer:	doc. Milan Hladík, Charles University, Faculty of Mathematics and Physics

Contents of the thesis

The thesis deals with two important and practical problems in optimization: energy optimization and project scheduling.

The first part, *energy optimization of robotic cells*, starts with a comprehensible introduction to the topic and drawing the state-of-the-art. Then three algorithms are presented. The first one is an exact formulation as a mixed integer linear programming problem. Since this is computationally expensive to solve, a parallel heuristic algorithm is proposed. The third algorithm is based on a branch & bound scheme. In order that an (arbitrary) branch & bound method is efficient, branching rules and tight lower and upper bounds are necessary to involve. In these issues, Libor Bukata developed suitable branching rules, convex envelopes for the lower bounds, and a special technique "deep jumping", which is a heuristic to tighten upper bounds. The key aspect of the implementation is its efficient parallelization. The numerical experiments carried out on benchmark data show that the proposed parallel algorithms perform better with respect to quality of the solutions and runtime in most of the cases. Even more, the case study on real data from Škoda auto resulted in 20% energy saving.

The second part is devoted to *project scheduling on graphics cards.* Libor Bukata gives an introduction into computing on graphics cards and mathematical formulation of the problem. Then he proposes a heuristic based on a tabu search approach and describes the particular steps. In particular for schedule evaluation, he proposed a new method (capacity-indexed evaluation) as an alternative to time-indexed evaluation. The experimental results show that computing on GPU with a suitable number of iterations outperforms the other Tabu search implementations with respect to both runtime and quality of solutions. It is also competitive with other heuristics.

From the reader's perspective, the thesis is written understandably and conscientiously, using illustrative pictures, diagrams and typesetting on a professional level. There are almost no typos and the level of English is high.

Scientific contribution

The main contribution lies in developing methods that solve practical problems and outperform the other known approaches. In order to compete with the existing state-of-the-art methods, one has to understand (and contribute to) different levels of the design: from the highest level of modelling and mathematical formulation, to the lowest level of software programming on suitable platforms. Libor Bukata obviously succeeded. There are many details that play role in developing the methods and where he contributed. For instance, effective parallelization and implementation on GPU, development of new heuristics, design of convex envelopes or a new approach to schedule evaluation (so called capacity-indexed evaluation).

Definitely, the topic is actual and very important in practice. The fact that the proposed method was able to save 20% energy consumption for Škoda auto robotic cell clearly underlines this fact.

The scientific results were presented on four international conferences and published in a series of papers. The publication list includes two journal papers, one book chapter and several conference proceedings. Some other papers are submitted or in the form of a technical report. Thus the number and quality of publications meets (and overcomes) the standard requirements on PhD candidates.

Questions and remarks

Some minor remarks:

- The nomenclature at the end of the thesis is very helpful. Maybe also symbols $\mathbb{R}_{\geq 0}$ and $\mathbb{B}$ from (2.20) can be listed there.
- (page 42) "Note that the optimality of the exact algorithm is preserved since Deep Jumping does not ignore any nodes that could be resulting in an optimal solution." Maybe this is easy to see, but a reader can appreciate a detailed explanation of this observation.

I have some questions that arose when reading the thesis:

- (page 19, below) The MILP formulation has some specific form. Cannot it be utilized for some kind of decomposition? Or for an abstraction in a similar way as people do it in algorithmic game theory?
- (page 24) "...could be iteratively added to heuristically resolve active collisions..." What method is used for solving linear programs? For iterative adding of constraints, usually a dual simplex method is recommended. Is it the case here?

- Why a tabu search approach is chosen as a heuristic for Section 3? There are many other heuristics known – they are not promising for this problem? Why?
- It was not much clear to me whether the methods for schedule evaluation (Section 3.7) are exact or heuristic. In the second case, what is the computational complexity of the problem – is it known to be NP-hard, for example?
- Related to Section 3.7, how the start time tables are computed when the schedule W is perturbed? They are re-computed from scratch or somehow updated?

Summary

The doctoral thesis fulfilled the declared goals. It contains original research results, published also as refereed papers in scientific journals and proceedings. Therefore I sincerely recommend to **accept** the thesis.

In Prague, July 3, 2018

doc. Milan Hladík, Ph.D.

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