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Ph.D. Dissertation Review

ENERGY-AWARE SCHEDULING WITH RESOURCE STATE CONSIDERATIONS: MODELING AND OPTIMIZATION

by Ing. Ondřej Benedikt

The presented Ph.D. dissertation deals with specific scheduling problems and thus falls in a wider research area of optimization algorithms. The scheduling problems studied in the dissertation are both interesting from a theoretical point of view and important from a practical point of view. There are three scheduling problems considered in the dissertation:

1. Scheduling of an electric vacuum furnace where the objective is to minimize energy consumption during idle periods by optimally scheduling the idle periods (which are uniquely defined by scheduling the tasks) and then regulating the power input in each idle period. This problem is inspired by a real use-case from Škoda Auto manufacturing plant.
2. Scheduling with time dependent energy prices and several resource states of the machine. This problem is the generalization of the previous problem (where energy prices were assumed to be constant).
3. Scheduling for multi-processor systems on a chip which is a completely different problem from the previous two. It deals with scheduling tasks (so called best-effort tasks) to cores (on a multi-core chip) and time windows in such a way that the chip does not overheat.

Before commenting on the content of the dissertation in more detail, let me first comment on the size of the dissertation. It has over 100 pages excluding bibliography and several appendices which is a decent amount of material for a predominantly theoretical work (at least in my experience theoretical dissertations are usually shorter). Clearly, the dissertation sums up several years of research done by the candidate with various co-authors. The quality (and novelty) of the presented results for all three scheduling problems considered in the dissertation was already verified by the fact that these results appeared in refereed publications, either in high quality international journals, or in conference proceedings from conferences well respected by the scientific community in the relevant fields (mostly rank B conferences in the widely used CORE ranking). What is truly exceptional is the fact that three of the six conference papers (on which this dissertation is primarily built) received best student paper awards at the conferences where they were presented. That is indeed quite a feat !!

Let me now comment in more detail on the presented results in all three of the studied areas.

Scheduling of an electric vacuum furnace

This problem is a special type of a single machine scheduling problem with release dates and deadlines. Each task has a fixed processing time and must be scheduled within the time window defined by its release date and its deadline. The order of all tasks is fixed (without this assumption the problem becomes intractable), which is a reasonable restriction in real manufacturing environments and in particular holds in the Škoda Auto use-case. The objective is to minimize the power consumption in the idle intervals, i.e. in those time intervals when no task is being processed. The following contributions are made in the dissertation:

- Under some mild assumptions (concavity) on the energy function it is shown that it pays off

to cluster the task together as much as possible without violating feasibility. Such schedules are called "block-form schedules" and the set of these schedules is proved to be dominating (which means that it suffices to look for an optimal schedule in this set).
- A graph-based polynomial time algorithm is designed to construct an optimal block-form schedule.
- A bilinear model for the energy function is proposed and an optimal control is defined (and proved to be optimal). The function is proved to be concave and thus satisfies the assumption needed for the dominance of block form schedules.
- It is shown by experiments (on synthetized data) that the proposed model together with the optimization algorithm outperforms commonly used approaches.

Scheduling with time-dependent energy prices

This problem generalizes the previous problem in two ways: the energy price varies in time, and the machine has several resource states (energy consumption levels) where the transition among the states is described by a deterministic finite automaton. On the other hand, no release times and deadlines are assumed, i.e. all tasks are available at any time and their order is not fixed. The main contribution of this chapter is a graph-based technique (which employs shortest path computations) that precomputes optimal switching costs (between states) and thus simplifies the model (which is then solved by ILP or CP solver) and reduces solution time. The performance of the novel preprocessing algorithm is verified by experiments (again on synthetized data) which show that this new approach persuasively outperforms state of the art algorithm from recent literature.

Scheduling for multi-processor systems on a chip (MPSoC)

MPSoCs are increasingly used in many application areas including safety-critical domains (such as automotive or aerospace industries). The tasks performed by MPSoCs can be divided into safety-critical tasks (which have to be executed at their pre-determined time window in any scenario) and best-effort (BE) tasks which may improve the quality of service but may be skipped or delayed if the chip is in a danger of overheating. Offline scheduling of BE tasks is the topic of this chapter of the dissertation. Thermal and power modelling is discussed and several optimization methods for scheduling BE tasks are proposed and subsequently tested on three different HW platforms. It is shown that the proposed methods outperform previously used approaches. This chapter is by far the most experimental (and compared to the first two brings only a limited amount of new theory). I do not feel to be competent to really judge the results in this chapter as the topic is very far from my field of expertise. However, this has no bearing on my evaluation, as already the first two chapters would make up an excellent dissertation.

Summary

To sum up my comments, Ondřej Benedikt's dissertation "Energy-aware scheduling with resource state considerations: modeling and optimization" is a high-quality scientific work. The presented results are novel, non-trivial, and quite numerous, and thus without any doubt satisfy the conditions defining "independent scientific work" as required by the rules for dissertations at CTU. Most of the results were already published in well respected journals and conference proceedings and received three best paper awards. Moreover, the problems studied in the dissertation are relevant for industrial practice. Thus, I strongly **recommend** the dissertation to be successfully defended.

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