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Mathematical challenges in scheduling theory

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Scheduling is the allocation of resources over time to execute a set of tasks that belong—in most applications—to computational and manufacturing processes. During execution, the tasks compete for required resources. Resources can be of different categories, e.g. manpower, money, processors (machines), energy, tools, transportation (by truck, robot, drone, etc.). There is a limited quantity of resources and the scheduler determines how to allocate the resources to tasks over time to complete them. The quality of a schedule is mostly determined by attributes of the tasks. These attributes may include release times, due dates, priority weights, functions describing task processing in relation to allotted resources, technical restrictions, economical limitations or temporal restrictions.

A scheduler must design a schedule that satisfies the specified restrictions while optimizing one or more goals that evaluate the quality of the generated solution. There

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is an incredible wealth of literature in this area, including many approximate and exact methods, fascinating theoretical results, and countless refined heuristics. The majority of these problems are computationally intractable and have been classified according to their varying degrees of intractability.

The variety of problems has its origin in diverse applications in industry, especially industrial manufacturing, logistics and services, personnel planning, project scheduling in construction, organization, software development, or generally scheduling in parallel and distributed systems, see (Blazewicz et al., 2018).

Researchers have been increasingly attracted by scheduling problems that arise from new applications. These applications include scheduling in decentralized systems, selfish organizations, and in seaports or automotive production facilities. Energy-efficient processing, efficient data processing, and online scheduling are challenges that increasingly affect relevant applications. As technology evolves over time, these modern technologies require efficient schedulers to ensure that the technologies are used to their full potential.

The criteria for measuring the quality of solutions in scheduling has evolved over time. For example, an emerging field is robust scheduling where the scheduler makes decisions in order to cope with the uncertainty of data. In this case, the scheduler may desire to optimize a worst-case metric of corresponding to the quality of the solution while also ensuring robustness to the parameters of the problem. A robust schedule has performance guarantees in worst-case scenarios and also provides minimum quality guarantees. These theoretical guarantees can be offered without extensive computational tests and simulation studies.

Other approaches use hierarchical planning processes or shiftable time windows in which parts of the data are available for planning the next steps. In this case, past decisions cannot be changed and the distant future is uncertain. An interesting question with online data is what sacrifices does a planner have to make when using it, as opposed to the optimal solution obtained through an offline model with complete knowledge? How well does a specific algorithm perform in



an online problem in comparison to its offline optimal solution?

This short list gives only a small insight into the multitude of new and extremely interesting applications or the underlying theoretical problems that motivate scientists worldwide to devote themselves again and again to new challenges in scheduling.

The papers featured in this issue not only offer insight into the current trends in research, but also suggest potential directions for future development. Given the changing industrial requirements and market conditions, future research questions must address the challenges posed by new technologies, particularly digitalization, and the opportunities and risks they bring. Industry 4.0, or the Internet of Things, is an integral part of the digital transformation of industrial production and transport. It allows for the design of highly adaptive cyber-physical (production) systems and provides the capacity to process Big Data in real time.

Between October 7 and 11, 2019, the 14th scheduling workshop entitled "Mathematical Challenges in Scheduling Theory" was held at Tsinghua Sanya International Mathematics Forum (TSIMF), Sanya, China. (The participants were very pleased with the friendly atmosphere and excellent organization.) The purpose of this recurring workshop is to explore and discuss the most up-to-date scheduling theory and applications that have emerged in recent years.

This special issue presents the results of a workshop that underwent a thorough and rigorous review process, with only 5 papers being selected out of numerous high-quality submissions. Listed below in alphabetical order by first author are the articles included in this issue, with each summary's length not indicating relevance or importance.

The paper Approximation algorithms for parallel-batch scheduling with processing set restrictions by Xing Chai, Wenhua Li, C. T. Ng and T.C.E. Cheng is considered with job scheduling on m parallel-batch machines/processors to minimize the makespan. Each job is characterized by a set of processors on which it is required to be processed. At the same time each machine/processor can process several jobs simultaneously as a batch. The authors analyze two models:

- Scheduling on parallel-batch processors under the nested processing set restriction and.
- Scheduling on uniform parallel-batch processors under the tree-hierarchical processing set restriction.

The uniform parallel-batch processors have different speeds. In the case of identical processors, an algorithm is described, where the complexity is strongly polynomial and which has the worst-case bound, respectively, equal to 2 in the case of non-identical batch capacities and to 2-1/m in the case of identical ones. We see that the presented approach

is better than the existing one, which in the case of identical batch capacities has the worst-case bound of 3–1/m and cannot deal with non-identical capacities. For the case of uniform processors, the authors present an algorithm which for non-identical batch capacities has the worst-case bound equal to 2. It is better than the known fast algorithm with a worst-case bound of 9/4, which can only be applied for the parallel-batch processors under the inclusive processing set restriction.

The paper *Competitive Algorithms for Demand Response Management in Smart Grid* authored by Vincent Chau, Shengzhong Feng and Nguyễn Kim Thắng considers a scheduling problem motivated by efficiently optimizing smart grids. In the problem considered, each client submits a job that has a power request at specific times. Jobs can be load balanced on a set of unrelated machines with varying power functions. The goal is to assign the jobs to minimize the total energy. The paper presents an online scheduling algorithm and shows this algorithm has a small competitive ratio depending on the power functions of the machines. Further, improved approximation results are given in the offline setting for special cases.

Xin Han, Yinling Wang, Yong Zhang and Jacek Blazewicz are the authors of *Improved approximation algorithm for a scheduling problem with transporter coordination*. There are n jobs that need to be processed on a single machine. Processed jobs need to be transported to one of two customers or areas by a single available transporter with limited capacity of 1. Each job requires a capacity (job size) between 0 and 1 during its transport to one of the two areas. The goal is to reduce the amount of time it takes for all jobs to reach their designated area and for the transporter to return to the machine. This is known as minimizing the makespan. The authors develop an $11/6 + \varepsilon$ approximation algorithm that improves the previous best approximation of 2.

The paper *Scheduling on a Graph with Release Times* authored by Wei Yu, Mordecai Golin and Guochuan Zhang considers a generalization of the well-studied traveling salesman problem. In the traveling salesman problem, a salesman must visit a collection of cities and the goal is to design an algorithm that minimizes the total travel time. This paper considers a variance where each city should not be visited until after a specified release time. The paper gives approximation results that beat the best known 5/2 approximation when there are a fixed number of release times or the graph has a *heavy* edge. They further show lower bounds that demonstrate that it is that unlikely a natural class of algorithms will lead to approximation guarantees better than 5/2. This matches the best known approximation.

Kameng Nip and Zhenbo Wang consider in their paper, which is entitled *Complexity and Algorithms for Two*machine Shop Scheduling Problems under Linear Constraints the well-known standard job scheduling problems, job store, flow store and open store. In addition to the usual sequence variables, the processing times of the jobs are also decision variables that must satisfy a system of linear constraints. The processing times and the job sequences on the machines are to be determined in such a way that the makespan is minimized. Motivations exist, for example, in the steel industry where the processing times could depend on the processing quantity. The processing times at the following stage can depend on the processing time at the previous stage. The authors prove that the flow shop and job shop variants with two machines, which are polynomially solvable in the standard case, become strictly NP-hard when the machining times must satisfy a set of linear constraints. Moreover, the authors develop polynomial time algorithms when the number of constraints is fixed. For the general case, they develop a 2-approximation and polynomial time approximation schemes (PTAS). Furthermore, the authors show that the open store problem with linear constraints is polynomially solvable.

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Reference

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