Scheduling.jl – Collaborative and Reproducible Scheduling Research with Julia

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Abstract

We introduce the Scheduling.jl Julia package, which is intended for collaboratively conducting scheduling research and for sharing implementations of algorithms. It provides the fundamental building blocks for implementing scheduling algorithms following the three-field notation of Graham et al., i.e., it has functionality to describe machine environments, job characteristics, and optimality criteria. Our goal is to foster algorithm and code sharing in the scheduling community. Scheduling.jl can also be used to support teaching scheduling theory in classes. We will show the main functionalities of Scheduling.jl and give an example on how to use it by comparing different algorithms for the problem of P||Cmax.

Index Terms

Scheduling Theory, Classic Algorithms, Gantt Charts, Open Science, Reproducibility, Education, Collaboration

I. INTRODUCTION

Scheduling is one of the fundamental research subjects, which is central to virtually all scientific domains that require any kind of resource sharing. Therefore, a large body of literature exists that introduces basic scheduling algorithms for various scheduling problems [11, 5, 5, 12, 13]. Most theoretical works in scheduling research use the three-field notation α|β|γ of Graham et al. [9] for classifying scheduling problems. By using this notation, each scheduling problem can be described by the machine environment α, the job characteristics β, and the optimality criterion γ. For example, P||Cmax defines the problem of scheduling jobs on identical parallel machines, where the maximum completion time (Cmax) should be minimized, while no further job characteristics are given. One example of such job characteristics could be the moldable job model (denoted as any), i.e., in the problem P|any|Cmax [5, 11]. In the moldable model, each job can not only be executed on 1 machine, but it may be allotted to several machines (between 1 and m machines). The number of machines is selected by the scheduler, but this number of machines will not change until a job has been completed. Another example of job characteristics are job processing times that are variable and depend on environmental factors such as the position r of a job in a schedule. For example, in the P|in-tree, pj,r = ϕ(r) | Cmax problem, the processing times of jobs with in-tree precedence constraints are described by the ϕ function [14, 15].

Since scheduling problems are so fundamental to many scientific disciplines, thousands of algorithms exist for a seemingly endless list of problem variations. Among them, a significant number of scheduling algorithms can be described in the three-field notation. Several surveys on specific scheduling problems, e.g., P||Cmax, have been conducted that compare the scheduling performance of different algorithms via simulations. Although these studies are very informative for the readers, they are often hard to reproduce, as many of the building blocks are imprecisely explained and because the source code is often not provided or has become inaccessible over the years. For that reason, many algorithms cannot be compared fairly or in a scientifically sound manner, as too many details are missing.
To overcome this problem, we propose Scheduling.jl, which provides a generic and open scheduling platform, on top of which a large number of scheduling algorithms can be implemented.

In the remainder of the article, we introduce the core functionalities of the Scheduling.jl package and show an example of how to use them.

II. OVERVIEW OF SCHEDULING.JL

Scheduling.jl provides the main building blocks for implementing scheduling algorithms in their most generic form, which are Job, Machine, JobAssignment, and Schedule. A classical Job $J_j$ is defined by its processing time $p_j$ but can also be characterized by a weight $w_j$, a release date $r_j$, a due date $d_j$, or a deadline $\bar{d}_j$. A Machine $M_i$ is mainly defined by its speed. Of course, the sets of parameters used can be easily extended. The task of a scheduling algorithm is to find an assignment of jobs to machines, such that a given criterion is optimized. An assignment of jobs to machines defines the starting and the completion time of a job $J_j$ on a machine $M_i$. The final Schedule is composed of a vector of jobs, a vector of machines, and a vector of job to machine assignments. It is worth noticing that Scheduling.jl is designed to operate on exact values (rational numbers) rather than inexact ones (floating point numbers).

Once a schedule has been obtained by executing an algorithm, the package Scheduling.jl provides different optimization criteria that can be computed for a schedule, e.g., the makespan $C_{\text{max}}$, the average completion time $\sum_j C_j$, or the number of tardy jobs $\sum_j U_j$. Additionally, the package is shipped with implementations of various scheduling algorithms, in particular, for $P || C_{\text{max}}$.

In order to obtain Scheduling.jl, one needs to install the package from [https://github.com/bprzybylski/Scheduling.jl](https://github.com/bprzybylski/Scheduling.jl). The stable version can be installed by calling Pkg.add("Scheduling") and the development version by executing Pkg.develop("Scheduling").

Listing 1 presents an example of how to leverage the basic functionality of Scheduling.jl. Here, we create a set of jobs $J$ and a set of machines $M$. Then, we can apply the LPT algorithm to obtain a schedule. On this schedule, we can compute various metrics like $C_{\text{max}}$ or $\sum_j C_j$.

Scheduling.jl also provides means to visualize the resulting schedules. For example, scientists can choose to produce an image of a schedule, where it is also possible to animate the schedule creation. If desired, the schedule can also be plotted as an TikZ image, which can directly be inserted into publications.

III. USING SCHEDULING.JL: THE CASE OF $P||C_{\text{max}}$

Now, we turn our attention to the NP-hard problem $P || C_{\text{max}}$, for which Graham [8] devised two fundamental approximation algorithms, namely the LIST and the LPT (Largest Processing Time) algorithm.
Graham [8] showed that for any instance of $P|C_{\text{max}}$, LIST provides a $2 - 1/m$ approximation, while LPT improves this bound to $4/3 - 1/(3m)$. Hochbaum and Shmoys [10] devised a PTAS for this problem, by developing a dual approximation algorithm to solve $P|C_{\text{max}}$, which internally relies on solving a bin packing problem.

Although our list is far from exhaustive, we discuss several heuristics that have been proposed to solve $P|C_{\text{max}}$. França et al. [6] developed the 3-PHASE algorithm for which the authors stated that it “outperforms alternative heuristics” on their respective test instances. Similarly, Dell’Amico et al. [4] presented heuristics that are combined to compute exact solutions for various instances of $P|C_{\text{max}}$. Last, Ghalami and Grosu [7] presented a parallel implementation of the algorithm of Hochbaum and Shmoys [10]. In each of these works, the authors implemented their own interpretation of existing algorithms. They also generated their own problem instances and reported results for a subset of the instances. Neither a lack of code and meta-information is a common problem in many scientific fields when looking at the reproducibility of results. Independent researchers, who would like to continue studying heuristics for $P|C_{\text{max}}$, will have to start from scratch and create implementations and instances themselves.

We have developed Scheduling.jl to improve the reproducibility in the scheduling domain. For the problem of $P|C_{\text{max}}$, Scheduling.jl contains several algorithms that can be used to solve given instances. Besides heuristics with guarantees (i.e., LIST and LPT), Scheduling.jl also contains an implementation of the algorithm of Hochbaum and Shmoys [10] as well as an exact algorithm that was presented by Drozdowski [5].

If independent researchers now set out to compare novel heuristics to already established methods, they could simply use the source code provided. Listing 2 exemplifies how different algorithms for one specific instance of a problem can be compared. In this particular case, we created three different TiKZ files containing the Gantt charts of the schedules. Figure 1 presents these Gantt charts produced by different algorithms when solving an instance of $P|C_{\text{max}}$.

### IV. Conclusions and Future Work

We have introduced the Julia package Scheduling.jl, which is an effort to increase the reproducibility in the scheduling community. By providing basic building blocks for developing scheduling methods as well as several implementations of well-known scheduling algorithms, Scheduling.jl can serve as a foundation for developing a large variation of scheduling algorithms. The package provides easy-to-use plotting functions to easily obtain Gantt charts of computed schedules.

The package is far from complete and it should serve as a starting point for future work. So far, we have focused on providing a general development platform for implementing various algorithms. We made sure that design choice are applicable by implementing multiple algorithms for the classical problem of $P|C_{\text{max}}$ ourselves. Now, we hope that the community will contribute new algorithms to this package.
will also continue to integrating more algorithms into Scheduling.jl, starting with algorithms for which Julia code already exists, e.g., the algorithm of Bleuse et al. [2] for $(Pm,Pk)|\text{mold}|C_{\text{max}}$.

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