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Shop and batch scheduling with constraints

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This is a summary of the PhD thesis defended by the author in September 2011 at the École des Mines de Nantes (EMNantes). The thesis was advised by Narendra Jussien (EMNantes) and co-advised by Louis-Martin Rousseau (École Polytechnique de Montréal – Poly), Christelle Guéret (EMNantes) and André Langevin (Poly). The manuscript is written in French and can be obtained from `http://tel.archives-ouvertes.fr/tel-00630122/fr/` or by email from `arnaud.malapert@unice.fr`. The focus of the dissertation is to study the resolution of shop and batch scheduling problems derived from real-world applications using constraint programming. The remainder of this abstract summarizes the results of the dissertation.

In shop problems, n jobs, consisting each of m tasks, must be processed on m machines. The processing orders of tasks which belong to a job can vary: global order (flow shop); order per job (job shop); no order (open shop). We consider the construction of non-preemptive schedules of minimal makespan, which is NP-Hard for $m \geq 3$. The study and classification of models and search algorithms show that one of the major challenge of solving optimally these problems is to provide good solutions as quick as the metaheuristics. Therefore, we introduce a new algorithm characterized by its: *simplicity*, most of its components are available in constraint solvers; *flexibility*, two constraint models offer different trade-offs among propagation strength, speed and simplicity; *genericity*, it is applicable to any disjunctive scheduling problem. The algorithm relies on recent constraint filtering algorithm and (randomized) branching techniques with new upper bound heuristics. The algorithm starts with a randomized constructive heuristic (without propagation) which initializes the upper bound so that the selection and propagation of initial choices are improved. During the search, the filtering is based on the disjunctive graph model and disjunctive global constraints, whereas the branching is conducted by adding precedences to the disjunctive graph with the profile strategy. Besides, randomized restart policies combined with nogood recording allow to search diversification and learning from restarts. Indeed, nogoods are recorded at each restart to prevent exploring the same part of the search space again. Then, we introduce another model combining simple filtering methods with a new variable selection strategy inspired by the weighted degree strategy, and empirically show that the complex inference methods and search strategies can, surprisingly, often be advantageously replaced by this naive model. The naive model is frequently faster, but less robust and only adapted to our weighted degree strategy. The proposed solving technique outperforms other exact algorithms and metaheuristics published so far on a wide range of benchmarks for the open shop problem. By contrast, our approach was not able to match the results of the best exact approach for job shop problems.

A parallel batch processing machine can process several jobs simultaneously as a batch. The processing time of a batch is equal to the longest one among its jobs. Such machines are encountered in chemical, pharmaceutical and aeronautical where an oven, a drier or an autoclave is used during the process. These machines are often a bottleneck because of their long processing times. We consider the minimization of the maximal lateness for a problem derived from a real application in the aeronautical industry. A set of n jobs and one single batching machine with capacity b are given. Each job is characterized by its processing time, its due date, and its size. The machine can process several jobs simultaneously as a batch as long as the sum of the sizes of the jobs that are in the batch does not exceed its capacity b. We propose a constraint programming formulation which relies on the decomposition of the problem into finding an assignment of the jobs to the batches, and then minimizing the maximal lateness of the batches on a single machine. The problem of assigning the jobs to the batches is equivalent to the *one-dimensional bin packing problem* which is NP-hard and so is our batch processing problem. Then, once the jobs are packed into the batches, the problem of scheduling the batches is equivalent to minimizing their maximal lateness on a single machine. This problem, known as $1||L_{max}$, is polynomially solvable by applying Jackson's scheduling rule. In addition, we introduce a new constraint which uses a relaxation of the problem that yields a lower bound for the objective function to prune portions of the search space whose lower bound is bigger than the best solution found so far. The optimization components provide the optimal solution of the relaxed problem, its value and a gradient function computing the cost to be added to the optimal solution for some variable-value assignments. At each node in the search tree, the branching, inspired by bin packing problems, assigns the largest remaining job to a batch. Our approach outperforms an integer programming formulation and a branch-and-price: it solves small instances with solution times that are orders of magnitude lower; it provides better solutions in less time for large instances.

Choco is a java library for constraint programming, which can be used for teaching, research and real-life applications (`www.choco.mines-nantes.fr`). Most of the contributions reported in this thesis have been implemented and are now publicly available to the academic and industrial communities.