A general approach for exam timetabling: a real-world and a benchmark case

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1 Introduction

We discuss, model and tackle two examination timetabling problems. The first is a real-world case while the latter is a well-known benchmark problem. Both are solved with the same hyper-heuristics approach. Unlike meta-heuristics, in which the search is executed on the space of solutions, hyper-heuristics operate on a search space of heuristics [Burke et al., 2003]. Hyper-heuristics were originally introduced for automating the low-level heuristics' selection, for example by applying machine learning techniques [Burke et al., 2008]. The low-level heuristics employed in both examination timetabling cases are built so that each of them can individually solve one specific part of the problem. By combining the low-level heuristics, the particular properties of each of them can be exploited to solve the problem.

Leaving the cost function aside, both approaches only differ in the low-level heuristics.

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2 Problem Description

First, the hyper-heuristics framework is applied to a real-world examination timetabling problem at the School of Engineering of KaHo Sint-Lieven in Gent (Belgium). The duration of a typical examination schedule is 4 weeks, which corresponds to 40 time slots of four hours each. In Belgium, there is a distinction between oral and written exams. All written exams of the same subject should be organized in the same time slot, while the organization of oral exams is a bit more complex. The maximum number of examinees per time slot for oral exams is 20. This means that if, for example, 200 students take the course, at least 10 oral exams at different time slots should be organized.

The hard constraints of the KaHo examination problem are:

- a student cannot take more than one exam per time slot;
- the number of students assigned to a room cannot exceed its capacity;
- all exams should be organized within the planning horizon of four weeks.

The corresponding soft constraints are:

- All written exams of the same subject should be scheduled in the same time slot.
- Oral and written exams should not be merged into the same room.
- All oral exams should be scheduled such that the maximum number of examinees per timeslot is 20. Lecturers who take oral exams cannot examine more than one group at the same time.
- Students should have sufficient study time between two consecutive exams. At KaHo Sint-Lieven, the minimum study time between two consecutive exams for a student should be at least 3 time slots.

This problem is of particular interest since the manual planner actually needed 48 time slots to organize all exams. He needed to incorporate time slots on Saturdays into the schedule in order to arrange the exams in a 4 weeks period.

In order to compare the hyper-heuristic's performance with the state of the art, we also have applied it to the data sets of the examination timetabling track of the 2007 International Timetabling Competition (ITC 2007) [McCollum et al., 2009]. The hard constraints of the ITC 2007 exam timetabling track are:

- a student cannot attend more than one exam per time slot;
- an exam cannot be split over several rooms;
- the room's capacity cannot be exceeded;
- some exams require rooms with special properties;
- since every exam has a duration, its duration should be less than or equal to the duration of the selected time slot where it is assigned to;
- some exams should be scheduled before, after, at the same time or not at the same time as other exams.

As can be deduced from the hard constraints, the time slots have different durations. Also, the order of the exams is important. These two constraints do not apply to the KaHo problem.

The following soft constraints should be taken into account:

- two exams taken by the same student should not be scheduled on the same day or in two consecutive time slots;
- exams should be spread as much as possible;

- exams with different durations should not be assigned to the same room;
- large exams should be scheduled early in the timetable;
- some of the time slots in the examination timetable should be avoided;
- some of the rooms should be avoided for examination.

The problems have some soft constraints in common, but there are also differences. The distinction between oral and written exams at KaHo is not present in the ITC 2007 examination timetabling track. On the other hand, the ITC 2007 examination timetabling track demands that large exams should be scheduled in the beginning of the examination period, and that some of the time slots and rooms should preferably be avoided.

3 Solution Approach

A typical hyper-heuristics framework consists of a *heuristic selection* mechanism and *move acceptance* criteria [Özcan et al., 2008]. The heuristic selection mechanism that is applied in both examination timetabling cases is *simple random*. This is actually the simplest selection mechanism, since it randomly selects a low-level heuristic from a list of low-level heuristics. Concerning the move acceptance criteria, we experiment with four meta-heuristics: *simulated annealing*, *great deluge*, *steepest descent*, and *late acceptance* [Burke and Bykov, 2008].

Both problems share the same solution representation: a two dimensional matrix, of which the rows represents the rooms, and the columns the time slots. A room-time slot combination can hold several exams.

Regarding the examination timetabling problem at KaHo, the following low-level heuristics are employed:

- move a randomly chosen exam to a random room-time slot combination;
- move a randomly chosen exam to a random room within the same original time slot;
- move a randomly chosen exam to a random time slot while maintaining the original room.

The hyper-heuristic approach finds feasible solutions satisfying all the soft constraints within only 40 time slots. The best performing move acceptance criteria appear to be simulated annealing and late acceptance.

Due to the extra constraints of the ITC 2007 case, additional low-level heuristics tackling them in particular had to be introduced. On top of the low-level heuristics that were already present in the KaHo approach, the following constraints are also applied to the ITC 2007 case:

- a randomly chosen exam is moved to the same room but to a time slot that introduces no extra period penalty;
- a randomly chosen exam is moved to the same time slot but to a room that introduces no extra room penalty;
- the size of a randomly chosen exam is analyzed. If it is recognized as a large exam, it is moved to a time slot in the beginning of the examination period.

In fact, the ITC 2007 problem could also be solved with only the KaHo low-level heuristics, but preliminary experiments showed that the quality of the solutions was improved by introducing the extra low-level heuristics. Besides the extra low-level heuristics, both approaches only differ in their respective cost functions, since both problems consider other constraints. Actually, both cost functions consist of a linear combination of the violations of the soft constraints and those hard constraints that cannot be expressed in the model. The remaining parts of both applications are the same. For more details we refer to [Demeester, 2010].

4 Conclusion and Future Work

With the general approach that was originally developed for tackling a real-world problem, we obtain results that are competitive with those generated during the competition. In future research we plan to replace the simple random heuristic selection mechanism by a more intelligent one, based on for example a learning automaton [Misir et al., 2009].

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