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Large-scale timetabling problems with adaptive Tabu search

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ABSTRACT: Timetabling problems are specific types of scheduling problems that deal with assigning certain events to the timeslots. This assigning is subject to certain hard constraints that should be achieved to get a feasible timetable, as well as, soft constraints that must meet as many as possible during forming a feasible schedule. In this paper introduces an adaptive tabu search. Eleven benchmark datasets of the year 2002 are applied to show the effectiveness of the introduced algorithm. These datasets consist of 5-small, 5-medium, and 1-large dataset. As compared to other methods from previous works, the proposed algorithm produces excellent timetables, which have minor drawbacks on each medium or small problem.

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1. INTRODUCTION

In reality, the timetabling problem is a challenging task in constructing a well-behaved solution [1]. The problem's size represents the main difficulty. This difficulty includes a sizeable volume of rooms, courses, teachers, and students that are correlated in several ways throughout conditions and objectives. Thus, a huge amount of variables and constraints should take into consideration during the procedure of each solution [2]. In the problem of course-timetabling, a heuristic algorithm is applied to obtain a feasible starting solution. It begins by assigning a course to time slots. Scheduling course is the first step in the strategy of starting. Since the course involves a sizeable number of students, it is very hard to reschedule. To place a course in the best appropriate time-slots, it is recommended to construct a schedule based on a blank timetable [1]. This technique is known as Least Saturation Degree.

This paper present the problem of university course time-tabling is examined using an adaptive tabu search algorithm to enhance the initial feasible solution. Eleven benchmark datasets presented by Socha *et al.* are employed for testing this approach. The findings appear that our method can produce excellent solutions in comparison with other methods in the literature.

The structure of this paper is logically organized where the next section portrays the related works. Introduce a brief explanation of the course-timetabling problem in section 3.

The meta-heuristic algorithm and its application to the course-timetabling problem are described in section 4. Section 5 presents experimental results, and a comparison between techniques from the related work, while section 6 reports brief concluding comments.

2. RELATED WORKS

Solving problems of course timetabling and specifically enrolment- based have been proposed in the last three decades. Four categories of automatic timetabling procedure can be extracted from wide-ranging literature reviews. The first category deals with timetabling as graph problems and known as sequential methods. The second category modelling the timetable as a group of events (variables) and assigning their values (resources like rooms and teachers) to achieve several soft and hard constraints. It is known as the constraint-based method. In the third category, which is called the cluster method, the problem is partitioned into several event sets. The last category is called the meta-heuristic method, which includes different algorithms like Ant Colony optimization (ACO) , neural networks, Tabu search, simulated annealing, and genetic algorithms.

Besides, many innovative approaches were recently developed for solving timetabling problems, which involve hyper-heuristics, fuzzy, and case-based reasoning approaches (Thatchai Lutuksin and Pupong Pongcharoen 2010).

In course timetabling, the enrolment-based problem is focused, which can be partitioned into six approaches: hyper-heuristic, population-based, hybridization meta-heuristic, meta-heuristic, graph-based, and constraint-based approaches.

In practice, meta-heuristics have recently achieved great usefulness in almost solving timetabling problems. The capability of escaping from local optima and handling a wide range of constraints are the key benefits of such methods (Glover and Laguna 1993).

To work out timetable problems of a Spanish secondary school, Alvarez-Valděs et al. (2002) introduced an approach of two stages. In the first stage, a heuristic algorithm is employed to produce the early answer. Improving this answer is done in the next stage using a tabu search algorithm. The Hyper-heuristic approach is applied in another work by Burke et al. (2003) to move up the generalization level of the computerized timetabling systems using a tabu search algorithm. The system was established to solve the problems of nurse scheduling and to achieve the course timetabling instances. Moreover, the course timetabling problem of enrollment-based was also solved using tabu –based memetic algorithm, as introduced by Turabieh and Abdullah (2009). Incorporating a tabu list enhanced the effectiveness of the solutions, as well as, controlling the selections of neighborhood structures using the memetic algorithm. In Vietnam, Nguyen et al. (2010) presented the tabu Search algorithm as a solution to a practical problem of university timetabling. Nine practical cases have been tested in that work. Further work focused on the lecture lengths at the University of Kebangsaan Malaysia, faculty of engineering, to resolve the university-course timetable, using multi-neighborhood structures and tabu search (Al_Tarawneh and Ayob, 2011). In contrast, the winner of the 2004 International Timetabling Competition applied an approach of three stages to solve problems of course timetabling. Out of 20 examples in the competition, the approach has achieved 13 best results. Feasible solutions, as an enhancement stage for the problem of course-timetabling, were obtained by Frausto-SolÍs et al. (2008), using a simulated annealing algorithm. Two types of neighbourhood structures were the basis of this enhancement. In another work designed by Sara et al. (2004) to answer the post-enrollment course-timetabling (PE-CTT), a simulated annealing algorithm was also applied within a metaheuristic approach. As compared to previous works, this work showed improved results regardless of the fact of using a somewhat straightforward single-step algorithm, against using complicated multi-step algorithms of most of the previous solvers. For complicated cases of university course timetabling, Obit & Landa-Silva (2010) introduced a non-linear great deluge algorithm. It is extended version of the traditional great deluge algorithm.

In contrast, a hybrid of Kempe-chain neighbourhood structure with a great delug algorithm was introduced by Shaker and Abdullah (2009) to resolve the timetabling problem. This approach can compete with other available approaches. Afterwards, the great deluge algorithm is combined with an electromagnetic-like mechanism to obtain a new meta-heuristic approach that was introduced by Salwani et al. (2012). The most important goal of the hyper-heuristic approach is to build up a general optimization approach that can be reused in diverse problem cases, as well as, a range of various problems. Lastly, Ayob and Jaradat (2009) introduced to apply a novel method for answering problems of university course-timetabling, which consists of two ant colony systems with hybrids. The first system combined the ant colony system and a simulated annealing algorithm, while the second system combined the ant colony system with a tabu search algorithm.

3. DESCRIBING THE PROBLEM

Timetabling problem can be described by assigning course materials to a collection of rooms and timeslots, taking into account a group of soft constraints and hard constraints. The problem involves two stages to obtain the final solution. The first stage is to attain a feasible solution depending upon satisfying the hard constraints. The second stage is to obtain a better solution by improving the primary solution through a reduction in the soft constraints as much as possible. Thus, the final solution can compete with other relevant solutions in the literature.

Socha et al. (2002) introduced a set of problem cases, which are used in this paper to test our algorithm. Firstly, the hard constraints are listed in the following:

- At any time, assigning only one course to the student.
- The room should achieve the course feature requirements.
- No more students can attend the course greater than the room capacity.
- For each room, assigning only one course is to the same timeslot.

Secondly, the soft constraints are listed as follows:

- The last day-timeslot should have a course scheduled for the student.
- At least two consecutive courses should assign to the student.
- On a day, only one course should the student have.

Lastly, the problem includes:

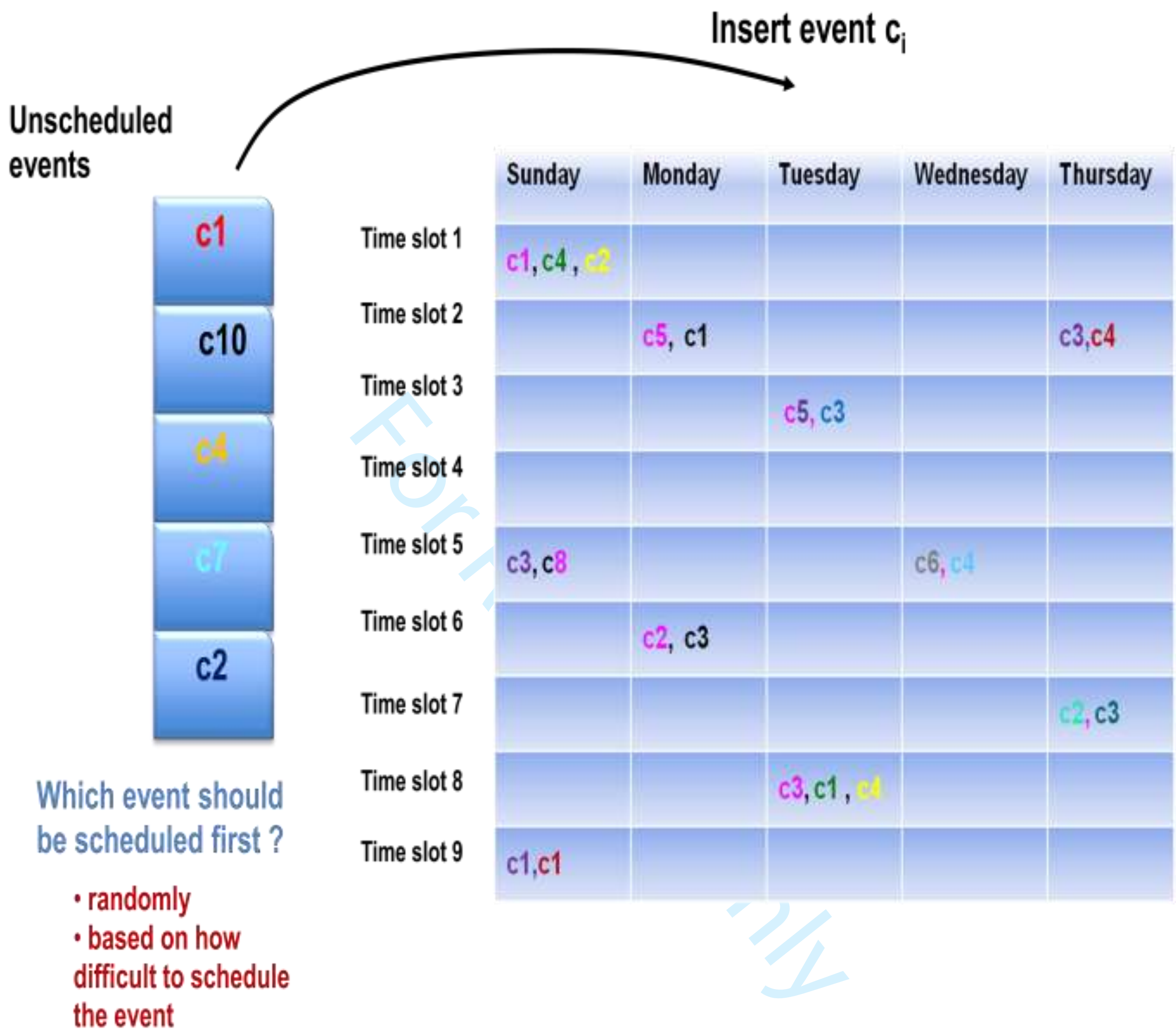
- No. of courses = N, e = {$e_1,\ldots,e_n$}.
- No. of timeslots = 45.
- No. of rooms = R.
- No. of room features = F.
- No. of students = M.

The final solution (the aim of the problem) is to achieve a feasible timetable (the hard constraints) with minimizing the soft-constraints infringement.

Socha et al. (2002) presented a case of post-enrollment course-timetabling problems, which is used in this paper. The datasets are partitioned into three classes based on their size: large, medium, and small. Besides, eleven case studies are considered: 1 large, 5 mediums, and 5 small (see section 5).

4. THE ALGORITHM

The work is partitioned into constructing and improving algorithms. The constructing algorithm is performed using the least saturation degree algorithm to get



an early solution. Next, in the improving algorithm, the tabu search algorithm is employed to decrease the soft-constraints infringement (improvement).

Four neighbourhood structures are utilized:

1- **Nb1**: Randomly choose a particular course and progress to a feasible time-slot, which can produce the smallest cost.
2- **Nb2**: Randomly select a room. Also, randomly select two courses for that room. Next, swap timeslots.
3- **Nb3**: Randomly select two times. Next, swap timeslots.
4- **Nb4**: Randomly select a particular time and swap it with another time, in the range between 0 and 44, which can produce the smallest penalty cost.

4.1 CONSTRUCTING ALGORITHM

The first stage of the work includes the production of the early solution, which can achieve the hard constraints without any accounting for the soft constraints infringement. A least saturation degree algorithm is employed in this stage. First, the events beside smaller number available rooms that seems hardly scheduled, are selected. The algorithm is terminated if a feasible solution is obtained. Else, the neighbourhood moves (N1 and/or N2) are performed to achieve feasibility. N1 is employed for a specific number of repetitions. Next, the algorithm is terminated if a feasible solution is achieved. Else, the algorithm continues using the N2 neighbourhood structure for a specific number of repetitions. Note that all case studies are examined before the improvement algorithm is employed since the solutions must be made feasible first (see fFig. 1).

Figure 1 constructive heuristics (the least saturation degree)

4.2 IMPROVEMENT ALGORITHM

The second stage includes using a set of neighbourhood structures that previously defined (Nb3, Nb4). During this stage, no hard-constraint infringement is completely allowed. Adaptive Tabu Search algorithm is applied to improve the early solution. Figure 2 shows the pseudo-code of the used algorithm.

Pseudo code :

```
SolTS ← Solution;
SolbTS ← Solution;
f(SolTS) ← f(Sol);
f(SolbTS)← f(Sol)
Set TL = 12, called Tabu List;
Set no. of iterations;
Set iteration ← 0;
Set Optimal Value =(according the user)
do while (penalty > Optimal Value and iteration < 750000)
Apply neighbourhood structure Nbi where i ∈ {Nb3,Nb4} on SolTS, called Temp-Sol-TSi ;
Get the cost function f(Temp-Sol-TSi );
Choose the best option from the options available Temp-Sol-TSi where i∈{Nb3,Nb4} call new solution SolTS*;
Maintain the generating neighborhood structure Sol-TS*, called NTS;
Moved = False ;
while !Moved
if (f(SolTS*) < f(SolbTS))
SolTS ← SolTS* ;
SolbTS ← SolTS*
penalty= f(SolTS);
Moved = True ;
endif
set check = 0, called co;
set min= penalty;
iteration +=1 ;
if penalty >= min ;
co +=1 ;
if co >=1000; then
TL - =2 ;
set co =0 ;
set min = penalty ;
end if
else
set co=0 ;
set min=penalty ;
end if ;
if (N-T-S is not tabu)
Push N-T-S into tabu list, TL ;
end
end   ;
return SolbTS ;
```

Figure 2: Pseudocode for Adaptive Tabu Search algorithm

Adaptive Tabu search depends on the tabu list and the penalty cost, by checking the changing of this penalty cost, if this changing is still invariant for a period of iterations (1000 iterations) the tabu list is reducing automatically (-2) otherwise the tabu list remains constant. This procedure will continue until the tabu list equals 2, figure 2.

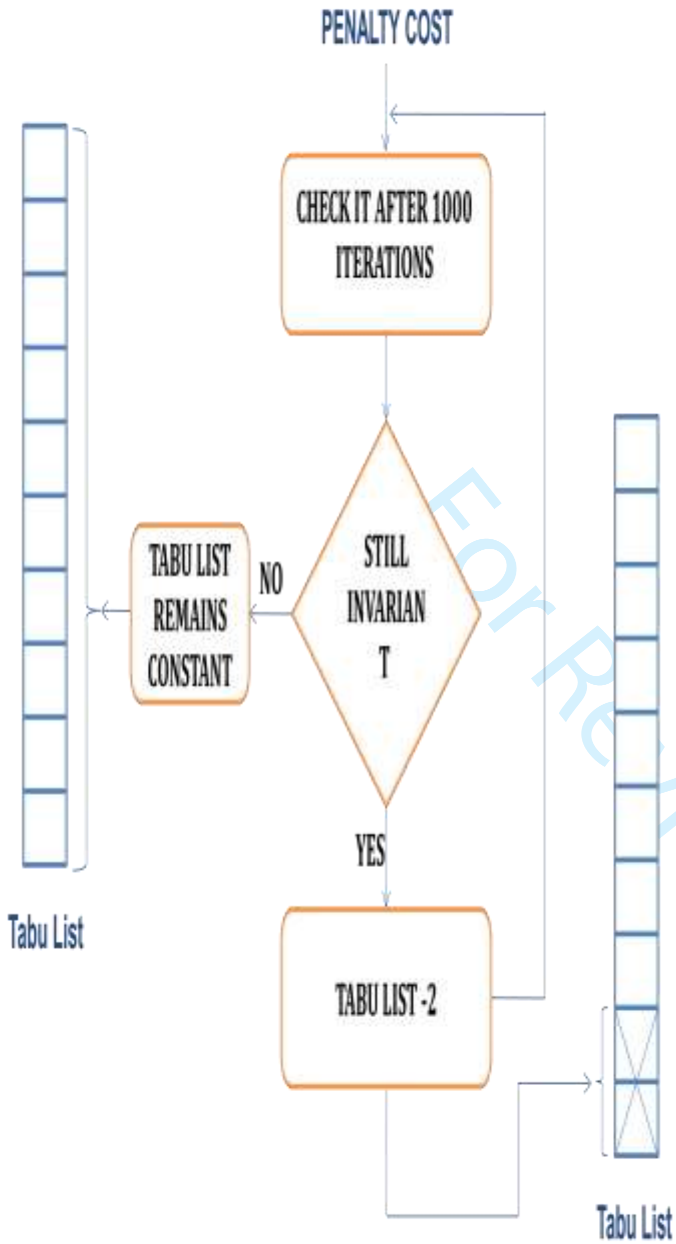


Figure 2 adaptive tabu list

5. EXPERIMENTAL RESULTS

Our algorithm is programmed in VB.NET using a PC of Win. 7, 1.7GHz CPU, and 2G RAM.

Socha (2002) datasets are used for evaluating our algorithm efficiency. The datasets include 1 large, 5 mediums, 5 small instances that are available at http://iridia.ulb.ac.be/~msampels/tt.data/.

The experiments for the course timetabling problem discussed in this paper were tested on the benchmark course timetabling problems that need to schedule (100-400) courses into a timetable with (45) timeslots corresponding to (5) days of (9) hours each, whilst the room features satisfying and room capacity constraints also satisfying. Table 1 lists the parameter values that define the types.

Table 1 shows the parameter values for the different types of course scheduling problems.

Type	*Small*	*Medium*	*large*
No. of courses	100	400	400
No. of rooms	5	10	10
No. of features	5	5	10
No. of students	80	200	400

On the eleven timetabling instances, we compare our technique to other algorithms in two parts: first, comparing with other literature that used tabu search even if it hybrid with another algorithm (table 2). Second part comparing with other works that used another algorithm (table 3).

Data set	Our	Alg1	Alg2	Alg3	Alg4	Alg5	Alg6	Alg7	Alg8
S1	___	___	___	___	___	___	___	___	___
S2	___	___	___	___	___	___	___	___	___
S3	___	___	___	___	___	___	___	___	___
S4	___	___	___	___	___	___	___	___	___
S5	___	___	___	___	___	___	___	___	___
M1	97	175	78	**55**	146	242	317	372	150
M2	91	197	92	**70**	173	161	313	419	179
M3	**65**	216	135	102	267	265	357	359	183
M4	95	149	75	**32**	169	181	247	348	140
M5	**50**	190	68	61	303	151	292	171	152
L	**347**	912	556	653	1166	___	___	1068	720

Alg1: Abdullah et al. (2012) combines an electromagnetic-like mechanism (EM) and the great deluge algorithm (GD)

Alg2: Shaker. (2010) Great Deluge and *Tabu Search*

Alg3: Hamza & Salwani (2009) Incorporating Tabu Search into Memetic Approach

Alg4: Burke et al.(2003a) a hyper-heuristic used tabu search

Alg5: Abdullah, Burke and McCollum composite neighbourhood structure with a randomised iterative improvement algorithm

Alg6: Abdullah et al. (2007b) Variable neighbourhood search with tabu

Alg7: Burke et al. (2007)

Alg8: Ayob and Jaradat (2009) hybrids Ant Colony Systems with the Tabu search (ACS-TS)

Table 2. Compare our results with the results of other Tabu search

Data set	Our	Alg1	Alg2	Alg3	Alg4	Alg5	Alg6	Alg7
S1	—	—	—	—	—	—	—	—
S2	—	—	—	—	—	—	—	—
S3	—	—	—	—	—	—	—	—
S4	—	—	—	—	—	—	—	—
S5	—	—	—	—	—	—	—	—
M1	97	254	174	227	139	175	143	124
M2	91	258	184	180	92	197	130	117
M3	65	251	188	235	122	216	183	190
M4	95	321	180	142	98	149	133	132
M5	50	276	132	200	116	190	169	73
L	347	1072	994	—	615	912	825	424

Table 3. comparing our results with other approaches in the literature

Data set	Alg8	Alg9	Alg10	Alg11	Alg12	Alg13	Alg14
S1	—	—	—	—	—	—	—
S2	—	—	—	—	—	—	—
S3	—	—	—	—	—	—	—
S4	—	—	—	—	—	—	—
S5	—	—	—	—	—	—	—
M1	180	140	117	**9**	338	236	243
M2	176	130	121	**15**	326	158	325
M3	219	189	158	**36**	384	261	249
M4	150	112	124	**12**	299	176	285
M5	196	141	134	**3**	307	147	132
L	—	876	645	**208**	100%Inf	296	1138

Alg1: Salwani and Hamza (2008) Genetic Algorithms and Local Search.

Alg2: AI-Betar et al. (2012) A MultiSwap Algorithm.

Alg3: Jat and Yang (2008) a memetic with genetic algorithm

Alg4: Yang and Jat (2011) Genetic Algorithms With Guided and Local Search Strategies.

Alg5: Abdullah et al. (2010a) Hybridization algorithm. Electromagnetic-like mechanism with a great deluge

Alg6: Abuhamdah and Ayob (2010) Round Robin (RR) Algorithm.

Alg7: Al-Betar et al. (2010) harmony search algorithm.

Alg8: Karami and Hasanzadeh (2012) hybrid genetic algorithm (HGA).

Alg9: Obit and Silva (2010) the non-linear great deluge Algorithm.

Alg10: Ayob and Jaradat (2009) hybrids Ant Colony Systems with the Simulated Annealing (ACS-SA).

Alg11: Sara et al. (2012) Simulated Annealing.

Alg12: Abdullah et al. Variable Neighbourhood Search.

Alg13: Abdullah Hamdan (2008): A Hybrid Approach.

Alg14: Asmuni et al. Fuzzy Multiple Heuristic.

Conclusion

The aim of this paper was to develop a tabu search algorithm to contain adaptive tabu list to compatible with the state of solution for the course timetabling problem. This has been accomplished, demonstrating that tabu search is a viable solution to the course scheduling problem. In most cases, tabu search outperforms the traditional method. In addition, the usage of aspiration and stopping criteria are critical to the algorithm's effectiveness. Tabu search heuristics are also known to be sensitive on parameter selection. As a result, fine-tuning the parameters may yield even better outcomes. Future work includes further analysis individual components of the contribution to develop a tabu search algorithm.

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