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A new hybrid algorithm for university course timetabling problem using events based on groupings of students ☆

Rakesh P. Badoni, D.K. Gupta *, Pallavi Mishra

Department of Mathematics, Indian Institute of Technology Kharagpur, Kharagpur 721302, India

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A B S T R A C T

In this paper, a new hybrid algorithm (NHA) combining genetic algorithm with local search and using events based on groupings of students is described to solve the university course timetabling problem. A list of events such as lectures, tutorials, laboratories and seminars are ordered and mutually disjoint groups of students taking them are formed in such a way that once a student is selected in any group, he is excluded from further selection in other groups. The union of all the events taken by all the students of each group is formed. The number of events in each group is termed as its group size whose upper bound is restricted by the total number of timeslots and can be reduced to the maximum number of events per student. The above process of forming groups is repeated till the size of each group is reduced within this bound by not choosing those events which are common for all the students in the group. Now, the genetic algorithm with local search (GALS) is applied on a number of benchmark problems. The experimental results show that our algorithm, NHA, is able to produce promising results when compared with the results obtained by using GALS and other existing algorithms.

1. Introduction

The development of automated timetables also known as the allocation of the resources for tasks under predefined constraints, reduces time for its creation, minimizes errors and satisfies as nearly as possible a set of desirable objectives. These problems involve timetabling for educational (course and examination), employees, sports events, transportation, etc. These are important and challenging problems encountered in computer science (CS), operation research (OR) and artificial intelligence (AI). Here, we are concerned with the university course timetabling problem which maximizes the possibility of allocations and minimizes the violation of constraints. These are high dimensional multi-objectives combinatorial optimization problems belonging to a class of NP-complete problems. A university course timetabling problem consists in assigning a set of events (lectures, tutorials, laboratories, seminars, etc.) into a limited number of time slots and rooms in such a way as to minimize violation of a predefined set of constraints. A general and effective solution for timetabling is very difficult as it involves problem diversity, constraints variances and changed requirements from university to university. As a result, the construction of their solution involving a weekly schedule of events acceptable to all people involved and satisfying hard as well as soft constraints as efficiently as possible is extremely difficult and grows exponentially with size. Hard constraints are those which can not be violated under any circumstances whereas soft constraints can be relaxed. For example, a hard constraint implies that a student can not be physically present in two different events at the same time. An example of a soft constraint can be to avoid the last time slot of the day for an event. Accordingly, a violation of soft constraints requires penalizing the underlying solution with some penalty value that is added to the cost of the solution. Thus, the aim of timetabling problem is usually to obtain a feasible solution that does not violate any hard constraints and minimizes its cost when penalty of soft constraints violations is also taken into consideration. As many combinatorial optimization problems, their solutions are generally obtained in the construction and the improvement phases. The algorithm starts with an empty timetable in construction phase and gradually constructs a timetable by adding one event into it. In general, the initial timetable is usually of poor quality and consists of many constraints violations. The improvement phase is used after achieving a complete timetable from construction phase and tries to gradually improve the quality of complete timetable. In the

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* Corresponding author. Tel.: +91 3222 283652 (O); fax: +91 3222 255303x282700.

E-mail addresses: rakeshbadoni@gmail.com (R.P. Badoni), dkg@maths.iitkgp.ernet.in (D.K. Gupta), mshrpal@gmail.com (P. Mishra).

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improvement phase, some events of the schedule may be altered hoping to achieve a better timetable.

The university course timetabling problems are extensively studied by a number of researchers (Cambazard, Hebrard, O'Sullivan, & Papadopoulos, 2012; Carter, 1986; Lewis, 2008; Nothegger, Mayer, Chwatal, & Raidl, 2012; Yang & Jat, 2011) and a number of approaches are proposed for their solutions. They have systematically categorized these problems, presented their mathematical formulations and described both exact and heuristic algorithms for their solutions. Some of the most important methods used are sequential methods, cluster methods, constraint-based methods and generalized search methods. The hybrid evolutionary algorithms, metaheuristics, multi-criteria approaches, case based reasoning techniques, hyper-heuristics and adaptive approaches to solve them are described in (Petrovic & Burke, 2004). One approach (Abdullah & Turabieh, 2008; Wijaya & Manurung, 2009) converted it to a graph in which the nodes correspond to lectures and the edges between the nodes correspond to the constraints and used graph coloring algorithms. The graph coloring algorithm assigns a limited number of colors to the nodes of the graph in such a way that no two nodes connected by an edge have the same color. The number of colors correspond to the number of available time slots. The techniques of constraint based reasoning (Cambazard et al., 2012; Wijaya & Manurung, 2009) were also successfully used for the solution of the university course timetabling problem. These problems are represented as the Constraint Satisfaction Problems (CSPs) and then solved by using techniques used for solving CSPs. An approach in which constraints were iteratively added to the CSPs and solved by backtrack algorithm is described in Banks, Van Beek, and Meisels (1998). Several metaheuristic approaches inspired from nature and apply nature-like processes to solutions or populations of solutions to get optimal solutions of these problems are ant colony optimization (Rossi-Doria et al., 2003; Nothegger et al., 2012), evolutionary algorithms (Rossi-Doria et al., 2003; Yang & Jat, 2011), simulated annealing (Abdullah, Shaker, McCollum, & McMullan, 2010; De Causmaecker, Demeester, & Vanden Berghe, 2009) and tabu search (Lü & Hao, 2010; Wilke & Ostler, 2008). Burke, McCollum, Meisels, Petrovic, and Qu (2007) employed tabu search within a graph based hyper-heuristic and applied it to the course timetabling benchmark datasets with the aim of raising the level of generality by operating on different problem domains. In Abdullah et al. (2010), a Dual-sequence Simulated Annealing algorithm is employed as an improvement algorithm. The Round Robin algorithm is used to control the selection of neighborhood structures within it. A genetic algorithm combined with a sequential local search for the curriculum based course timetabling problem which also used the two phased approach, i.e., the construction phase and the improvement phase is presented in Abdullah, Turabieh, McCollum, and Burke (2009). A guided search genetic algorithm for their solutions is discussed in Yang and Jat (2011). By grouping similar lectures in a timetabling problem, a decomposed heuristic is described in De Causmaecker et al. (2009). In Rossi-Doria et al. (2003), the performance of the implementations of five different metaheuristics on a university course timetabling problem are compared unbiasedly. For fairness, all the algorithms implementing them use a common solution representation and a common local search. Lewis and Paechter (2005) presented a grouping genetic algorithm for feasible solution of university course timetabling problem. They used the definition of grouping (Falkenauer, 1998) as one where the task is to partition a set of objects U into a collection of mutually disjoint subsets u_i of U such that $\cup u_i = U$ and $u_i \cap u_j = \phi,\ i \neq j$, and according to a set of problem-specific constraints that define valid and legal groupings. The NP-hard bin packing problem defined for a finite set of items of various sizes is a well known example of it. Here, the task is to partition all of the items into various bins such that the total size of all the items in any one bin does not exceed the bin's maximum capacity with the minimum number of bins used. Further, when genetic algorithm with grouping is applied to solve university course timetabling problem, the representations and resulting genetic operators are used in such a way that allow the groupings of objects to be propagated as they are the building blocks of the problem and not the particular positions of any one object on its own. They also considered feasibility and optimality as two separate subproblems. They suggested that the performance of any algorithms satisfying hard and soft constraints might be different. This means, what may be a good approach for finding feasibility may not necessarily be good for optimality of solutions. They further suggested that algorithms comprising two stages, the first to find feasibility and the second to optimize soft constraints whilst staying in feasible regions of the search space might be the more promising approach. In their work, the set of events represents the set of objects to partition and the groups are defined by the timeslots. So, a feasible solution is therefore one in which all the events $|E|$ are partitioned into $|T|$ feasible timeslots $t_1, t_2, \ldots, t_{|T|}$. A feasible timeslot t_i $(1 \leqslant i \leqslant |T|)$ is one in which none of the events in t_i conflict and all the events in t_i can be placed in their own suitable room. We have considered the set of students as the set of objects to partition into mutually disjoint student groups and then events taken by these student groups are assigned to timeslots and rooms by using GALS. This is applied in two phases, construction phase and improvement phase. In the first phase, the goal is to achieve feasibility by satisfying all hard constraints whereas in the second phase it is to optimize soft constraints whilst maintaining the feasibility of the solution.

In this paper, a new hybrid algorithm (NHA) combining genetic algorithm with local search and using events based on groupings of students is described to solve the university course timetabling problem. A list of events such as lectures, tutorials, laboratories and seminars are ordered and mutually disjoint groups of students taking them are formed in such a way that once a student is selected in any group, he is excluded from further selection in other groups. The union of all the events taken by all the students of each group is formed. The number of events in each group is termed as its group size whose upper bound is restricted by the total number of timeslots and can be reduced to the maximum number of events per student. The above process of forming groups is repeated till the size of each group is reduced within this bound by not choosing those events which are common for all the students in the group. Now, the genetic algorithm with local search (GALS) is applied on a number of benchmark problems. The experimental results show that our algorithm, NHA, is able to produce promising results when compared with the results obtained by using GALS and other existing algorithms.

This paper is organized as follows. Section 1 is the introduction. In Section 2, our university course timetabling problem and its mathematical formulation is described. Genetic algorithm with local search (GALS) is discussed in Section 3. The proposed new hybrid algorithm (NHA) combining GALS and using events based on grouping of students, instead of individual student, to get an optimal solution is given in Section 4. In Section 5, the results of the newly designed algorithm along with its comparison with the GALS and the other state-of-the-art algorithms considered from the literature are displayed. Finally, conclusions are included in Section 6.

2. University course timetabling problem

In this section, a university course timetabling problem and its mathematical formulation is described. It is a multidimensional assignment problem, in which events (lectures, tutorials,