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Robust Time Table Scheduling Problems Using Constraint Programming

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***Abstract*—This paper describes a scheduling system to fulfill the timetabling needs of various institutions. It can handle both the constraints of timetabling problems and constraints specific to the given problems. It will have the flexibility of allowing both manual and automatic assignments of duties. The initial phase tackles the allocation of resources i.e the problem of assigning available faculties to various courses. The second phase tackles the problem of assigning consistent time slots to courses. The problems are tackled such that we get optimized results.**

***Index Terms*—I. INTRODUCTION, II.BACKGROUND, III. COURSE SCHEDULING SYSTEM,IV.HEURRISTICS, V.CONCLUSION**

I. INTRODUCTION

The designing, construction and maintenance of course timetables for various universities or other schools can be an extremely complex problem whose difficulty grows exponentially with its size. A manual solution typically require much effort. The process of scheduling involves various formulations of the problem's settings in order to find an optimal and efficient solution.

The problem instance constitutes one in which both general and specific constraints need to be handled efficiently with as much flexibility as possible. Various features are added to this system in order to increase the usability and reliability of the system. Some of these features are:

- Preferences for courses by the faculty.
- Scheduling is done such that no two courses are handled at the same time.
- Choices between manual assignment as well as automatic assignment can be made.

II.Background

A Constraint satisfaction problem is composed of a finite set of variables, each of which is associated with a finite domain, and a set of constraints that restrict the values that the variables can simultaneously take. The task is to assign a value to each variable in the problem satisfying all the constraints. Variation of algorithm have been devised to deal efficiently with CSPs encompassing a broad field of solving methods.One instance of timetabling problem is the problem of scheduling courses in an educational institution. In general, one must assign instructors to courses, and then assign the courses to classrooms and time slots. The objective is to obtain a timetable of courses-professors-classrooms- times over a prefixed period, satisfying a set of constraints of various types. The manual solution of the timetabling problem usually requires several days of work. Hence the automated system is undeniable.Most of the early techniques for solving the timetabling problem were based on a successive augmentation, that I, a partial timetable is extended, course by course, until all the courses have been scheduled. They are simple search procedures based on backtracking and in heuristics such as scheduling the most constrained course first. The complexity of the second phase has led to efforts in solving it automatically instead of manually.

III COURSE SCHEDULING SYSTEM

A detailed description of the system is described in the

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following section.

- A) The Problem:

  The main problem is to automate the process of scheduling courses, for a given institution. In addition to the general constraints imposed on course scheduling, there are constraints specific to this institution.

- B) Modeling:

  The scheduler is split into two phases; each phase is modeled as a CSP. The input to the system are files that specify

  1. A set of Faculty member
     a. Name of the faculty member
     b. Work load for the term at hand
     c. Course preferences
     d. Time preferences
     e. An indication if the faculty member needs a break between classes.
  2. A set of offered courses where each element includes the
     a. Course node
     b. Course name
     c. Optional fields
        i. Faculty that has been designated to each of the courses
        ii. Time slot when the course will be taught
  3. A schedule of the previous corresponding term where each element includes a
     a. Course node and
     b. Time at which the course was scheduled
  4. A set of correlated courses where each element consists of a set of courses that, because of their logical correlation, cannot be taught at the same time.
  5. A set of implicit constraints that restricts the time slots of courses. More specifically, these constraints are the following:
     a. Courses taught by the same professor should not overlap in time.
     b. Undergraduate courses can be scheduled at any valid time slot, but graduate courses, as well as undergraduate courses that meet with graduate courses, can only be scheduled at certain times in the late afternoon and evening.

The output of the system is an optimal valid timetable of courses, faculty assignments, and time slots. A detailed description of each of the phases follows.

C) Phases 1: Faculty-Course assignment

The first CSP tackles the problem of assigning faculty to courses. This problem is, in general, tackled manually in timetabling systems. The constraints on the assignment of courses to professors are:

- A course is assigned to only one professor.
- Each professor should be assigned the number of courses specified in the work load of the given term.

The objective of this phases is to find an optimal assignment of courses to faculty members. Such an assignment has to satisfy all the constraints and be minimal in terms of total penalties. Penalties are specified for pairs of faculty and courses; the lower(higher) the penalty is the more(less) willing, or qualified, the faculty is to teach the corresponding course. The scheduler reads from the faculty file their preferences of courses they would like to teach for the term at hand. The preferences are expressed in a table form, with each record consisting of a penalty value and a list

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of courses. A professor lists only the courses that are within his/her ability to teach, assigning lower penalties to those that are most preferred and higher penalties to those that are least preferred. To preserve the fairness of the algorithm, the range of penalty value must be the same for all faculty members.

The search procedure looks for a global assignment of courses to faculty that minimizes the total penalty. The system uses a branch and bound algorithm to reduce the search space and find the optimal solution in a reasonable amount of time. The variables of the problem are the faculty member in the list. At each step of the procedure, M courses for the current professor are considered. Their penalty is added to the accumulated penalty, and at this point the search continues or is bounded; if the penalty accumulated so far is larger than the minimal total penalty obtained in a previous solution, then that branch of the search space can be pruned because it will not contain any assignment of courses to faculty with a better total penalty. Once an optimal solution is found, the system will halt waiting for the approval from the user. If the user approves, the system moves to the second phase, If the user does not approve, then a modification to the input should be made. Then phase 1 will be repeated and a new solution is found.

D) Phase 2: time-course assignment

This phase tackles the problem of assigning consistent time slots to courses. This implies assigning a time slot to each courses so that all faculty time preferences, course correlation restrictions, and general constraints are satisfied. In our system, time slots can be considered as grouped lectures: all weekly meetings of one class are considered as one slot, and a half.

The optimization criteria is the discrepancy over previous comparable term. This means that the optimal schedule is one that is as close as possible to the previous corresponding term schedule. This optimization criteria is problem specific and is related to the university's procedure for classroom assignment. For all the courses that the department schedules at exactly the same time as the reference semester, the classroom used then will automatically be used now. Only changes to the old schedule have to be dealt with: new courses or a course that is scheduled at a different time requires a search for an available classroom in a campus-wide database. If no classroom is available for any of those courses, the timetable where the minimum number of changes from the old schedule occur, this minimizing the possibility of running into a classroom conflict.

The variables in this second CSP are the courses, whose domains are all possible time slots. The constraints are the following:

- Courses taught by the same professor should not overlap in time.
- Faculty preferences have to be satisfied. This includes the time range they specify for their courses and the possible need for breaks between classes.
- Courses that are correlated cannot be scheduled at the same time.

The goal of this phases is to obtain a valid schedule, i.e. an assignment of time slots to courses that satisfies all the constraints. The number of valid timetables, in the absence of inconsistencies, is very large.

Once the solution to the first phase is accepted, the system compiles all the courses that are not TBA (To Be Assigned) and begins the process of assigning times to them. The first step in the procedure is time preferences *consistency checking,* a preprocessing of faculty time preferences to make

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sure there is no initial inconsistency. Each faculty specifies their preferred time slots as well as their wishes in having temporal gaps between classes. Sometimes, there are inconsistencies in the specification, such as specifying only 3 time slots as preferences with gaps between classes while the work load is 3 courses.

- **Stage 1: Consistency checking**

At this stage, the system determines if the specified time slots for each professor allow for sufficient slot expansion, where these are defined as follows.

Definition 1 A slot expansion for a set of time slots is the maximum number of courses that can be scheduled in these time slots taking into consideration overlaps of time slots, gaps between classes, and constraints on time range of courses.

Definition 2 Sufficient slot expansion. A set of time slots S has a sufficient slot expansion for a faculty F if the work load of F is no more than the slot expansion of S taking into consideration F's preference for gaps between classes and the constraints on courses assigned to F.

In other words, this stage detects if finding times for a specific professor's courses is impossible with the current preferences of the faculty member. For a professor's preferences to pass this consistency phase, the time preference have to satisfy the inequality

Slot expansion ≥ course load

In case a faculty member does not satisfy this condition, the system notifies the user that the faculty's time preferences need to be relaxed. Otherwise, the second stage starts.

- **Stage 2: Assigning time to courses**

At this stage, each course is assigned a time slot that satisfies faculty time preferences, course correlation restrictions, and general constraints. Also, the assignment should be as closes as possible to the previous corresponding term schedule.

Definition 3 A slot usage is the number of courses scheduled at each time slot.

Slot overuse occurs when more courses are assigned than was assigned for the same slot in the previous term.

The system reads the reference file and obtains a table of slot usage for the reference term. A systematic constraint satisfaction method is applied to search through the space of schedules, coupled with branch and bound to optimize the solution in terms of the number of changes from the reference timetable. The variables of the problem are the courses. Each course has to be assigned a timeslot which has to be consistent with previously assigned ones and with all the constraints. The procedure is initially called to start with the first course in the list. At each step of the procedure, a time slot is considered for the giver course. The overuse, if any that would occur if the course is assigned the current slot is added to the accumulated overuse, and at this point the search continues or is bounded. If the overuse accumulated is larger than the minimal total overuse obtained in a previous solution, then that branch of the search space can be pruned. The optimal solution obtained is one with a minimum slot overuse.

IV Heuristics

Initially, the system processed courses in the order in which they appeared in the input file. This order is based on the course number where undergraduate courses has lower numbers than graduate courses. However, since graduate courses have a smaller range of time slots at which they can be scheduled, tests were performed where the system orders the list of courses to place graduate ones at the top of the list, hence applying the variable ordering heuristic of most-

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constrained-first. It was found that by scheduling the most constrained courses first, the search space is pruned much quicker since most inconsistencies arise during the first nodes of the search tree, which results in huge performance gains.

Value ordering was also tested in a similar way. Evening time slots, in our domain, have more demands than day time slots. This is because graduate courses, which equals in number to undergraduate courses, are restricted to evening slots which are less than day slots. Experiments were conducted by considering the most conflict-prone values first, but the response of the system was actually very similar in both cases of value ordering.

A different approach to value ordering was also tested for the purpose of enhancing the output. Several instances of the problem's solution space could be scored the same by our optimization function, and the search algorithm would output the first of those encountered. Hence, we enforced an ordering on the time slots such that the most preferred one is chosen first. This will guarantee that the output from the set of optimal solutions is the one with the most preferred slots.

V CONCLUSIONS

The system presented in this paper exhibits several differences with timetabling programs from the literature. In our system, time slots can be considered as a collection of meetings for a course over a week, where each of those individual meetings is often referred to in the literature as a lecture. By grouping weekly lectures of courses into time slots, the system not only resolves the so called multiple sections problem, but we have also reduced the size of the domain while including the common constraint that all lectures of a given courses should be taught at the same time and evenly distributed during the week.

While many other timetabling programs leave out some features to decrease complexity, our system is able to manage many objectives successfully. Non-standard characteristics of timetabling systems that are all considered in our course scheduling program are:

- Division of the problem into two easier to tackle, relatively independent, phases.
- Tackling of the faculty-course assignment problem.
- Presence of constraints associated with correlated courses.
- The flexibility of fixing a course to a specific faculty or a specific time slot.
- Management of simultaneous lectures.
- Existence of overlapping time slots.
- Accommodating faculty preferences in terms of courses to teach and time slots.
- A domain-dependent efficient treatment of the classroom assignment problem.
- Optimization of the solutions.

Future work includes investigating more elaborate techniques that will allow the system to scale to larger domains. This includes employing advanced systematic search algorithms coupled with branch and bound, and constraint relaxation techniques.

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