Fuzzy Methodologies for Automated University Timetabling Solution Construction and Evaluation

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Abstract

This thesis presents an investigation into the use of fuzzy methodologies for University timetabling problems. The first area of investigation is the use of fuzzy techniques to combine multiple heuristic orderings within the construction of timetables. Different combinations of multiple heuristic ordering were examined, considering five graph-based heuristic orderings - *Largest Degree*, *Saturation Degree*, *Largest Enrolment*, *Largest Coloured Degree* and *Weighted Largest Degree*. The initial development utilised only two heuristic orderings simultaneously and subsequent development went on to incorporate three heuristic orderings simultaneously. A central hypothesis of this thesis is that this approach provides a more realistic scheme for measuring the difficulty of assigning events to time slots than the use of a single heuristic alone. Experimental results demonstrated that the fuzzy multiple heuristic orderings (with parameter tuning) outperformed all of the single heuristic orderings and non-fuzzy linear weighting factors. Comprehensive analysis has provided some key insights regarding the implementation of multiple heuristic orderings.

Producing examination timetables automatically has been the subject of much research. It is generally the case that a number of alternative solutions that satisfy all the hard criteria are possible. Indeed, there are usually a very large number of such feasible solutions. Some method is required to permit the overall quality of different solutions to be quantified, in order to allow them to be compared, so that the 'best' may be selected. In response to that demand, the second area of investigation of this thesis is concerned with a new evaluation function for examination timetabling problems. A novel approach, in which fuzzy methods are used to evaluate the end solution quality, separate from the objective functions used in solution generation, represents a significant addition to the literature.

The proposed fuzzy evaluation function provides a mechanism to allow an overall decision in evaluating the quality of a timetable solution to be made

based on common sense rules that encapsulate the notion that the timetable solution quality increases as both the *average penalty* and the *highest penalty* decrease. New algorithms to calculate what is loosely termed the 'lower limits' and 'upper limits' of the proximity cost function for any problem instance are also presented. These limits may be used to provide a good indication of how good any timetable solution is. Furthermore, there may be an association between the proposed 'lower limit' and the formal lower bound. This is the first time that lower limits (other than zero) have been established for proximity cost evaluation of timetable solutions.

Chapter 1

Introduction

1.1 Background and Motivation

The problem of timetabling examinations and courses is of much interest and concern to academic institutions. The basic problem is to allocate a time slot and a room for all events (exams, lectures, seminars, tutorials) within a limited number of permitted time slots and rooms in order to find a feasible timetable. This assignment process is subject to 'hard' constraints which *must* be satisfied in order to get a feasible timetable. An example of such constraint is that no student is required to attend two events at the same time.

In addition, it is also important to build a *good quality* lecture timetable that considers not only the administration requirements, but also takes into account lecturers' and students' preferences. It is generally desirable (but not essential) to satisfy these preferences and, as such, they are termed 'soft' constraints.

As this task is time consuming and tedious to carry out manually, much effort has been directed over the last few decades to generate timetables automatically. With a large number of events needing to be assigned to resources (time slots and rooms) and a list of constraints (both hard and soft) needing to be addressed, there are a large number of potential solutions to this problem. Furthermore, the process of generating timetables is complex, with a number of key decision points. Two major decision points are how to construct feasible solutions and how to evaluate their effectiveness (essentially, how to decide which of several alternative solutions is 'the best'). Many factors need to be considered in both these key decision areas, with much information being available. To date, there has been relatively little research into how the available information can be combined, with the goal of achieving better solutions.

Since Zadeh introduction the notion of fuzzy sets in 1965 (Zadeh, 1965), fuzzy methodologies have been widely utilised in a number of decision support contexts. Indeed, fuzzy methodologies have made significant impact in many areas, including consumer technologies such as fuzzy logic auto-focus digital cameras and fuzzy washing machines. It has been shown that such fuzzy approaches can be successful in combining multiple sources of information (Zimmermann, 1996). The motivation for the work presented in this thesis is to investigate whether the use of fuzzy methodologies could be of benefit in automating the decision making process in the construction and evaluation of solutions to the examination timetabling problem. Although the main focus of this thesis is on examination timetabling, the solution construction technique was also applied to course timetabling.

1.2 Aims and Scope

The first area of investigation, described in Chapters 4 to 6, is an exploration of how fuzzy techniques can be employed to combine multiple heuristics within the construction of timetables. During the process of construction, the order in which exams are assigned to time slots has been shown to have a major effect on the eventual solution. An assessment of how difficult it is to place a given exam into a timetable (in effect, some measure of how hard it is to satisfy the constraints relevant to the particular exam) is often used to guide the order of placement. The usual strategy is to place the most difficult exams first, on the basis that it is better to leave the easier exams until later in the process when there are fewer time slots remaining. There are many different criteria that may be used when assessing this difficulty.

A common approach has been to employ graph based heuristics (a heuristic is an approximate rule or a 'rule-of-thumb' (Burke and Kendall, 2005, Chap. 1)) to provide a quantitative indication of difficulty. This measure is then used to determine the order in which the exams are assigned into the timetable and, hence, are referred to as 'heuristic orderings'. Examples of such heuristics are the number of other exams in conflict with the given exam, the number of students enroled on each exam, etc. Detailed descriptions of these heuristic orderings are given in Section 2.2.2. In this thesis, for the first time, fuzzy methodologies are used to combine multiple heuristics *simultaneously* in order to provide a measure of the difficulty of placing each exam. This measure is then used to order (rank) the exams for assignment. Various combinations of heuristics are investigated in the construction process. To investigate the wider applicability of this novel fuzzy approach, the techniques were also applied to the domain of course timetabling.

The second major area of investigation, described in Chapters 7 and 8, is the use of fuzzy methodologies in the evaluation of the quality of timetable solutions. It is generally the case that a number of alternative solutions that satisfy all the hard criteria are possible. Indeed, there is usually a very large number of such feasible solutions. Some method is required to permit the overall quality of different solutions to be quantified, in order to allow them to be compared, so that the 'best' may be selected. In principle, a range of different measures of quality might be used to evaluate how well a given solution satisfies the various soft constraints. Such a measure is termed an 'objective function' which can be used either to evaluate a range of solutions manually, or can be used in an automated process to determine the best solution. Again, in principle, a number of alternative objectives can be combined into a single objective function or can be kept separate in a multi-objective framework. The trade-offs between different objectives underpin the motivation for studying multi-objective methods. In this thesis, fuzzy methodologies are employed to evaluate the quality of solutions using a number of identified key criteria, *after* a variety of alternative solutions have been produced.

There are a number of objectives that were addressed in order to accomplish the primary aim of the research which can be outlined as follows:

1. to investigate the use of fuzzy techniques to combine, initially, two heuristics simultaneously in ordering events in examination timetabling;
2. to compare the fuzzy combination of heuristics with a non-fuzzy approach;
3. to expand the investigation to consider three heuristics simultaneously;
4. to investigate the wider applicability of the technique through its application to course timetabling;
5. to explore the use of fuzzy techniques in the evaluation of constructed solutions; and
6. to establish the boundaries of the fuzzy evaluation method in order to determine how good a solution actually is.

1.3 Overview of this Thesis

The remaining Chapters of this thesis are divided into three parts. Part I describes the timetabling problem in general, distinguishing examination and course timetabling, and goes on to describe the current state of research in examination timetabling and the basics of fuzzy set theory. In Part II (which covers Chapters 4 to 6) the implementation of fuzzy approaches in constructing solutions to examination timetabling is described. Part III (which covers Chapter 7 and 8) presents a novel fuzzy approach to evaluate the quality of timetables. The individual Chapters of this thesis are summarised below.

Chapter 2 provides a description of educational timetabling problems and presents a review of different algorithms and approaches developed in attempting to automate the generation of solutions to University timetabling problems. The examination timetabling benchmark data sets that are used in this research are also described together with a description of objective functions currently used in the evaluation of timetable solution quality. Chapter 3 provides a description of fuzzy set theory and fuzzy reasoning. This is a self-contained Chapter that provides the material necessary for understanding the basic features of the fuzzy techniques used in this thesis. This self-contained Chapter is intended for readers who are not familiar with fuzzy methodologies.

In Chapter 4, a new fuzzy approach that uses two heuristic orderings simultaneously to measure the difficulty of assigning exams into time slots is developed and tested on the benchmark data sets. The aim of this initial study was to investigate the effects of using multiple heuristic ordering as compared to a single heuristic ordering. Chapter 5 presents a comparison of fuzzy and non-fuzzy multiple heuristic ordering approaches. The technique implemented in Chapter 4 is further enhanced to include the use of three heuristic orderings simultaneously. In Chapter 6, a generalisation of the technique is investigated. First, the suitability of fuzzy multiple heuristic ordering in course timetabling is assessed. Then, an exploration was carried out of all possible combinations of orderings using either two or three heuristics simultaneously, from a set of five heuristics. Finally, a range of methods to tune the fuzzy models utilised in these techniques were investigated.

Chapter 7 presents a new fuzzy evaluation function for examination timetabling, based on both how good the constructed timetable is as a whole and on how good the solution is for individual students. In Chapter 8, two algorithms for determining lower boundaries of the quality of solutions based on the underlying structure of the problem are presented. Finally, Chapter 9 provides some concluding remarks and suggestions for future research that arise from the work presented in this thesis.

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