UNIVERSITI PUTRA MALAYSIA

HYBRID GENETIC ALGORITHM FOR UNCAPACITATED UNIVERSITY EXAMINATION TIMETABLING PROBLEM

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Abstract— This study proposes a Hybrid Genetic Algorithm (HGA) for university examination timetabling problem (UETP). UETP is defined as the assignment of a given number of exams and their candidates to a number of available timeslots while satisfying a given set of constraints. This study presents a solution for an uncapacitated UETP where five domain-specific knowledges in the form of low-level heuristics are used to guide the construction of the timetable in the initial population. This study propose to use 10% from the total exams to be scheduled with the combination of Largest Degree (LD), Largest Weighted Degree (LWD) and Largest Enrollment (LE) while another 90% is the combination of Saturation Degree (SD) and Highest Cost (HC). The main components of the genetic operators in a Genetic Algorithm (GA) will be tested and the best combination of the genetic operators will be adopted to construct a Pure Genetic Algorithm (PGA). The PGA will then hybridised with three new local optimisation techniques, which will make up the HGA; to improve the solutions found. The first local optimisation technique focuses on inserting a scheduled exam to a new timeslot, second technique is concerned with the swapping of two scheduled exams between two different timeslots and the third technique deals with interchanging the timeslots in the timetable. These new local optimisation techniques will arrange the timeslots and exams using new explicit equations, if and only if, the modification will reduce the penalty cost function. All proposed algorithms are coded in C using Microsoft Visual C++ 6.0 as the compiler. The performance of the proposed HGA is compared with other metaheuristics from literature using the Carter set of benchmark problems which comprises of real-world timetabling problem from various universities. The computational results show that the proposed HGA outperformed some of the metaheuristic approaches and is comparable to most of the metaheuristic approaches.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Master Sains

ALGORITMA GENETIK HIBRID BAGI MASALAH JADUAL WAKTU PEPERIKSAAN UNIVERSITI TIDAK BERKAPASITI

Oleh

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Kajian ini mencadangkan Algoritma Genetik Hibrid (HGA) untuk menyelesaikan masalah jadual waktu peperiksaan universiti (UETP). UETP ditakrifkan sebagai penjadualan peperiksaan dan calon-calon peperiksaan tertentu kepada beberapa slot masa yang disediakan dengan memenuhi set kekangan yang ada. Kajian ini membentangkan penyelesaian untuk UETP tidak berkapasiti dimana lima domain pengetahuan khusus dalam bentuk heuristik peringkat rendah telah digunakan untuk membantu pembinaan jadual waktu diperingkat awal. Kajian ini mencadangkan penggunaan 10 peratus daripada jumlah peperiksaan yang ingin dijadualkan dengan kombinasi Darjah Terbesar (LD), Darjah Timbangan Terbesar (LWD) dan Pendaftaran Terbesar (LE) sementara 90 peratus adalah kombinasi daripada Darjah Penyerapan (SD) dan Nilai Terbesar (HC). Komponen utama di dalam operasi genetik akan diuji dan kombinasi terbaik daripada operasi genetik dalam Algoritma Genetik (GA) ini akan digunakan dalam pembinaan Algoritma Genetik Asli (PGA). PGA akan dihibrid dengan tiga teknik pengoptimuman yang baru untuk membentuk HGA bagi meningkatkan hasil penyelesaian. Teknik pengoptimuman yang pertama memberi tumpuan kepada memasukkan peperiksaan yang sudah dijadualkan kepada satu slot masa yang baru, teknik kedua menumpu pada proses tukar ganti dua peperiksaan yang sudah dijadualkan kepada dua slot masa yang baru dan teknik ketiga membincangkan tentang teknik tukar ganti dua slot masa didalam jadual waktu peperiksaan. Teknik-teknik pengoptimuman yang baru ini akan membuat penyusunan yang baru kepada slot masa atau peperiksaan dengan menggunakan persamaan yang baru, jika dan hanya jika, pengubahsuaian itu akan mengurangkan nilai kos penalti. Kesemua algoritma yang dicadangkan ini dikod dalam C menggunakan Microsoft Visual C++ 6.0 sebagai penyusun. Prestasi HGA yang dicadangkan ini akan dibandingkan dengan kaedah metaheuristik lain yang menggunakan set masalah penanda aras Carter yang mana merupakan masalah jadual waktu sebenar dunia dari pelbagai universiti. Hasil keputusan kajian ini menunjukkan bahawa HGA dapat mengatasi beberapa kaedah metaheuristik dan setanding dengan kebanyakan kaedah metaheuristik yang lain.

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I certify that a Thesis Examination Committee has met on 28 December 2015 to conduct the final examination of Suhada Ishak on her thesis entitled "Hybrid Genetic Algorithm for Uncapacitated University Examination Timetabling Problem" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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LIST OF ABBREVIATIONS

ACO	-	Ant Colony Optimisation
BPP	-	Bin Packing Problem
CEA	-	Combine Evolutionary Algorithm
CHIP	-	Constraint Handling in Prolog
CLM	-	Complete Local Search With Memory
COP	-	Combinatorial Optimisation Problem
CSAET	-	Clonal Selection Algorithm
DA	-	Developmental Approach
EA	-	Evolutionary Algorithm
ETP	-	Examination Timetabling Problem
FES	-	Exam Scheduler
FHC	-	Fixed length Heuristic Combination
GA	-	Genetic Algorithm
GDA	-	Great Deluge Algorithm
GHH	-	Generic Hyper-Heuristic
GPAuc	-	Genetic Programming by Evolving Agent's Binding Function
GRASP	-	Greedy Randomised Adaptive Search Procedure
HC	-	Highest Cost
HGA	-	Hybrid Genetic Algorithm
IGA	-	Informed Genetic Algorithm
INAET	-	Immune Network Algorithm

IT	-	Interchange Timeslots
LD	-	Largest Degree
LE	-	Largest Enrollment
lse-91	-	London School of Economics, London, UK
LWD	-	Largest Weighted Degree
M1PC	-	Modified One Point Crossover
M2PC	-	Modified Two Point Crossover
MA	-	Memetic Algorithm
ME	-	Moving Exams
MESP	-	Modular Exam Scheduling Problem
MMAS	-	Max–Min Ant System
MOC	-	Modified Order Crossover
NHC	-	N-times Heuristic Comnination
NP	-	Non-Polynomial
NSAET	-	Negative Selection Algorithm
RCL	-	Restricted Candidate List
RO	-	Random Ordering
SA	-	Simulated Annealing
SD	-	Saturation Degree
SE	-	Swapping Exam
SSR	-	Steady-State Replacement
sta-83	-	St. Andrew's Junior High School, Toronto, Canada
TS	-	Tabu Search

TSP	-	Traveling Salesman Problem
UDSM	-	University of Dar es salaam
UETP	-	University Examination Timetabling Problem
UPM	-	Universiti Putra Malaysia
VDHC	-	Violation Directed Hierarchical Hill Climbing
VHC	-	Variable length Heuristic Comnination
VRP	-	Vehicle Routing Problem
P_{pop}	-	Population Size
P_c	-	Crossover Rate
P_m	-	Mutation Rate
p_s	-	Probability of Selection
$\sigma_{k,i}$	-	the value of the total number of common students between an exam e_k with all other exams scheduled in a timeslot, t_i .
$\mu_{i,j}$	-	value of the total number of common students between two timeslots, t_i and t_j

CHAPTER 1

INTRODUCTION

1.1 Introduction

Timetabling concerned in assigning objects (eg. people, vehicles, machines or exams) subject to a certain number of constraints in a pattern of time or space. There are many examples of scheduling and timetabling such as scheduling of employees' shifts and working hours, transit route for urban transit scheduling problem, scheduling of sports or business events and constructing timetables for exams and courses in educational institutions. The third edition Cambridge Advance Learner's Dictionary defines timetable as 'list of the times when events are planned to happen, especially the times when buses, trains and planes leave and arrive. In this study, attention will be given to the university examination timetabling problem (UETP). The construction of university timetabling, particularly course and examination timetabling is a common difficult task, face by all tertiary education institutions in every semester.

Nowadays, many education institutions are introducing to the concept of the cross-faculty. This will allow the students to have much greater flexibility in enrolling courses that they want to take as well as giving a much greater choices to them. The examination timetable will be more difficult to construct when the percentage of enrollment at the university is increasing every year. For instance, in Universiti Putra Malaysia (UPM), a total of 7,643 students registered for final examination in the first semester, of 2013/2014 have to be fitted into 1,153 exams over two weeks period. Consequently, the UETP is a difficult combinatorial optimization problem which has to be tackled manually by the examination officers in a university which often required a couple of weeks of hard labor. Furthermore, the results are often not satisfied because some students need to sit for two or more exams at the same time (clashed exams) and multiple examinations in one day which may caused the students to not have enough time to revise for the exams. Hence, it is important to construct a good quality examination timetable that is flexible and fulfill the requirement of universities, lectures and students. This motivates us to carry out the studies to this problem.

According to Abdullah (2006), the basic terminologies used in UETP are as follows:

1. Event : an activity to be scheduled, for instance, exams and courses
2. Timeslot (period) : the duration in which events can be scheduled
3. Resource: resources required for the events, for instance, equipments and facilities.
4. Constraints: the requirement to schedule the events, for instance, the number of timeslots allowed
5. Individuals: person who involved in the activity
6. Conflict: a common person should not be scheduled at more than one event simultaneously

As this task is challenging and requires a long time to carry out manually, a wide variety of studies has been conducted over the last few decades to construct an automatic system for examination timetabling problem. Various methods have been investigated such as graph based sequential techniques, constraint based techniques, and meta-heuristic method (especially tabu search, genetic algorithms, ant algorithms, memetic algorithms, artificial immune algorithms and simulated annealing) to solve this problem. Detailed discussions on the solution methods will be given in Chapter 2.

UETP can be categorized as either capacitated or uncapacitated examination problem. In the capacitated UETP, room capacities to allocate the exams are taken into consideration and the number of students sitting for the examination must not exceed the available seats of the room. Whereas in the uncapacitated UETP, room capacities are not considered.

1.2 Problem Statement

The UETP can be seen as: given a set of exams, $E=\{e_1,e_2,...,e_m\}$, a set of students, $S=\{st_1,st_2,st_3,...,st_s\}$ and a set of enrollments, the problem is to assign the exams to a set of timeslots $T=\{t_1,t_2,t_3,...,t_n\}$, which satisfied the constraints. The constraints in the UETP are usually divided into two categories: hard constraints and soft constraints. The hard constraints are those which cannot be violated under any conditions in order for the timetable to be feasible. The commonly used hard constraints are:

i. Students are not allowed to sit for more than one exam simultaneously.
ii. Total number of students sit for the exam must not exceed the room capacity.

On the other hand, the soft constraints are those we desire to meet, but not absolutely necessary. The most common soft constraint in the UETP literature is to spread out the exams during the examination period so that the students are not over loaded and they also have enough time to do revision during examination week. To improve the quality of the examination timetable, we must minimize the violation of the soft constraints. But, it is impossible that all the soft constrains can be completely satisfied because some are contradicting to each other. More details regarding the hard and soft constraints is given in Section 4.2, Chapter 4. The overall objectives of this problem are to build an examination timetable that fulfills the hard constraints and at the same time to minimize the soft constraints cost.

1.3 Objectives of Studies

The main goal of this study is to design a Hybrid Genetic Algorithm (HGA) for solving UETP. We want to investigate how a GA when hybridized with three new local optimization techniques can improve the overall quality of the solution. The specific objectives of this study are:

i. **To identify the best operator for Pure Genetic Algorithm (PGA) operators in solving the UETP.**

   In order to satisfy the students' need, a GA is developed to solve the UETP. The main components of the genetic operators in a GA will be tested and the best combination of the genetic operators will be used to construct the GA to solve UETP. Detailed discussions will be given in Chapter 4.

ii. **To develop a HGA to improve the solution quality of UETP**

   The quality of a timetable is measured using a penalty cost function that calculate the ability to spread students's exam throughout the available timeslots with the minimum cost. This cost is calculated in terms of how well the exams with common students are spaced. In this study, HGA with three new local optimisation techniques is used to find the optimal solutions so that all the exams can be spread over the timetable given by the institution. These three new local optimisation techniques will be discussed in detailed in Chapter 4.

iii. **To validate the performance of the HGA with different methodologies applied in this domain using the results obtained from the benchmark data.**

   This study will investigate the performance of the proposed algorithms using the Carter benchmark. The computational results obtained will be compared with other metaheuristic approaches from the past literature.

1.4 Scope and Limitations

As mention earlier, the complexities in UETP arise since there are different types of constraints, some of which contradict from one to another. In this study, attention will be given to uncapacitated UETP and tested on a wide range of real world timetabling problem called the Carter benchmarks dataset. This dataset can be found at http://www.cs.nott.ac.uk/~rxq/data.htm. Solving the UETP is a challenging task. Below listed the difficulties faced:

- The UETP is a NP-hard problem. According to Garey and Johnson (1979), in the computational complexity theory, NP-hard is a class of problems informally " at least as hard as the hardest problem in NP".

- The main objective of UETP is firstly to construct a conflict-free timetable in the available timeslots provide by higher institutions that satisfy the hard constraint. Secondly is to reduce the penalty function by spreading students exams as evenly as possible over the timetable. These two objectives are sometimes contradict from one to another. To find the trade off between these two objectives reminds a challenge.
- Often in reality there are more constraints than those we are considering in this study. For example, the allocated number of seats per period should not be exceeded the capacity of the rooms.

1.5 Overview of the Thesis

This thesis consists of six chapters. In this current chapter, we present the introduction, problems statement, scope and limitation in solving the UETP, and also the objectives of this study. The remaining of this thesis is organized as follows:

Chapter 2 explores the literature in solving the UETP. We reviewed a variety of methods from the literature which include constraints-based approaches, graph-based approaches and metaheuristic approaches.

Chapter 3 introduces an overview of the standard GA where each representation: integer, binary and matrix representation is discussed in detailed. Besides, each main component used in a GA is also being explained in detailed.

Chapter 4 discusses the main components of genetic operators for the proposed GA used in this study. Three new local optimization techniques are discussed in detail at the end of this chapter. Computational comparisons to find the best combination of GA's operators for solving the UETP were examined at the beginning of Chapter 5. This best combination of GA is then hybridized with three new local optimizations techniques and was tested on the benchmark uncapacitated examination datasets called Carter benchmarks. The computational results and discussions are explained. In addition, the computational results will be compared with the previous published results from the literature. Finally, the conclusion and research directions for future work are given in Chapter 6.

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