FUZZY-LOGIC MULTI-AGENT SYSTEM FOR SOLVING COURSE TIMETABLING PROBLEMS

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ABSTRACT

Course timetabling problems are defined to assign a set of courses in suitable timeslot and room subject to a set of constraints. This research aims to solve the course timetabling problems of Universiti Malaysia Sabah Labuan International Campus (UMSLIC). In UMSLIC, course timetable is manually prepared by timetabling officer. The timetabling process is cumbersome as it involves different kinds of elements such as students, lecturers, courses, timeslots and rooms. Therefore, it is very difficult for timetabling officer to produce a feasible course timetable manually. Usually, they will go through several times of drafts and discussions to make sure the final timetable is ready-to-use. However, the outcomes are often infeasible timetables. Besides, timetabling officer does not take those students who retake subject into consideration during the timetabling process. Once the timetable is officially published, those students need to deal with the lecturer personally. This research presents a framework which integrates fuzzy logic and multi-agent system to generate feasible course timetable. The main algorithm used in the proposed framework is Sequential Constructive Algorithm. The concept of sequential constructive algorithm is to schedule a set of events based on the heuristic orderings. There are different types of heuristic orderings and this research only uses three of them: Largest Degree (LD), Largest Enrolment (LE), and Saturation Degree (SD). Fuzzy Logic is applied to combine multiple heuristic orderings and generate three different fuzzy approaches: Fuzzy LDLE, Fuzzy SDLE, and Fuzzy SDLD. The fuzzy approaches are used to generate initial feasible solutions and further improve the quality of the solutions. The performance between the fuzzy approaches are compared to investigate which of them solves UMSLIC course timetabling problems well. After that, develop the proposed framework with integrating the fuzzy approaches with multi-agent system. The main objective of the proposed framework is to investigate how the communication between fuzzy approaches generates a high quality and feasible timetable for UMSLIC. Besides, the framework is also used to conduct experiments with benchmark datasets to investigate the applicability of the framework. The experimental results show that the proposed framework produced comparable results to the literature.

ABSTRAK

FUZZY-LOGIC MULTI-AGENT SYSTEM UNTUK MENYELESAIKAN MASALAH PENJADUALAN KURSUS

Masalah penjadualan didefinisikan sebagai pengurusan kuliah dalam slot masa dan bilik kuliah yang sesuai untuk mengelakkan pertindihan antara kursus. Tujuan kajian ini adalah menyelesaikan masalah penjadualan kuliah Unversiti Malaysia Sabah Labuan International Campus (UMSLIC). Di UMSLIC, jadual kuliah dihasilkan oleh pegawai jadual kuliah secara manual. Proses penghasilan jadual kuliah adalah kompleks kerana melibatkan pelbagai jenis faktor seperti pelajar, pensyarah, kursus, slot masa dan bilik kuliah. Oleh yang demikian, proses pembinaan jadual kuliah secara manual adalah satu cabaran untuk pengawai jadual kuliah. Biasanya, draf dan perbincangan dijalankan beberapa kali untuk memastikan jadual kuliah dibina tanpa melanggar syarat-syarat proses penjadualan kuliah. Walau bagaimanapun, jadual kuliah dibina secara manual biasanya tidak boleh digunakan. Selain itu, pegawai jadual kuliah tidak mempertimbangkan pelajar yang mengambil kursus semula semasa proses penghasilan jadual kuliah. Selepas jadual kuliah diterbitkan secara rasmi, pelajar perlu menyelesaikan masalah pertindihan antara kursus dengan pensyarah secara peribadi. Kajian ini mencadangkan rangka kerja (framework) yang menggabungkan "fuzzy logic" dengan kerangka "Multi-Agent System" (MAS) untuk menghasilkan jadual kuliah yang praktikal dan berkualiti. Algoritma terutamanya digunakan di dalam kajian ini adalah "Sequential Constructive Algorithm". Konsep "Sequential Constructive Algorithm" adalah menyusun kursus berdasarkan pesanan heuristik (heuristic ordering). "Sequential Constructive Algorithm" mengandungi pelbagai jenis pesanan heuristik tetapi kajian ini hanya menggunakan tiga daripadanya: "Largest Degree" (LD), "Largest Enrolment" (LE), dan "Saturation Degree" (SD). "Fuzzy Logic" digunakan untik menggabungkan pelbagai pesanan heuristik dan membina tiga jenis fuzzy pendekatan: Fuzzy LDLE, Fuzzy SDLE, dan Fuzzy SDLD. Fuzzy pendekatan digunakan untuk menubuhkan penyelesaian permulaan yang praktikal dan seterusnya meningkatkan kualiti penyelesaian. Pembandingan prestasi pesanan heuristik dilaksanakan untuk mengkaji jenis fuzzy pendekatan yang boleh menyelesaikan masalah penjadualan UMSLIC secara terbaik. Selepas itu, kerangka MAS diintegrasikan dengan fuzzy pendekatan. Objektif terutama adalah untuk mengkaji bagaimana komunikasi antara pelbagai jenis fuzzy pendekatan dapat menghasilkan jadual kuliah yang berkualiti. Di samping itu, eksperimen dijalankan dengan menggunakan "dataset benchmark" untuk mengkaji kebolehgunaan rangka kerja bagi menyelesaikan data yang berbeza. Hasil kajian eksperimen menunjukkan rangka kerja yang dicadangkan dapat menghasilkan penyelesaian yang setanding dengan hasil kajian penyelidik lain.

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LIST OF ABBREVIATIONS

UMSLIC	-	Universiti Malaysia Sabah Labuan International Campus
FMSH	-	Fuzzy Multiple Sequential Heuristics
MAS-FMSH	-	Multi-Agent System incorporates with Fuzzy Multiple Sequential Heuristics
LD	-	Largest Degree
LE	-	Largest Enrolment
SD	-	Least Saturation Degree
LCD	-	Largest Coloured Degree
WLD	-	Weighted Largest Degree
RO	-	Random Ordering
IH1	-	Largest Degree, Local Search and Tabu Search
IH2	-	Saturation Degree, Local Search and Tabu Search
IH3	-	Largest Degree, Saturation Degree, Local Search and Tabu Search
IH4	-	Constraint Relaxation Approach
M1	-	Move one
M2	-	Move two
Fuzzy LDLE	-	Fuzzy Largest Degree and Largest Enrolment
Fuzzy SDLD	-	Fuzzy Saturation Degree and Largest Degree
Fuzzy SDLE	-	Fuzzy Saturation Degree and Largest Enrolment
CLP	-	Constraint Logic Programming
BC-FC	-	Backtracking with Forward Checking
SA	-	Simulated Annealing
GD	-	Great Deluge
GA	-	Genetic Algorithms
BTMK	-	Information Technology and Communication Department
BPA	-	Academic Service Division
PPIB	-	Knowledge Enhancement Courses
KOKUM	-	Co-Curricular Courses
IC_{ic}	-	IndividualCourse matrix

CT_{ct}	-	CourseTimeslot matrix
CR_{cr}	-	CourseRoom matrix
CC_{xy}	-	CourseCourseConflict matrix
OOP	-	Object-oriented programming
HC	-	Hard constraint
SC	-	Soft constraint
FRBS	-	Fuzzy Rule-Based System
FLC	-	Fuzzy Logic Controller
COG	-	Centre of Gravity Method
COS	-	Centre of Sums Method
BOA	-	Bisector of Area
UC	-	unscheduledCourses
SC	-	scheduledCourses
FC	-	failedScheduledCourses
FCL	-	Fuzzy Control Language
RC	-	RescheduledCourses

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CHAPTER 1

INTRODUCTION

1.1 Research Background and Motivation

Timetabling problems are defined as combinatorial problems which generate a feasible timetable by organizing a set of events in a limited number of resources such as time slots and rooms subject to a set of constraints (Asaju La'aro Bolaji, 2014). Timetabling problems are common in our daily life as they involve in a variety of areas such as academic institution, transportation, healthcare institute and so forth. For academic institution, it consists of three categories: school timetabling problem, course timetabling problem, and examination timetabling problem (Schaerf, 2003).

The main goal of this research is to solve a real-world problem which is course timetabling problems of Universiti Malaysia Sabah Labuan International Campus (UMSLIC). In course timetabling problem, there are two types of constraints which are hard constraints and soft constraints. Hard constraints are used to determine the feasibility of the timetable. A feasible timetable indicates that it must be clash-free and without any violation of hard constraints. One of the common hard constraints is no students are assigned to attend more than one course at the same time slot. While soft constraints are used to measure the quality of the timetable, it is not necessary to satisfy all the soft constraints but reduce them as many as possible in order to improve the quality of the timetable. For instance, a student should not attend only a course in a day. As there are a lot of universities around the world, different universities use different data and enforce different sets of policy and regulations, therefore, it is difficult to find an ordinary solution to solve the real-world university course timetabling problem (Jonasson and Norgren, 2016).

As mentioned above, hard constraints play the most crucial role to define the feasibility of a timetable. All the hard constraints are equally important in a timetabling problem. Research (Zimmermann, 1996) has proved that fuzzy approaches managed to integrate numerous sources of information successfully such as fuzzy washing machine and auto-focus cameras. It means the fuzzy approach is very beneficial when dealing with a number of constraints. It motivated (Asmuni *et al.*, 2009) to implement fuzzy logic to consider multiple sequential heuristics for generating high quality of timetable for course and examination timetabling problems. There are three different fuzzy approaches: Fuzzy LDLE, Fuzzy SDLE, and Fuzzy SDLD. The results proved that all the fuzzy approaches can produce very high quality of feasible solutions. The details of the fuzzy approaches and the introduction to fuzzy logic will be discussed in Chapter 2.

This research is inspired by (Asmuni *et al.*, 2005) to extend the implementation of fuzzy multiple sequential heuristics to improve the quality of timetable. The purpose is to evaluate the performance of the fuzzy approaches (Fuzzy LDLE, Fuzzy SDLE, and Fuzzy SDLD) on improving the quality of timetables. This research names the fuzzy approaches as FMSH. In order to achieve the objective, there are two different phases in FMSH: construction and improvement phases. In construction phase, each fuzzy approach is used to generate a feasible timetable without considering the violations of the soft constraints. After a feasible timetable is produced, it undergoes the improvement phase which implements Hill Climbing with Monte-Carlo acceptance criteria. The results generated by each of the fuzzy approach are used to compare their performance in solving the course timetabling problems. Further explanation on the development of FMSH is described in Chapter 4.

In (Ouelhadj Djamila, 2009), a multi-agent system is defined as a group of intelligent agents interact with each other to solve a common problem. The objective of a multi-agent system is to provide a dynamic environment which supports coordination, cooperation, and robustness to the unexpected changes. This allows the agents to efficiently integrate with other agents and achieve the global objectives of the problem. Multi-agent systems have been successfully implemented to optimize

a wide range of applications especially timetabling problems. More details can be referred in Section 2.6.

(Obit *et al.,* 2017) proposed a multi-agent system incorporates with hyper-heuristics to solve course timetabling problems. The idea of hyper-heuristic is to use a heuristic choosing heuristic (E. Burke *et al.,* 2003). In (Obit *et al.,* 2017), it contained three different low-level heuristics and each hyper-heuristic agent could select one of the low-level heuristics to improve the quality of solutions. The result proved that the cooperation between low-level heuristics performed beyond single low-level heuristic. Hence, it inspired this research to form a multi-agent system that allows the fuzzy approaches of FMSH working together (MAS-FMSH). The purpose of MAS-FMSH is to investigate if MAS-FMSH performs better than individual FMSH. Although this research aims to solve UMSLIC course timetabling problem, both FMSH and MAS-FMSH are also used to solve a benchmark course timetabling problem (Socha, 2002).

1.2 Problem Statement

i. How effective is UMSLIC's method generating course timetable?

In UMSLIC, the course timetable is developed by timetabling officer manually. The distribution of the set of courses in a suitable room and slot under consideration of the constraints make the scheduling process cumbersome. Additionally, the produced timetable could be unfeasible and hence prolong the scheduling process by taking extra procedures and amendments until a feasible timetable is generated. Therefore, it is a time-consuming task and the current method is not effective enough to handle such a burdensome process. Besides, UMSLIC's timetabling officer stated that they do not take those retake students into considerations. Those students need to arrange with their lecturer personally in order to avoid the conflict. Therefore, the final version of timetable could be unfeasible to some of the students.

ii. How to obtain the most optimal quality of timetable in using fuzzy multiple sequential heuristics?

The implementation of fuzzy multiple sequential heuristics in (Asmuni *et al.*, 2005) mainly focused on generating a feasible timetable. Besides, in (Asmuni *et al.,* 2005) the different sets of approaches (Fuzzy LDLE, Fuzzy SDLE, and Fuzzy SDLD) were used to compare their performance on solving timetabling problem. The results showed that different fuzzy approaches have different capabilities when solving the timetabling problem. Hence, this research is motivated to develop a multi-agent system which allows the different sets of fuzzy approach to corporate with each other.

iii. **How effective are FMSH and MAS-FMSH in solving different problem dataset?**

As mentioned earlier in this chapter, different universities implement different policy and regulations. It is difficult to implement one solution to solve all course timetabling problems from different universities. Therefore, this research conducted experiments with different datasets in order to evaluat of FMSH and MAS-FMSH to generate feasible solution as well as improving the quality of solution.

1.3 Research Objectives

In order to solve UMSLIC course timetabling problems, it is important to develop an automated timetabling system. The purpose of the automated system is to ease all the manual procedures for conducting the scheduling process. Therefore, the main goal of this research is to develop a robust and effective approach for the system. The sub-objectives are as follow:

1. **To evaluate the performance of fuzzy multiple sequential heuristics (FMSH) in minimizing the soft constraints violation of timetables.**
    - FMSH involves in two phases: construction and improvement phase
    - Construction phase: produce a solution without hard constraints violation
    - Improvement phase: improve the quality of solution by minimization of soft constraints (Hard and soft constraints are listed in Chapter 3)

2. **To develop a multi-agent system which allows the different sets of fuzzy multiple sequential heuristics to corporate with each other (MAS-FMSH) and compare the performance of MAS-FMSH and FMSH in solving UMSLIC course timetabling problems.**
    - Fuzzy LDLE, Fuzzy SDLE, and Fuzzy SDLD are formed by different criteria and have different capabilities
    - A multi-agent system allows them to work and help each other to generate feasible a feasible solution and improve its quality

3. **To extend the implementation of FMSH and MAS-FMSH to solve benchmark problem datasets and evaluate their performance.**
    - Different problem datasets have different level of difficulty
    - Larger dataset involves in larger number of events and causes higher conflict index
    - Implement FMSH and MAS-FMSH to solve benchmark course timetabling problems which contains 11 different level of difficulty datasets.

1.4 Overview of this thesis

There are total six chapters in this thesis. Chapter 2 introduces timetabling problem and explains the differences between examination, course, and school timetabling problems. Besides, Chapter 2 provides a review of the common techniques applied in timetabling problems such as heuristic, meta-heuristic and hybrid heuristics approaches. In addition, the application of fuzzy logic and multi-agent system in different problem domains are also described in Chapter 2.

Chapter 3 describes the process conducted by this study to achieve the objectives. Furthermore, it also provides the description of UMSLIC course timetabling problem and the information required to conduct experiments. Moreover, the method of evaluating the feasibility and quality of timetable is presented.

Chapter 4 explains the concept of fuzzy logic and the development of the FMSH which is composed by three different fuzzy multiple sequential heuristics. The actual data from UMSLIC is used for development and testing. The experimental

results produced by FMSH are used to compare with the timetable generated by UMSLIC's timetabling officer.

Chapter 5 explains the fundamental of multi-agent systems and the construction of the proposed framework, MAS-FMSH. Same as first experiment, the real-world data from UMSLIC is used for construction and testing for MAS-FMSH framework. The experimental results of MAS-FMSH are used to compare with results of first experiment and the timetable produced by UMSLIC. In order to achieve the third objective, MAS-FMSH is also being used to conduct experiments with benchmark datasets. The performance of MAS-FMSH is compared with FMSH and the results obtained from literature. Lastly, Chapter 6 summarizes the whole thesis and provides future work regarding the FMSH and MAS-FMSH.

1.5 Contributions of the Research

This research focuses on the investigation of the implementation of fuzzy logic and multi-agent system for solving real-world course timetabling problems. This research applies the same concept as conventional sequential heuristic algorithm to schedule a given set of courses based on their difficulty value. By implementing fuzzy logic, it allows considering more than one sequential heuristic to determine the difficulty value of the courses. The main contributions of this research are listed as follow:

1. This research proposes using fuzzy logic to generate and improve the quality of timetable. The implementation of fuzzy logic can imitate the way of human decision-making as it is difficult to justify which constraints should be prioritized.
2. This research proposes a multi-agent framework that allows different fuzzy multiple sequential heuristics to work with each other. Each of them has different capabilities, the communication allows them to cooperate to achieve the predefined objectives.

1.6 Summary Chapter

This chapter gives a general review of timetabling problems and the motivation of this research. The research objectives were presented in order to improve the problem as discussed earlier in this chapter. In addition, this chapter also provides