Application of Graph Coloring in the Course Scheduling Case of Mathematics Education Department in Unai

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ABSTRACT
Courses scheduling is a very important activity in the teaching and learning process in the Mathematics Education Department. The teaching and learning process is carried out by all students and lecturers, so that the schedule of courses arranged must benefit the lecturers and students. If some of the provisions in scheduling are not properly calculated, it will cause difficulty during the scheduling process. These provisions include courses held, number of classes available, amount of time available, number of students taking and availability of lecturers who teach. This study aims to create an automation on the course scheduling using six stages FAST Methodology which includes Scope Definition, Problem Analysis, Requirement Analysis, Logical Design, Decision Analysis, Physical Design and Integration. The Welsh-Powell algorithm has used which is one of the algorithms in the graph coloring method and implemented using C++ programming. The results of the study show that the programme is able to provide a quick and accurate solution for setting up course schedules. The results of this study can provide convenience in managing the right courses scheduling so that it helps the courses scheduling process to be even better.

Keywords: Course schedule, graph coloring, Welsh – Powell algorithm

INTRODUCTION
Routine activities of every study program at Universitas Advent Indonesia before each semester begins are course scheduling. The scheduling process was still manual, which often cause some schedule clashing. As a result, lecture sessions are ineffective because the clashing courses have to be rescheduled until no clashing schedules are left.

In preparing the schedules, several components have to be considered, such as courses, lecturers, rooms, available schedule hours, and students who must repeat several courses or students who want to take additional courses. This process is quite complicated and time-consuming, especially if done manually.

To improve the quality of the academic services, finding a solution to these problems is necessary. One technique that can be used to overcome these problems is by using graph
coloring techniques (Munir, 2014). Graph coloring has many applications such as map coloring, task scheduling, parallel computation, network design, etc (Dandashi, 2010). In course scheduling, courses represent the vertices, and the connection between two courses such that both cannot be scheduled simultaneously represent the edge.

One of the graph coloring algorithms is the Welch-Powell algorithm (Munir, 2014). Welch-Powell algorithm performs coloring based on the highest vertices degree or Largest Degree Ordering (LDO) (Astuti, 2011). Although this algorithm does not always provide the minimum number of colors needed to color a graph, but it's practical enough.

In this study, Welch-Powell Algorithm was applied using C++ programming language to help the scheduling process in the Mathematics Department at Universitas Advent Indonesia for the even semester of the 2018/2019 academic year.

**METHODS**

The developed application program in this research applied FAST methodology consisting of six stages which were conducted sequentially. Below are the conducted procedures (Heriyanni, 2014):

1. **Scope definition**
   
   This stage was started by collecting relevant information, then continued to formulating the problems and scope.

2. **Problem analysis**

   At this stage, the problems were identified and evaluated.

3. **Requirement analysis**

   Collecting and analyzing the required data was carried out at this stage.

4. **Decision analysis**

   Selection was performed on the development algorithm, as well as the hardware and software used to implement the algorithm.

5. **Logical design**

   A logical design for the application program development was made at this stage.

6. **Physical design and integration**

   The conducted activity in this stage was developing the application program used to implement the selected algorithm. After that, the application program was installed and used.
RESULTS
Scope Definition
1. Problems
To gather the information in the form of course scheduling problems faced by the Mathematics Education Department (MED), direct observations were conducted during the registration process at the beginning of the semester. Besides that, an interview session was made with the dean of MED to enrich the information gathered. According to the observation and interview results, some course scheduling problem faced by the MED are listed below:

1) The scheduling process was still manual. The dean has a hard time scheduling the courses, and the process requires a lot of time to complete.
2) There are still some clashing courses and need to be rescheduled during the registration period.

2. Scopes
The anticipated result was to boost the course scheduling process and avoid course clashing.

Problem Analysis
There were several weaknesses determined on the current course scheduling process. In addition to that, the solutions to overcome the weaknesses were also given. The table below shows the identification and the solution of the problems.

Table 1. The Identification And The Solution Of The Problems.

| Problems          | Time-consuming | No practical scheduling skill | Course clashing                                              |
|-------------------|----------------|-------------------------------|--------------------------------------------------------------|
| Solutions         | Automatic      | Implement a graph coloring   | Graph coloring avoids coloring the same color for every     |
|                   | scheduling     | technique as a practical      | two-vertex connected with an edge. In the other words no     |
|                   | made by        | scheduling skill.             | clashing courses will be scheduled at the same time.        |
|                   | machines       |                               |                                                             |
|                   | reduce         |                               |                                                             |
|                   | scheduling     |                               |                                                             |
|                   | time.          |                               |                                                             |
Requirement Analysis
The required data for course scheduling were gathered from the Academic Administration Bureau (BAA). In addition to that, an interview with the dean of MED was made to identify the course scheduling limitations.

The data collected for this research was the even semester courses list for each batch in the Mathematics Education Department, credits (C) and course type (T) for each course, the instructor for each course, instructors which have been scheduled in the other departments, special case students, and fixed schedule. Schedules for general courses were already set by the BAA, and schedules for the senior courses (batch 2015) were set in the evening due to Praktek Pengalaman Lapangan sessions from the morning till afternoon. As for the Skripsi II course, it was scheduled on Friday at 1300 until 1600 which was out of the normal available schedule time because no class will be held for this course.

Table 2. **Collected Data**

| No | Course Code | Course Name                  | T | C | Instructor | Batch | Special Case | Fixed Schedule |
|----|-------------|------------------------------|---|---|------------|-------|--------------|----------------|
| 1  | MKU143      | Bahasa Indonesia             | G | 2 | Susri      | 2018  | 26, 27       |                |
| 2  | ENG1206     | Bahasa Inggris II            | G | 2 | X          | 2018  | 10, 11       |                |
| 3  | KIP1202     | Falsafah Dasar-Dasar Kesehatan | M | 2 | Y          | 2018  | 12, 13       |                |
| 4  | MAT1212     | Fisika Dasar II              | M | 3 | Andi       | 2018  |              |                |
| 5  | MAT1201     | Geometrik Analitik           | M | 3 | Nora       | 2018  |              |                |
| 6  | KIP1203     | Kapita Selecta Matematika Sekolah Menengah Pertama | M | 3 | Nora       | 2018  |              |                |
| 7  | MKU1103     | Pendidikan Kewarganegaraan   | G | 2 | Z          | 2018  | 8, 9         |                |
| 8  | KIP1201     | Pendidikan Sosial dan Budaya | M | 2 | Mangadar   | 2018  |              |                |
| 9  | MA152414    | Aljabar Matriks              | M | 2 | Sonya      | 2017  |              |                |
| 10 | MKU2201     | Bahasa Inggris IV            | G | 2 | A          | 2017  | 14, 15       |                |
| 11 | MKU2202     | Daniel dan                  | G | 3 | B          | 2017  | 8, 9, 24     |                |
| N | Kode | Judul Mata Kuliah | Kredit | Dosen | Tahun |
|---|------|------------------|-------|-------|-------|
| 12 | MA152449 | Fisika Listrik Magnet | M 3 | Andi | 2017 |
| 13 | MTK2202 | Kalkulus Integral | M 3 | Louise | 2017 | 1522012 |
| 14 | MA152413 | Kurikulum dan Pembelajaran | M 2 | Kartini | 2017 | 1522012 |
| 15 | MA152412 | Profesi dan Pengelolaan Pendidikan | M 2 | Kartini | 2017 |
| 16 | MA152416 | Statistika Dasar | M 3 | Kartini | 2017 |
| 17 | MA153624 | Media Pembelajaran Matematika | M 3 | Kartini | 2016 | 1722009, MTK2017 |
| 18 | KIP3201 | Metode Penelitian Matematika | M 2 | Louise | 2016 | 1522012, 1722009 |
| 19 | MTK3201 | Pogram Linier | M 3 | Sonya | 2016 |
| 20 | MTK3202 | Persamaan Diferensial Biasa | M 3 | Andi | 2016 | 1522012, 1722009 |
| 21 | MTK3203 | Teori Bilangan | M 2 | Louise | 2016 | 1522012, 1722009 |
| 22 | KIP3203 | Kajian Masalah Matematika | M 2 | Sonya | 2016 | 1722009 |
| 23 | MKK1234 | Fisika Modern II | M 3 | Horasdia | 2016 | 1722009 | 32, 33, 34 |
| 24 | A12 | Transformasi Geometri | M 3 | Sonya | 2016 |
| 25 | ENG3210 | Bahasa Inggris VI | G 2 | C | 2015 | 1722009, MTK2016 | 26, 27 |
| 26 | MTK4201 | Fungsi Variabel Kompleks | M 3 | Nora | 2015 | MTK2016 |
| 27 | MTK4202 | Metode Numerik | M 3 | Andi | 2015 | MTK2016 |
| 28 | MTK4203 | Analisis Real | M 3 | Louise | 2015 |
| 29 | KIP4201 | Bimbingan Konseling | M 2 | Mangada r | 2015 |
| 30 | MTK4204 | SKRIPSI II | M 3 | Louise | 2015 |
| 31 | B11 | | O 3 | Andi | 0, 1, 16 |
| 32 | B12 | | O 3 | Andi | 2, 17, 18 |
| 33 | B13 | | O 3 | Nora | 0, 1, 16 |
| 34 | B14 | | O 3 | Nora | 2, 17, 18 |
| 35 | B15 | | O 3 | Kartini | 0, 1, 16 |
| 36 | B16 | | O 3 | Kartini | 32, 33, 34 |
The limitations for the scheduling process are as follows:

1) Every course which has three credit hours are divided into two sessions and for each session of the same course to be scheduled at the same day is minimalized. Each session of a course has to be assigned to the same room.

2) The available schedule time is from Monday to Thursday at 0800 until 1700 with rest at 1200, while on Friday from 0800 until 1100. This means that the total time slots are 18 slots with 17 two-hours slots and one one-hour slot.

3) There are three rooms provided for the MED main courses which are room 113, room 114, and room 115.

Decision Analysis

1. Development algorithm
   The graph coloring algorithm used for the course scheduling was the Welch-Powell algorithm.

2. Hardware selection
   The hardware used in this research was a laptop with the specification AMD A4-9125 Radeon R3 2.30 GHz processor, 4 GB RAM, and 500 GB hard disk

3. Software selection
   The software chosen for the development of the application program was CodeBlocks to write C++ programming language, and Microsoft Excel to make the input file and read the output file.

Logical Design

The logical design for the application program development are as follows:

![Flowchart of Welch-Powell algorithm scheduling procedures.](image)

**Figure 1.** Welch-Powell algorithm scheduling procedures.
1. Data parsing

The data for all the courses which is the course code, course name, course type, instructors, credit hours, department, batch, special case students, and fixed schedule obtained from the interviews were put into the input (.csv) file with the help of Microsoft Excel. Then, each course data is put into a class and stored in a map.

![Input file format](image)

**Figure 2. Input file format.**

2. Sorting courses randomly by degree

Degree calculation process was done to the parsed courses data. The degree of a course was determined by the number of other courses which has the same instructor or common student participants. After that, every course was sorted randomly by degree in descending order. The course was sorted randomly because there were some courses with the same degree. This will vary the courses arrangement for each sorting. Different courses arrangement means different output.

3. Scheduling

In the Welch-Powell algorithm, vector coloring and vector deletion is done. In scheduling, a vector represents a course. Two vectors are called adjacent to each other when the vector has the same instructor or student participants or allocated room. If two vectors are allocated to the same time slot, then the vectors are called related to each other. The room were allocated along with vector coloring process, and time slot were allocated during the initial vector coloring. The Welch-Powell algorithms procedure in course scheduling are as follows:

1) Initial vector coloring
Uncolored vector with the largest degree is colored with a new color, a compatible room were allocated to the vector, and a free time slot is allocated with the color. If the vector has a fixed schedule, the time slot corresponding to the fixed schedule is allocated with the color instead and all vectors related with the initial vector is colored with the same color.

2) Vector deletion
   Vector deletion is done to all vectors which are adjacent with the previously colored vector (current color). If there are vectors with fixed schedule colored with the current initial vector color, then all the uncolored vectors with fixed schedule is deleted as well.

3) Next vector coloring
   The remaining vector with the largest degree is colored with the same color as the initial vector and a compatible room is allocated to the vector if no room is allocated to the vector. If the vector has a fixed schedule and there are no deleted vectors related with the current vector then all the related vectors is colored with the same color, and the time slot corresponding to the fixed schedule, instead of the previously allocated time slot, is allocated with the current color.

4) Repetition
   Step b) and step c) is repeated until all the remaining vector were colored or all rooms has been allocated.

5) New color
   All the deleted vectors were restored and step a) until step d) is repeated until all vectors are colored.

4. Schedule check
   If the total color is more than the total time slots, then the scheduling process is repeated from step 2.

5. Output
   The scheduling results are displayed.

Physical Design and Integration

1. Physical design
   Below is the display for the main page of the application program
The main page has the following components:

1) New, Save, Save As, and Print menus to manage workings.

2) Block, Unblock, Lock, Unlock menus to manage the available schedule hours as well as the fixed course schedule.

3) Courses, Groups, Instructors, and Rooms menus to view the courses, groups, instructors, and rooms data respectively.

4) Start Auto-Scheduling menu to start the course scheduling process.

5) Refresh menu to refresh the components and data.

6) Timetable to view and manage the allocated courses.

7) Details of the selected items are shown at the bottom right part.

Below are the display for the data view page of the application program.

**Figure 3. Main page display.**
The data view page has the following components:

1) Import menu to import the input (.csv) data file.
2) Data table to view or edit the input data.
3) Text editor at the top right position to edit the rooms data.
4) A window at the bottom right position to generate the code for a group by clicking the Generate button.

The output (.mht) design viewed by *Microsoft Excel* is shown below. This output file can be accessed by clicking the Print menu in the main page.
2. Integration

After several tests, when the application program was ready, it was integrated into the course scheduling process in the MED. The performance test results of the application program are as follows:

Table 3. The performance test results of the application program

| Test No. | Iterations | Execution (seconds) | time  |
|----------|------------|---------------------|-------|
| 1        | 10         | 0.718               |       |
| 2        | 10         | 0.625               |       |
| 3        | 6          | 0.359               |       |
| 4        | 3          | 0.235               |       |
| 5        | 9          | 0.516               |       |

Figure 6. Batch 2017 and batch 2018 schedules.
DISCUSSION

The application of graph coloring helps course scheduling. Graph coloring provide a quick and accurate solution for setting up course schedules.

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