Searching Algorithm for Match Mapping in Kidney Exchange Program

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***Abstract*—Before kidney transplant is performed, the kidney donor and the kidney recipient must be a compatible pair. In reality, it's not uncommon that incompatibility occurs between the donor-recipient pair. To solve this problem, Kidney Exchange Program was created so that an incompatible pair can exchange the kidney to another incompatible pair, making cross donation easier. But to search for the optimal match map from incompatible pairs pool is not an easy task. Match map searching algorithm is an algorithm created for this task. Edmond's Algorithm, the existing algorithm, is suboptimal because it closes the possibiliy of three or more-way exchanges. Therefore, in this paper, by modifying existing two-way match map searching algorithms, *N*-way match map searching algorithm is implemented. Based on the test results, using 3000 incompatible pairs data, it is proven that *N*-way match map searching algorithm is superior in terms of matching efficiency compared to the two-way match map searching algorithm. The increase in matching efficiency obtained on average reaches 7.75% in comparison to the matching efficiency obtained by Edmond's Algorithm.**

***Index Terms*—kidney transplantation, kidney exchange, match map searching algorithm**

I. Introduction

Kidney transplantation is the most recommended treatment method for serious kidney diseases [1]. Every year, in Indonesia alone, there are more than 100,000 patients with kidney transplantation needs. But among those patients, only about 20% can get a kidney transplantation [2]. There are many types of problems that leads to this condition, for example financial problems, public opinions, and the most common, kidney availability. Even though live donor numbers are steadily increasing [3], availability problem arises because many criteria must be met before kidney transplant can be performed [2]. The donor needs to have a healthy kidney, matching blood type, and no blood-borne diseases. Also, the patient's immune system must be able to accept the donor's kidney without killing it.

A. Kidney Transplant Prerequisites

There are few tests that have to be performed before kidney transplant can be done [4]. The blood type test is performed to both the donor and the recipient. Donors can only make a donation if one's blood type is compatible with the recipient's blood type. In Table I, number 1 indicates compatibility and 0 indicates incompatibility. Donors with blood type O are considered Universal Donors because they can give donors to every patients regardless of the blood type. Recipients with blood type AB are considered a Universal Recipients because they can accept kidney donation from every donors regardless of the blood type [5]. The immune test is performed after the donor-recipient pair passes the blood type test [4]. The tests are cross match test and Human Leucocyte Antigen (HLA) test. In cross match test, donor's blood are met with recipient's blood to see whether there is a resistance reaction from recipient's immune system. The resistance reaction happens when the donor kidney is considered a foreign object that must be killed by recipient's immune system [6]. HLA test tests the same reaction as cross match test, but donor's and recipient's tissue cells are being used instead of blood [7]. Finally, to test whether the donor has any blood-borne diseases, serology is performed [6].

TABLE I
Blood Type Compatibility between Patient and Donor [8]

Recipient \ Donor	O	A	B	AB
O	1	0	0	0
A	1	1	0	0
B	1	0	1	0
AB	1	1	1	1

B. Kidney Exchange Program

Because of kidney transplant prerequisites, Kidney Exchange program named Kidney Paired Donation (KPD) was created so that an incompatible donor-recipient pair can exchange their incompatible kidney to another incompatible pair, making cross-donation possible [8]. The kidney exchange can be done two-way, three-way, and can go up to *N*-way.

Unfortunately, because of the large number of incompatible pairs, hospitals cannot find the optimal matching solution for the pool of incompatible pairs. An algorithm that perform a mapping search is needed to address this issue. One of the most known algorithm to tackle this problem is Edmond's Algorithm [8]. In Edmond's Algorithm, the pool of incompatible pairs are represented as a graph with each node representing an incompatible pair and each edge representing a match between two incompatible pairs. The algorithm focuses on high priority pairs so that pairs who need a transplantation more can get an exchange first. Another algorithm regarding this problem is

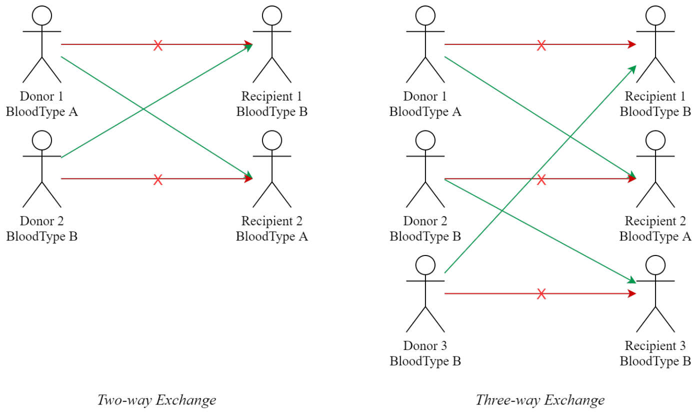

Fig. 1. Two-way(left) and Three-way(right) Exchange in KPD program

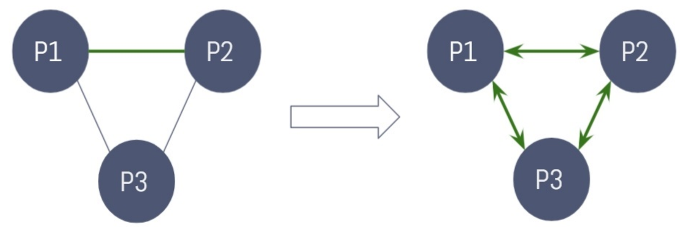

Fig. 2. Edge Detection(left) vs. Cycle Detection(right) in Compatibility Graph

First Accept Heuristic Match [8] which focuses more on the heuristic if one registers first, then one gets an exchange first.

These algorithms are called Match Map Searching Algorithms. To evaluate and measure the performance of an algorithm, a few specific performance metrics are use [9]. There are two performance metrics to evaluate these algorithms. The first one is Matching Efficiency, which measures the number of donor-patient pairs that matched another pair and were able to exchange divided by the total number of donor-patient pairs, represented in a percentage. The second metric is execution time, which measures how long does the algorithm run to get the optimal match map, usually measured in millisecond. The best match map searching algorithm is the algorithm that can produce high matching efficiency with low execution time. Meaning that many patients can be saved as fast as possible.

As good as it looks, Edmond's Algorithm and First Accept Heuristic Match can only find two-way exchanges from the incompatible pairs pool. Meaning these algorithms are not able find a solution with three-way exchanges or more, closing the possibility.

II. Methodology

From the existing algorithms problems addressed in the previous section, match map searching algorithms that can find *N*-way exchanges from incompatible pairs pool are needed. By modifying existing algorithms and the used data structure, new algorithms can be created.

A. Compatibility Graph

Before creating new algorithms, incompatibility pairs pool data structure needs to be redefined. Compatibility Graph used in Edmond's Algorithm is an undirected graph [8], meaning that every edge connecting two vertices represent a back-and-forth relationship between the aforementioned two vertices, making the returned exchanges to be edges, closing up possibility of three-way exchanges or more. If the algorithm is modified to use cycle detection instead of edge detection, Edmond's Algorithm can already be used to return *N*-way exchanges. As seen in Fig. 2, using cycle detection yields a result with three-way exchange instead of the two-way exchange result returned by edge detection, resulting in a higher matching efficiency using the same compatibility graph.

B. Cycle Detection for Directed Graph

As stated in the previous subsection, edge detection used in existing algorithms needs to be converted to cycle detection. However, changing edge detection to cycle detection is not enough. The cycles returned from the graph are all back-and-forth cycles. If the compatibility graph is converted into a directed graph instead of undirected, one-way cycles can also be returned, further increasing the number of cycles, therefore increasing the matching efficiency. Directed graph is a data structure consisting a set of vertices that are connected via edges, where each edge has a one-way direction that shows the direction of movement from one vertex to another [10]. Cycle detection for directed graph is used to find the existence of a one-way path in a graph that starts and finishes at the same vertex [11].

The cycle detection algorithm being used here is a little bit different from the usual cycle detection algorithm that detects whether a graph has a cycle or not, instead this algorithm collects and returns all possible cycle in a graph in a list. Each cycle in this list is a possible exchange that can be excecuted. The length of the cycle represents the *N* in *N*-way exchange (e.g., a cycle with the length of 3 represents a three-way exchange). These modification is performed with the hope that the amount of cycles being detected will increase and therefore increasing matching efficiency and saving more patients.

C. N-way Match Map Searching Algorithms

With directed graph as compatibility graph and using cycle detection algorithm, *N*-way match map searching algorithms can be created. This algorithms receive the list of cycles returned from cycle detection and returned a reduced list of cycles called match mapping. The reduction mentioned is done because each pairs in compatibility graph can exist in more than one cycles in list of cycle, creating a many-to-many relationship among the pairs. This is obviously impossible as every pair can only donate and receive exactly one kidney. The reduction is done to change this many-to-many relationship to be a one-to-one relationship. This reduction usually leaves some pairs to be not matched at all, therefore matching efficiency is used as a performance metric to measure how many pairs can get matched out of the full incompatible pairs pool.

1) First Accept Searching Algorithm: The first N-way match map searching algorithm is first accept searching algorithm which is inspired by first accept heuristic match algorithm. The first-accept approach being used in this algorithm is to to use the first cycles in cycles list returned from cycle detection algorithm. This algorithm ensures that no pair gets matched twice or more by deleting cycles that contains pairs that have been matched earlier.

This algorithm uses two parameters. The first parameter is the number of N, knowing that this algororithm is an N-way algorithm. The second parameter is the method to use N. The number of N can be used as a maximum or exact way of exchanges. When the maximum method is used, the algorithm will search for cycles that represents two-to-N-way exchanges. Meanwhile when exact method is used, the algorithm will search for cycles that have an exact length of N.

2) Priority-based Searching Algorithm: The second N-way match map searching algorithm is priority-based searching algorithm which is inspired by Edmond's algorithm. This algorithm works similarly with First Accept Searching Algorithm, but each cycle is given a priority value so that exchanges with highest priority can be returned first compared to the others.

This algorothm uses three parameters. The first two are the same parameter used in First Accept Searching Algortihm, number of N and the method to use N. The third parameter is priority assignment method. There are two methods to measure priority of every cycles. The first assignment method is the greedy method. This method assigns higher priority for longer cycles, indirectly affecting the algorithm to return more of the longer cycles with the hope that it can increase the matching efficiency. The second assignment method is the infrequent method. This method assigns higher priority for cycles with infrequent pairs. In implementation, infrequent pairs are indicated as vertices that are connected with a low number of edges, meaning that the pairs can only be matched with a low number of other incompatible pairs.

III. Experiment

Before experiment is performed, Edmond's Algorithm is also implemented as a baseline algorithm so comparisons can be made against an existing algorithm. The data being used in this experiment can be found in this link: https://rdm.inesctec.pt/dataset/ii-2020-001 while the source code of the implementation and the experiment can be found in this link: https://github.com/Mingtaros/Kidney-Exchange-Match-Mapping-System.

A. Abbreviations and Acronyms

Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE, SI, MKS, CGS, ac, dc, and rms do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

B. Units

- Use either SI (MKS) or CGS as primary units. (SI units are encouraged.) English units may be used as secondary units (in parentheses). An exception would be the use of English units as identifiers in trade, such as "3.5-inch disk drive".
- Avoid combining SI and CGS units, such as current in amperes and magnetic field in oersteds. This often leads to confusion because equations do not balance dimensionally. If you must use mixed units, clearly state the units for each quantity that you use in an equation.
- Do not mix complete spellings and abbreviations of units: "Wb/m^2" or "webers per square meter", not "webers/m^2". Spell out units when they appear in text: ". . . a few henries", not ". . . a few H".
- Use a zero before decimal points: "0.25", not ".25". Use "cm^3", not "cc".)

C. Equations

Number equations consecutively. To make your equations more compact, you may use the solidus (/), the exp function, or appropriate exponents. Italicize Roman symbols for quantities and variables, but not Greek symbols. Use a long dash rather than a hyphen for a minus sign. Punctuate equations with commas or periods when they are part of a sentence, as in:

$$a + b = \gamma \tag{1}$$

Be sure that the symbols in your equation have been defined before or immediately following the equation. Use "(1)", not "Eq. (1)" or "equation (1)", except at the beginning of a sentence: "Equation (1) is . . ."

D. LaTeX-Specific Advice

Please use "soft" (e.g., `\eqref{Eq}`) cross references instead of "hard" references (e.g., `(1)`). That will make it possible to combine sections, add equations, or change the order of figures or citations without having to go through the file line by line.

Please don't use the `{eqnarray}` equation environment. Use `{align}` or `{IEEEeqnarray}` instead. The `{eqnarray}` environment leaves unsightly spaces around relation symbols.

Please note that the `{subequations}` environment in LaTeX will increment the main equation counter even when there are no equation numbers displayed. If you forget that, you might write an article in which the equation numbers skip from (17) to (20), causing the copy editors to wonder if you've discovered a new method of counting.

BibTeX does not work by magic. It doesn't get the bibliographic data from thin air but from .bib files. If you use BibTeX to produce a bibliography you must send the .bib files.

LaTeX can't read your mind. If you assign the same label to a subsubsection and a table, you might find that Table I has been cross referenced as Table IV-B3.

LaTeX does not have precognitive abilities. If you put a `\label` command before the command that updates the counter it's supposed to be using, the label will pick up the last counter to be cross referenced instead. In particular, a `\label` command should not go before the caption of a figure or a table.

Do not use `\nonumber` inside the `{array}` environment. It will not stop equation numbers inside `{array}` (there won't be any anyway) and it might stop a wanted equation number in the surrounding equation.

E. Some Common Mistakes

- The word "data" is plural, not singular.
- The subscript for the permeability of vacuum μ_0, and other common scientific constants, is zero with subscript formatting, not a lowercase letter "o".
- In American English, commas, semicolons, periods, question and exclamation marks are located within quotation marks only when a complete thought or name is cited, such as a title or full quotation. When quotation marks are used, instead of a bold or italic typeface, to highlight a word or phrase, punctuation should appear outside of the quotation marks. A parenthetical phrase or statement at the end of a sentence is punctuated outside of the closing parenthesis (like this). (A parenthetical sentence is punctuated within the parentheses.)
- A graph within a graph is an "inset", not an "insert". The word alternatively is preferred to the word "alternately" (unless you really mean something that alternates).
- Do not use the word "essentially" to mean "approximately" or "effectively".
- In your paper title, if the words "that uses" can accurately replace the word "using", capitalize the "u"; if not, keep using lower-cased.
- Be aware of the different meanings of the homophones "affect" and "effect", "complement" and "compliment", "discreet" and "discrete", "principal" and "principle".
- Do not confuse "imply" and "infer".
- The prefix "non" is not a word; it should be joined to the word it modifies, usually without a hyphen.
- There is no period after the "et" in the Latin abbreviation "et al.".
- The abbreviation "i.e." means "that is", and the abbreviation "e.g." means "for example".

An excellent style manual for science writers is [9].

F. Authors and Affiliations

The class file is designed for, but not limited to, six authors. A minimum of one author is required for all conference articles. Author names should be listed starting from left to right and then moving down to the next line. This is the author sequence that will be used in future citations and by indexing services. Names should not be listed in columns nor group by affiliation. Please keep your affiliations as succinct as possible (for example, do not differentiate among departments of the same organization).

G. Identify the Headings

Headings, or heads, are organizational devices that guide the reader through your paper. There are two types: component heads and text heads.

Component heads identify the different components of your paper and are not topically subordinate to each other. Examples include Acknowledgments and References and, for these, the correct style to use is "Heading 5". Use "figure caption" for your Figure captions, and "table head" for your table title. Run-in heads, such as "Abstract", will require you to apply a style (in this case, italic) in addition to the style provided by the drop down menu to differentiate the head from the text.

Text heads organize the topics on a relational, hierarchical basis. For example, the paper title is the primary text head because all subsequent material relates and elaborates on this one topic. If there are two or more sub-topics, the next level head (uppercase Roman numerals) should be used and, conversely, if there are not at least two sub-topics, then no subheads should be introduced.

H. Figures and Tables

a) Positioning Figures and Tables: Place figures and tables at the top and bottom of columns. Avoid placing them in the middle of columns. Large figures and tables may span across both columns. Figure captions should be below the figures; table heads should appear above the tables. Insert figures and tables after they are cited in the text. Use the abbreviation, even at the beginning of a sentence.

TABLE II
TABLE TYPE STYLES

Table Head	**Table Column Head**		
	Table column subhead	***Subhead***	***Subhead***
copy	More table copy[a]		

[a]Sample of a Table footnote.

Figure Labels: Use 8 point Times New Roman for Figure labels. Use words rather than symbols or abbreviations when writing Figure axis labels to avoid confusing the reader. As an example, write the quantity "Magnetization", or "Magnetization, M", not just "M". If including units in the label, present them within parentheses. Do not label axes only with units. In the example, write "Magnetization (A/m)" or "Magnetization {A[m(1)]}", not just "A/m". Do not label axes with a ratio of quantities and units. For example, write "Temperature (K)", not "Temperature/K".

IV. Results and Analysis

ababwa

V. Related Work

this is still a template

VI. Conclusion

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ACKNOWLEDGMENT

The preferred spelling of the word “acknowledgment” in America is without an “e” after the “g”. Avoid the stilted expression “one of us (R. B. G.) thanks ...”. Instead, try “R. B. G. thanks...”. Put sponsor acknowledgments in the unnumbered footnote on the first page.

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