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

Every year, in Indonesia alone, there are more than 100,000 patients with kidney needs. But among those patients, only about 20% can get a kidney transplantation [1]. There are many types of problems that leads to this condition, for example financial problems, public opinions, and the most common, kidney availability. This availability problem arises because many criteria must be met before kidney transplant can be performed [1]. 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

TABLE I
Blood Type Compatibility between Patient and Donor [2]

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

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 [3]. 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 [5]. HLA test tests the same reaction as cross match test, but donor's and recipient's tissue cells are being used instead of blood [6]. Finally, to test whether the donor has any blood-borne diseases, serology is performed [5].

B. Kidney Exchange Program

Because of kidney transplant prerequisites, Kidney Exchange program named Kidney Paired Donation (KPD) was created [2] so that an incompatible donor-recipient pair can exchange their incompatible kidney to another incompatible pair, making cross-donation possible. The kidney exchange can be done two-way, three-way, and can go up to *N*-way.

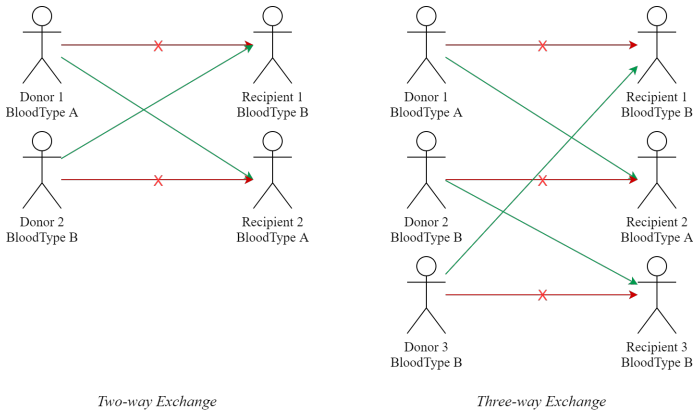

Fig. 1. Two-way(left) and Three-way(right) Exchange in KPD program

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 [2]. 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 First Accept Heuristic Match [2] which focuses more on the heuristic if one registers first, then one gets an exchange first.

These algorithms are called Match Map Searching Algorithms. 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 [2], 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. 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.

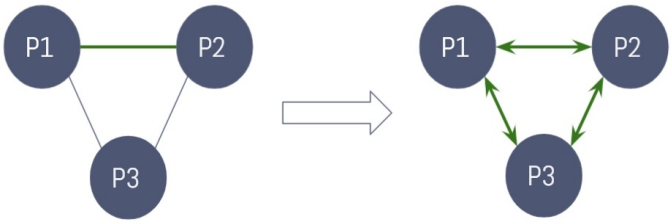

Fig. 2. Edge Detection(left) vs. Cycle Detection(right) in Compatibility Graph

B. 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.

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.

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.

III. Experiment

Before you begin to format your paper, first write and save the content as a separate text file. Complete all content and organizational editing before formatting. Please note sections III-A–III-E below for more information on proofreading, spelling and grammar.

Keep your text and graphic files separate until after the text has been formatted and styled. Do not number text heads—LaTeX will do that for you.

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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".
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Spell out units when they appear in text: ". . . a few henries", not ". . . a few H".
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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 . . ."

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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.

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E. Some Common Mistakes

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- 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.)
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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).

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TABLE II
TABLE TYPE STYLES

Table Head	**Table Column Head**		
	Table column subhead	***Subhead***	***Subhead***
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[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

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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.

REFERENCES

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Unless there are six authors or more give all authors' names; do not use "et al.". Papers that have not been published, even if they have been submitted for publication, should be cited as "unpublished" [**?**]. Papers that have been accepted for publication should be cited as "in press" [**?**]. Capitalize only the first word in a paper title, except for proper nouns and element symbols.

For papers published in translation journals, please give the English citation first, followed by the original foreign-language citation [**?**].

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