Kidney Exchange: Models and Algorithms: Socially Relevant Projects Program of IIT Madras

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1 Introduction

Patients with Kidney Failure, also called End Stage Kidney Disease (ESKD) have to resort to either dialysis at regular intervals or undergo a kidney transplant. A kidney transplant offers the patient the best quality of life and also has multiple health benefits which the dialysis treatment does not offer. However, not every patient with kidney failure receives a kidney transplant. One of the main reasons for this is the gross disparity in the demand and supply of organs. Deceased donor programs enable the distribution of organs from a brain dead donor to patients on waitlist. However, due to the ever increasing number of patients with kidney disease often the waiting times are more than $3-4$ years. In a developing country like India, the deceased donor program is not available in many parts of the country. Up to 80% of kidney transplants in our country are from living related donors. Kidney transplant requires blood group compatibility between the patient and donor pair, similar to blood transfusions. One major hurdle in living donor transplant is ABO incompatibility between a voluntary donor and patient pair.

Kidney Paired Donation (KPD) offers the best chance of getting a blood group compatible living donor kidney to patients without a ABO blood group compatible donor. In addition, receiving a kidney from a living donor offers better kidney and patient survival compared to receiving a deceased donor transplant. KPD programs also provide the best hope for patients with HLA antibodies to find a suitable donor. Single centre KPD is rarely successful due to the limited number of matches possible. The success of the KPD program would depend on the availability of a large patient donor pool with the help of a city or state based registry and the availability of a software which automates the task of finding multiple patient donor pairs matched for multiple variables. Computer based algorithms also increase the scope of KPD programs by innovative strategies like domino exchanges or chains.

The goal of our project is to work towards a feasibility study of both these aspects. In particular, we would like to work with Hospitals in Chennai and build a local registry of patients and donors with the relevant information. We would like to contribute by building a software prototype which allows us to find the compatible matches based on the appropriate notions of optimality.

1.1 Kidney Exchange Worldwide and in India

The Kidney Paired Donation Programs are well established in the U.S. [1], U.K. [2] and other European countries. These programs are facilitated by the existence of centralized National Kidney Registry.

Moreover, most centers employ efficient algorithms to find the pairs which can be swapped. The U.S is currently leading in terms of number of Kidney Paired Donations in the world. This is also partly due to the fact that they already have in place a centralized registry in the form of National Kidney Registry (NKR). Moreover most centers employ efficient algorithms to find long chains and maximize the number of swaps done.

To the best of our knowledge, in India, Kidney Paired Exchange is restricted to few centers. The largest and the leading amongst them is the Institute of Kidney Diseases and Research Center (IKDRC) - Institute of Transplantation Sciences (ITS), Ahmedabad in Gujrat. The center has performed over thousands of transplants over the years and starting June 2018 the center has employed algorithmic solvers for finding compatible donors. As per personal communication with Dr. Vivek Kute, Professor, Nephrology and Transplantation, prior to 2018 , even IKRDC-ITS relied on manual matching for Kidney Paired exchanges. The solver has been procured from another transplant center in the United States. Another centre that has a functioning KPD program is Apex Astra (Apex Swap Transplant Registry) in Mumbai. They use an online application to register patients and donors for Kidney Exchange which has been developed in collaboration with IIT Bombay as reported by [3]. Currently there is no KPD program in India that involves exchange between patients from multiple hospitals. There is no locally developed software that addresses this aspect of KPD in India.

The goal of this proposal is to perform a feasibility study of developing a software which would serve as a database for registering patients and donors across multiple institutions in the city of Chennai and develop a matching algorithm for KPD. However, building a registry is not in the scope of this proposal.

We plan to submit a detailed report on our findings with respect to the feasibility of having a Kidney Paired Donation Center in Chennai. We would like to build and demonstrate a working prototype for one or more hospitals which allows patients and donors to be registered. At regular intervals (when there are significant number of patient donor pairs available), we would like to execute to matching algorithm which outputs the candidate matches between patients and donors. Finally, we would verify the "goodness of the matches" produced in consultation with the doctors.

2 Scoring Function Summary

Component	**Criteria**	**Score**
DR-locus mismatch	0 mismatch	2
	1 mismatch	1
	Any Other	0
Zero-Antigen Mismatch	Yes	6
	No	0
Travel Distance	Same Area	3
	Any Other	0
Pediatric Patient	Age <= 5	4
	Age <= 17	2
	Any Other	0
Donor Age Difference	Difference <= 20	3
	Any Other	0

Table 1: Components of Scoring function along with score of each criteria

3 Example Dataset

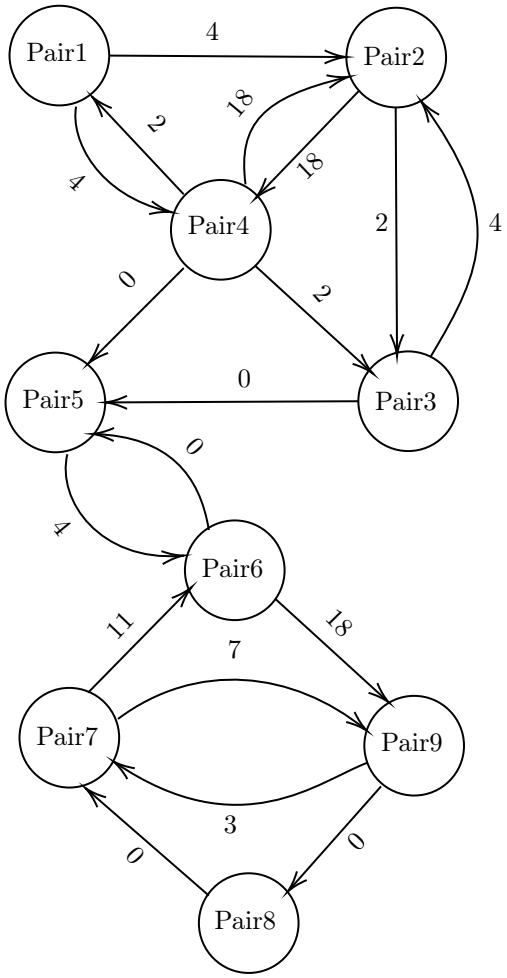


Figure 1: Compatibility Graph of 9 Node Example Dataset

We have constructed an example dataset with 9 patient-donor pairs. We denote them as $pair1$, $pair2$ and so on. For the sake of illustration the details of patients of the $pair1$ and $pair4$ are given in Table 2 and the details of donors of the $pair1$ and $pair4$ are given in Table 3. Figure 1 shows the possible exchanges in the 9 size dataset along with the scores obtained by the scoring function described above. To illustrate the diagram we give the details of $pair1$ and $pair4$ and show how the scores on the edges are computed.

	Patient-1	Patient-4
Age	16	4
Blood Group	O -ve	AB -ve
HLA	A10, A11, B12, B13, DR14(6), DR1403	B5, B8, A3, A9, DR9, DR10
Unacceptable Antigens	A1, B5, DR1, A2, B7, DR2, Cw2, DR51	DR1, A2, B7, DR2, Cw1, Cw2, DR51
Pincode	600003	600001

Table 2: Patient Details for *pair*1 and *pair*4

	Donor-1	Donor-4
Age	75	30
Blood Group	B -ve	O +ve
HLA	A1, A11, B12, B13, DR15(2), DR17(3)	A10, A11, B12, B13, Cw1, DR11(5), DR12(5)
Pincode	600003	600001

Table 3: Donor Details for *pair*1 and *pair*4

3.1 Computing the Score of an Arc

Consider the arc between *pair*1 and *pair*4. In this sub-section, we calculate the score of the donation between the donor of *pair*1 and patient of *pair*4 using the information in Table 1.

1. **DR-Locus Match Score**:
   - the donor of *pair*1 has the following HLA:
     A1, A11, B12, B13, DR15(2), DR17(3) as can be seen in Table 2
   - the patient of *pair*4 has the following HLA as can be seen in Table 3: B5, B8, A3, A9, DR9, DR10 and unacceptable antigens: DR1, A2, B7, DR2, Cw1, Cw2, DR51
   - we see that none of the unacceptable antigens of the patient are present in the HLA of the donor, thus the match is allowed
   - computing the DR-locus score we see that none of the DR antigens match, thus, **the corresponding score is 0**
2. **Zero Antigen Mismatch Score:** Since DR locus match score is zero, it implies that all HLA of patient and donor cannot match and thus, the **score of this component is also 0**
3. **Travel Distance Score:** The patient and donor have different pincodes and so **corresponding score is 0**
4. **Pediatric Patient Score:** Patient-4 is 4 years old, i.e., a pediatric patient; this **contributes a score of 4**
5. **Donor Age Difference Score:** The difference in donor ages is 45 years and thus, there is **no contribution in score** from the corresponding component

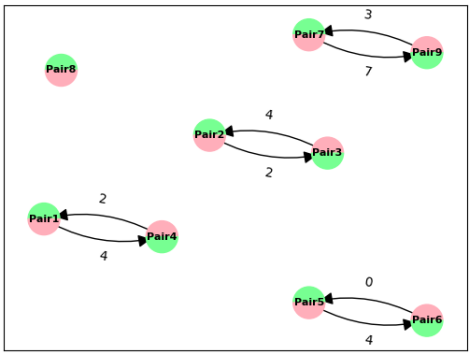
$\therefore$ **Total score of the arc = 4**. Similarly, the scores of the other arcs in Figure 1 can be calculated.

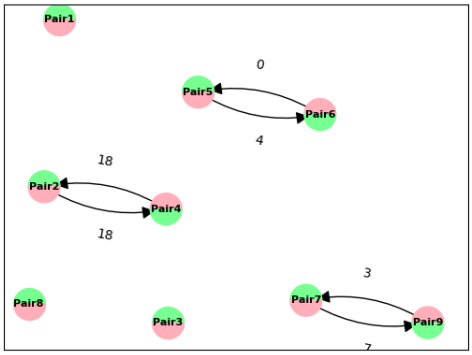
4 Global Match Optimality Criteria

We have implemented the global match using the scoring function described in Table 1. The global match is available at the IIT-M server. It allows the user to select two parameters:

1. the maximum cycle length which can be one amongst **2** or **3**
2. the optimality criteria can be one amongst:
   (a) maximize total **number** of transplants or (b) maximize the total weight of transplants.

We show the results of the global match for the 9 sized dataset using the above two selections in the figures given below. The figures for maximum cycle size 3 are present on the next page.



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MATCH INFORMATION
---------------------
Number of Patient-Donor Pairs participating in the run      : 9
Number of Patient-Donors Matched                            : 8
Number of Patient-Donors Unmatched                          : 1
Total Weight of the transplant                              : 26


Constraints used to compute the pairing: Maximum cycle length = 2
Optimality Criteria used: Maximize the number of effective pairwise exchange
-----------------------------------------------------------------------
```

```
MATCH INFORMATION
---------------------
Number of Patient-Donor Pairs participating in the run      : 9
Number of Patient-Donors Matched                            : 6
Number of Patient-Donors Unmatched                          : 3
Total Weight of the transplant                              : 50


Constraints used to compute the pairing: Maximum cycle length = 2
Optimality Criteria used: Maximize the total weight
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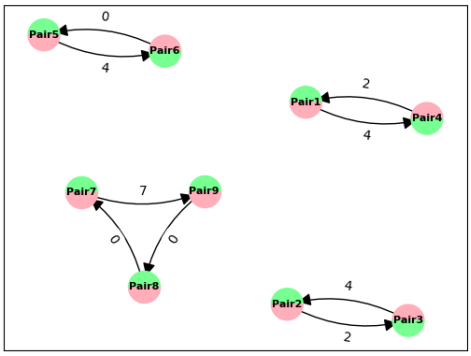
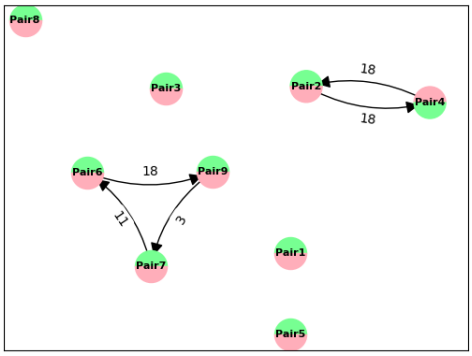
Figure 2: Maximum cycle size is 2 for both the figures. For the figure on the left the goal is to maximize the **number** of transplants. For the figure on the right, the goal is to maximise total **weight** of transplants

5 References

1. Alliance Paired Donation. https://paireddonation.org/.
2. Organ Donation and Transplantation. https://www.odt.nhs.uk/.
3. Dr. Ganesh Sanap. Apex ASTRA. https://www.organindia.org/ORGAN-DONATION/apex-swap-transplantregistry-story-far/, 2018 .






```
MATCH INFORMATION
---------------------
Number of Patient-Donor Pairs participating in the run      : 9
Number of Patient-Donors Matched                            : 9
Number of Patient-Donors Unmatched                          : 0
Total Weight of the transplant                              : 23


Constraints used to compute the pairing: Maximum cycle length = 3
Optimality Criteria used: Maximize the number of effective pairwise exchange
-----------------------------------------------------------------------
```

```
MATCH INFORMATION
---------------------
Number of Patient-Donor Pairs participating in the run      : 9
Number of Patient-Donors Matched                            : 5
Number of Patient-Donors Unmatched                          : 4
Total Weight of the transplant                              : 68


Constraints used to compute the pairing: Maximum cycle length = 3
Optimality Criteria used: Maximize the total weight
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Figure 3: Maximum cycle size is 3 for both the figures. For the figure on the left the goal is to maximize the **number** of transplants. For the figure on the right, the goal is to maximise total **weight** of transplants