A Short Course on Market Design and Matching

Özgür Yılmaz

College of Administrative Sciences and Economics
Koç University

KU Leuven
January 2018

Lecture 5: Kidney Exchange

Kidney transplant

- Transplantation is the preferred treatment for most forms of serious kidney diseases.
- Buying and selling kidneys is illegal in the U.S. as well as many other countries.
  - Section 301 of the 1984 National Organ Transplant Act makes paying for an organ for transplantation a felony.
  - “It shall be unlawful for any person to knowingly acquire, receive or otherwise transfer any human organ for valuable consideration for use in human transplantation.”

Kidney transplant

- Two sources for kidney transplantation: deceased-donor kidneys and live-donor kidneys:
  - Deceased donors: A centralized mechanism has been used for allocation of deceased donor kidneys.
  - Living donors: Living donors usually come from friends or relatives of a patient (because the monetary transaction is prohibited).

The US data

- Currently, around 100,000 patients are on waiting lists for kidney in the U.S. In 2012:
  - 34,848 patients were added to the waiting list,
  - 10,868 transplants from deceased donors,
  - 5,618 transplants from living donors,
  - 4,185 patients died while on the waiting list and 2,667 patients removed from the list due to being too sick for a transplantation

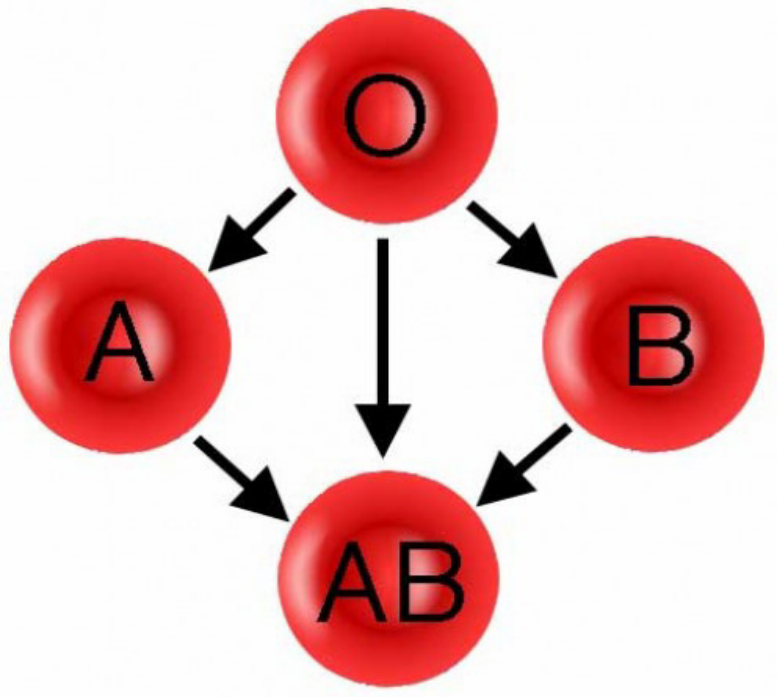
The US data

- The donations wrt the donor types (note that live donation has been increasing recently):

	2008	1998	1988
All donors	10,920	9,761	9,761
Deceased donors	5,992	5,339	3,876
Live donors	3,876	4,422	1,817

Transplant immunology: ABO blood types

- ABO blood type (in)compatibility
- e.g. People with blood type A have only the A antigen and anti-A antibodies are not produced.



Biologically Disadvantaged Groups for Transplantation

- Blood type O patients: Disadvantaged because of the natural injustice induced by ABO blood type compatibility
- Blood type B patients: More likely to be ethnic minorities who are more likely to suffer from kidney disease
  - % of patients transplanted within two years of going on the wait list:

O patients	22.4
B patients	18.3
A patients	38
AB patients	52.6

  - African American, Hispanic and Asian ethnicities comprise the bulk of the B wait list (71 percent of the B list, and it is by far the highest among other blood type groups)

Transplant immunology: tissue types

- Tissue type incompatibility
- Panel Reactive Antibody (PRA) is an immunological laboratory test routinely performed on the blood of people awaiting organ transplantation.
- It represents the proportion of the population to which the person being tested will react via pre-existing antibodies. A high PRA usually means that the individual is primed to react immunologically against a large proportion of the population.
- These antibodies target the Human Leukocyte Antigen (HLA), a protein found on most cells of the body.

Transplant immunology: tissue types

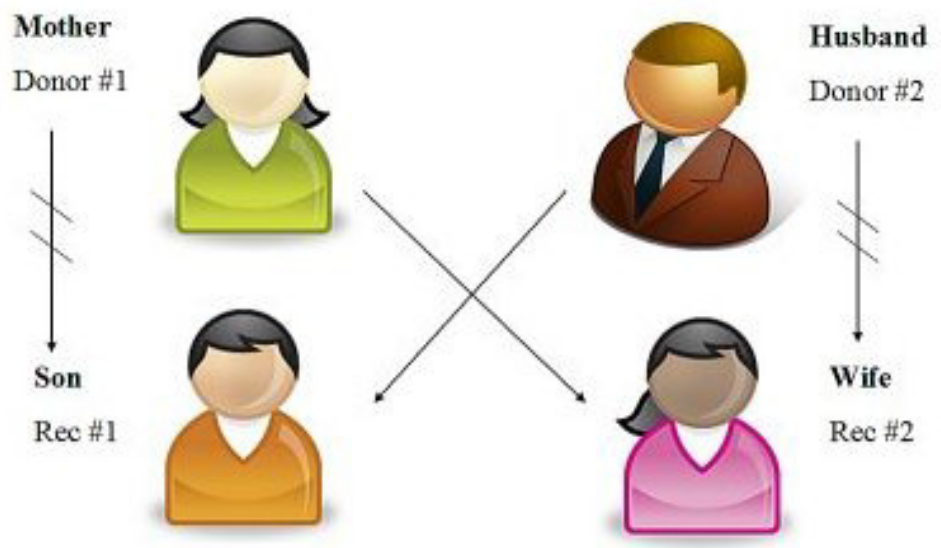
- Odds that patients have a crossmatch with a random donor
  - Low PRA patients: who have a positive crossmatch with less than 10 percent of the population
  - Medium PRA patients: who have a positive crossmatch with 10-80 percent of the population
  - High PRA patients: who have a positive crossmatch with more than 80 percent of the population
- The PRA distribution for the US is as follows (ref. OPTN/SRTR database):

	Frequency (percent)
Low PRA	70.19
Medium PRA	20.00
High PRA	9.81

Kidney exchange: Transplants

Types of donations

- Direct donation: between a patient and his donor
- Deceased donation: between a patient and a deceased donor
- Kidney paired donation: between two incompatible pairs



Kidney exchange: Transplants

Types of donations (cont'd)

- Listed donation: between one incompatible patient-donor pair and the deceased donor waiting list. That is,
  - The donor of the incompatible pair donates his/her kidney to someone on the waiting list, and
  - The patient of the incompatible pair is placed at the top of the waiting list.
- Good samaritan donation: between a live good samaritan donor and between a patient whom has no relation with the donor
- Altrustic paired donation: between a compatible patient-donor pair and an incompatible patient-donor pair

Kidney exchange: The US experience

- In 2004, the Renal Transplant Oversight Committee of New England approved the establishment of a clearinghouse for kidney exchange.
- Roth, Sonmez and Unver as well as doctors design the clearinghouse.
- Potential issues include
  1. Efficiency (e.g. maximizing the number of transplantation)
  2. Incentives (Strategy-proofness)
  3. Fairness

Kidney exchange: The US experience

- Centralized clearinghouses since 2004: The NEPKE, APD, etc.
- The National KPD Pilot Program administered by UNOS.
  - The Organ Procurement and Transplantation Network (OPTN) operates a national KPD system. The United Network for Organ Sharing (UNOS), as the OPTN contractor, administers this system, which is open to all OPTN/UNOS approved transplant programs that perform living donor kidney transplants. As of August 2013, 130 OPTN transplant centers are participating in the national KPD pilot program.

Design 1 (Roth et al, 2004)

1. There is no limit on the number of pairs participating in one exchange.
2. Patients have strict preferences over compatible kidneys and the waitlist.
   - Increase in the number of HLA mismatch decreases the likelihood of kidney survival. Other characteristics such as body size and donor age affect kidney survival (Opelz, 1997).
3. Indirect exchanges are feasible.

Design 1

The first model is very similar to the generalized assignment problem.

Kidney Exchange	House allocation with existing tenants
patient	agent (tenant)
donor	occupied house
waitlist	vacant house

Design 1

- (1) At each stage of the procedure each remaining active patient p_i points to her most preferred remaining unassigned kidney or to the wait-list option w, whichever is more preferred, each remaining passive patient continues to point to her assignment, and each remaining kidney k_i points to its paired recipient p_i.

Design 1

- (2.1) Proceed to Step 3 if there are no cycles. Otherwise, locate each cycle, and carry out the corresponding exchange (i.e., each patient in the cycle is assigned the kidney she is pointing to). Remove all patients in a cycle together with their assignments.
  (2.2) Each remaining patient points to his top choice among remaining kidneys, and each kidney points to its paired recipient. Locate all cycles, carry out the corresponding exchanges, and remove them. Repeat until no cycle exists.

Design 1

- (3) If there are no pairs left, we are done. Otherwise, each remaining pair is the tail of a *w*-chain. Select only one of the chains with the chain selection rule. The assignment is final for the patients in the selected *w*-chain. The chain selection rule also determines whether the selected *w*-chain is removed and the associated exchanges are all immediately assigned (including the kidney at the tail, which is designated to go to a patient on the cadaver queue), or if the selected *w*-chain is kept in the procedure although each patient in it is passive henceforth.

Design 1

- (4) After a *w*-chain is selected, new cycles may form. Repeat Steps 2 and 3 with the remaining active patients and unassigned kidneys until no patient is left.

Design 1

Theorem (Roth et al, 2004)

Consider a chain selection rule such that any w-chain selected at a nonterminal round remains in the procedure, and thus the kidney at its tail remains available for the next round. The TTCC mechanism, implemented with any such chain selection rule, is Pareto efficient.

Design 2 (Roth et al, 2005)

1. Only pairwise exchanges may be possible (at least initially) because all surgeries should be conducted simultaneously (contracting is illegal).
2. Patients may have dichotomous preferences (0-1 preferences), that is, all compatible kidneys are equally good and all incompatible kidneys are equally bad.
3. List exchange may be ruled out, because of the concern that it harms O blood-type patients.

Design 2

Lemma (Roth et al, 2005)

All Pareto optimal matchings match the same number of pairs.

Design 2

Theorem (Roth et al, 2005)

Each priority mechanism is strategy-proof (such that each patient reveals all her acceptable kidneys) and Pareto-efficient.

The structure of Pareto-efficient matchings is given by the Gallai-Edmonds Decomposition Theorem (1963, 1964).

Design 3

A pair is denoted as type X-Y if the patient and donor are ABO blood-types X and Y, respectively. An example: Consider a population composed of

- O-B, O-A, A-B, A-B, B-A (blood-type incompatible),
- A-A, A-A, A-A, B-O (positive crossmatch).

Assume there is is no tissue rejection between patients and other patients' donors.

- If only two-way exchanges are possible:
  (A-B,B-A), (A-A,A-A), (O-B,B-O).
- If three-way exchanges are also feasible:
  (A-B,B-A); (A-A,A-A,A-A); (B-O,O-A,A-B).