# ECO 426 (Market Design) - Lecture 5

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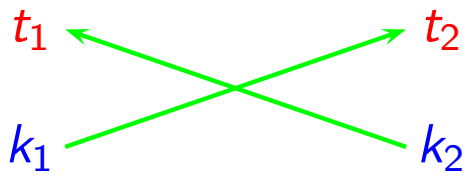
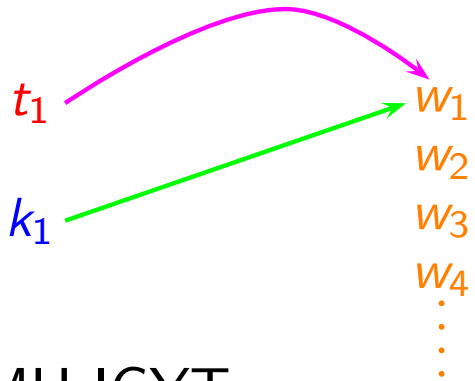
# Exchanging Kidneys

- Two types of kidney exchanges
  - Pairwise kidney exchange: exchange kidney with another patient-donor pair




  - Exchange to list: donate kidney to patient on waiting list in exchange of a better spot on waiting list



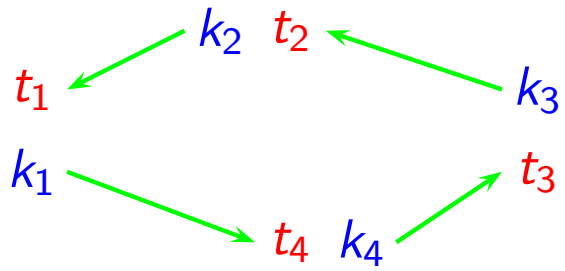

- Looks similar to YRMH-IGYT

# Kidney exchange problem

- A Kidney exchange problem consists of:
  - A set of donor-patient pairs $\{(t_1, k_1), \ldots, (t_n, k_n)\}$
  - For each patient, $t_i$, a set of compatible kidneys $K_i \subseteq K = \{k_1, \ldots, k_n\}$
  - For each patient, $t_i$, a (strict) preference ordering over the set of compatible kidneys $K_i$ **and** the option of exchanging own kidney, $k_i$ for priority $w$ on the waiting list
- Question: How do we organize a kidney exchange program such that
  - The outcome is Pareto efficient, it is not possible to improve further the welfare of **all**
  - For each patient, the outcome is never worse than not participating in the mechanism, ensures broad participation, no donor kidney is un-necessarily "wasted"
  - The mechanism is strategy proof, patients have incentive to disclose their preferences honestly

# Kidney exchange - model

- Assumptions:
  - Multi-way exchanges: No constraint on the number of patient-donor pairs that can participate in an exchange (i.e. multi-way exchanges are allowed)

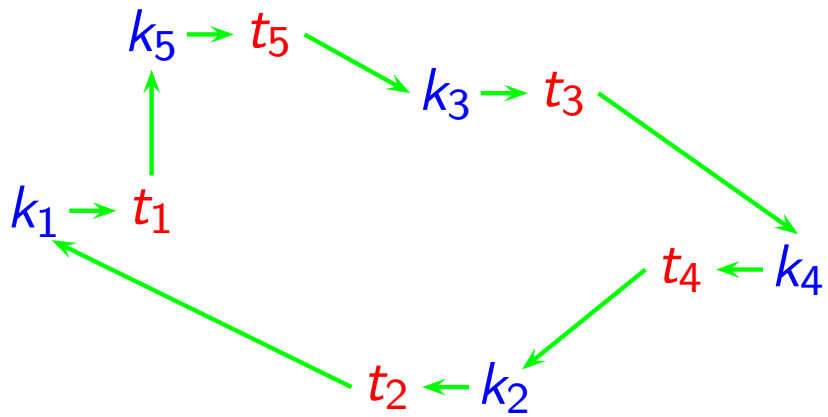


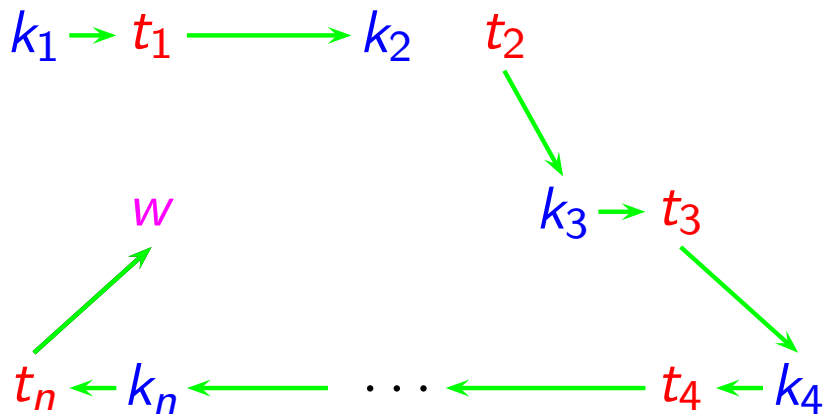

  - List exchanges: Exchange to list are possible (i.e. exchanging a kidney for a better spot on the wait-list)
  - Strict preferences: No patient is indifferent between any two (compatible) alternatives (i.e. strict preferences over: compatible kidneys + trading donor for wait list + remaining with own donor)
- Interpreting live donors' kidneys as "owned" by their respective patients, the problem resembles one of house allocation with existing tenants
  - Maximizing "supply" of live donors as maximizing participation

# TTC(and C)

- TTC mechanism key properties
  - Each patient points to favorite kidney or the waiting list
  - Each kidney donor points to his/her patient

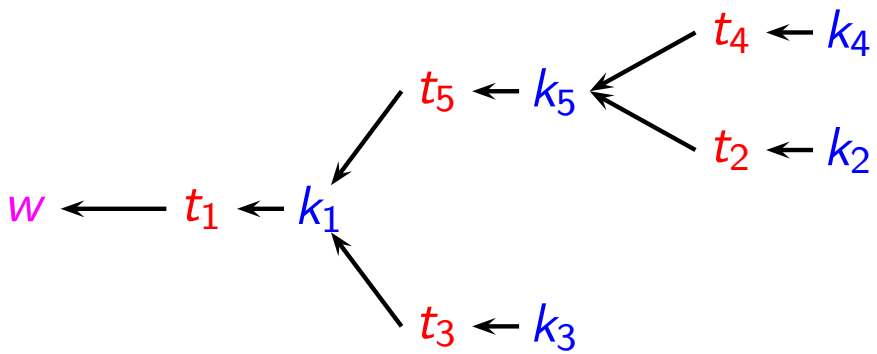
- In a given round
  - A cycle might form
    - each patient in the cycle receives the best compatible kidney available
  - A cycle might not form
    - some patient point to wait-list
  - If there is no cycle there must be at least a *w*-chain



## Top Trading Cycles and Chains mechanism: key ideas

- When a cycle form:
  - Carry out exchange
  - Remove kidneys and patients in cycle and restart
- When no cycle form
  - There can be more than one chain

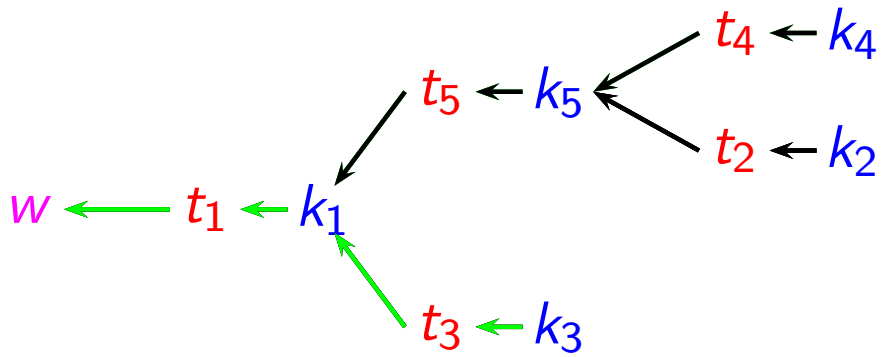



  - Multiple chains can be in "competition" with each other
    - Need a chain selection rule

# chain selection

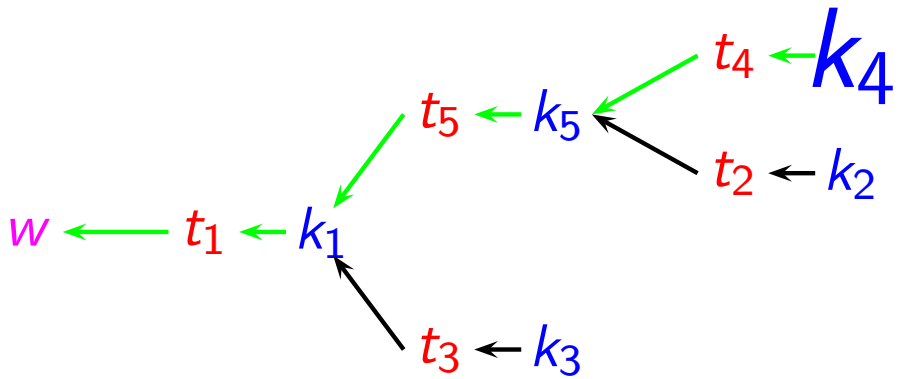
- Examples of chain selection rules

- Choose based on length
  - longest chain
  - minimal chain
- Choose based on donor-patient priority
  - Choose chain with the highest priority donor-patient pair (e.g. $t_3$, $k_3$)



# "tail kidney"

- The "tail kidney" in a chain (i.e. the kidney of the last patient receiving a transplant in the kidney exchange) is not strictly needed for the exchange




- The tail kidney can be
  - Assigned to some compatible patient on wait list (i.e. list exchange) (might have welfare consequences, Pareto efficiency is not guaranteed)
  - Remain available to remaining patients on the kidney exchange program (guarantees Pareto efficiency)

# chain selection

Combining chain selection and tail kidney options

1. Choose longest chain and remove tail kidneys (not strategy proof, not Pareto efficient)
2. Choose longest chain and keep tail kidney (not strategy proof, Pareto efficient)
3. Choose minimal chain and keep tail kidney (strategy proof , Pareto efficient)
4. Choose chain starting with highest priority patient-donor pair and remove tail kidney (Strategy proof, not Pareto efficient)
5. Choose chain starting with highest priority patient-donor pair and keep tail kidney (Strategy proof, Pareto efficient) - equivalent to YRMH-IGYT

- Key properties
  - Minimal chains for strategy proofness
  - Keep kidney for Pareto efficiency

# Constrained kidney exchange

Practical shortcomings:

- Multi-way exchanges can be difficult to implement
  - Being illegal to enter a contractual agreement for a "kidney exchange" all surgeries must be performed simultaneously to ensure compliance with the agreed exchange
    - Pairwise kidney exchange requires four "simultaneous" surgeries (two nephrectomies two kidney transplants)
    - Trilateral exchange requires six "simultaneous" surgeries etc.
- Preferences are "in practice" not strict
  - Compatibility is treated as a binary variable (0-1)
- List exchanges pose a "selection" problem
  - Most common blood type is O-type
  - Most likely donor kidney exchanged to wait-list will be O-type incompatible (otherwise the donating patient would have it)
  - List exchanges may harm O-type patient on wait-list

# Pairwise Kidney exchange with binary preferences

- A constrained bilateral Kidney exchange problem with binary (compatibility based) preferences consists of:
  - A set of donor-patient pairs $\{(t_1, k_1), \ldots, (t_n, k_n)\}$
  - For each patient, $t_i$, a set of compatible kidneys $K_i \subseteq K = \{k_1, \ldots, k_n\}$
- The set of agents $N$ and a compatibility matrix, $R$, suffice to describe the problem
  - $R$ is an $N \times N$ matrix with

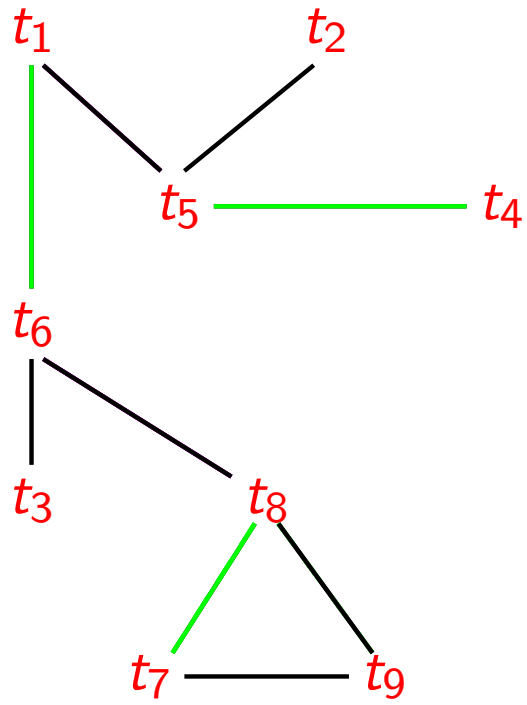
$$r_{i,j} = \begin{cases} 1 & \text{if } i \text{ and } j \text{ are compatible} \\ 0 & \text{otherwise} \end{cases}$$

- Objective: Find a collection of bilateral kidney exchange among mutually compatible donor-patient pairs

# Priority Mechanism

- Order donor-patient pairs according to priorities
  Example: Nine patient-donor pairs $\{t_1, t_2, \ldots, t_9\}$ priority ordering $\{1, 8, 4, 2, 6, 3, 7, 9, 5\}$
  - medical priority and/or random

- match top priority patient if possible (i.e. if there is a patient-donor pair mutually compatible with the priority 1 patient-donor pair), else skip
- match priority 2 patient, if possible, in conjunction with priority 1 agent else skip priority 2 agent
- ...
- match priority n patient, if possible, in conjunction with all earlier priorities, else skip



# Priority Mechanism

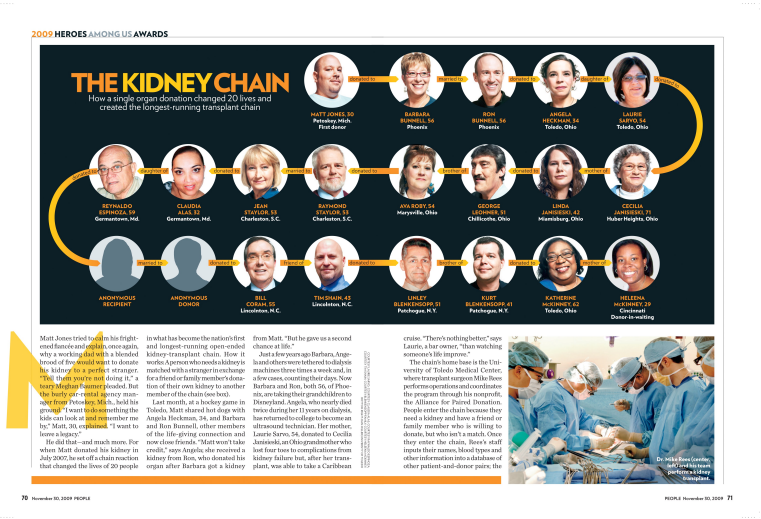
- The priority mechanism is
  - Pareto efficient
  - Strategy proof
- Limits:
  - Allowing tri-lateral exchanges can make many more transplants possible
  - Additional benefits from more complex multi-lateral exchanges decline rapidly
- Example: Blood incompatible pairs (O-B,O-A,A-B,A-B,B-A); HLA incompatible pairs (A-A,A-A,A-A,B-O)
  - Only bilateral exchanges: (A-B,B-A) (A-A,A-A) (O-B,B-O)
  - Bilateral and trilateral: (A-B,B-A) (A-A,A-A,A-A) (B-O,O-A,A-B)

# Kidney exchange programs

- New England Program for Kidney Exchange (2004)
  - Priority mechanism
  - up to 4-lateral exchanges
  - list exchanges allowed
  - altruistic donor exchanges (i.e. chains starting from an altruistic live donor, rather than a list exchange)
- Ohio - Living Kidney Donor Program
  - Performed a Six-way paired kidney exchange (September 2011)
- National program under construction

# NEAD: Never Ending Altruistic Donor Chain

- Alliance for Paired Donation - 10 kidney transplant chain



2009 HEROES AMONG US AWARDS

THE KIDNEY CHAIN

How a single organ donation changed 20 lives and created the longest-running transplant chain

MATT JONES, 30 Petoskey, Mich. First donor

BARBARA BUNNELL, 56 Phoenix

RON BUNNELL, 56 Phoenix

ANGELA HECKMAN, 56 Toledo, Ohio

LAURIE SARVO, 54 Toledo, Ohio

CECILIA JANISEWSKI, 71 Huber Heights, Ohio

HELEENA MCKINNEY, 29 Cincinnati Donor-to-waiting

KATHERINE MCKINNEY, 62 Toledo, Ohio

KURT BLENKINSOPP, 41 Patchogue, N.Y.

LINLEY BLENKINSOPP, 51 Patchogue, N.Y.

TIN SHAUN, 42 Lincolnton, N.C.

BILL CORAM, 55 Lincolnton, N.C.

JEAN STAYLOR, 53 Charleston, S.C.

RAYMOND STAYLOR, 53 Charleston, S.C.

AYA BOBY, 54 Marysville, Ohio

GEORGE LEHMER, 71 Chillicothe, Ohio

LINDA JANISEWSKI, 62 Miamisburg, Ohio

REYNALDO ESPINOZA, 58 Germantown, Md.

CLAUDIA ALAS, 32 Germantown, Md.

ANONYMOUS RECIPIENT

ANONYMOUS DONOR

Matt Jones tried to calm his frightened fiancée and explain, once again, why a working dad with a blended brood of five would want to donate his kidney to a perfect stranger. "Tell them you're not doing it," a teary Marissa Fairner pleaded. But the burly car-rental agency manager from Petoskey, Mich., held his ground. "I want to do something the kids can look at and remember me by," Matt, 30, explained. "I want to leave a legacy."

He did that—and much more. For when Matt donated his kidney in July 2007, he set off a chain reaction that changed the lives of 20 people in what has become the nation's first and longest-running open-ended kidney-transplant chain. How it works: A person who needs a kidney is matched with a stranger in exchange for a friend or family member's donation of their own kidney to another member of the chain (see box).

Last month, at a hockey game in Toledo, Matt shared hot dogs with Angela Heckman, 34, and Barbara and Ron Bunnell, other members of the life-giving connection and now close friends. "Matt won't take credit," says Angela; she received a kidney from Ron, who donated his organ after Barbara got a kidney from Matt. "But he gave us a second chance at life."

Just a few years ago Barbara, Angela and others were tethered to dialysis machines three times a week and, in a few cases, counting their days. Now Barbara and Ron, both 56, of Phoenix, are taking their grandchildren to Disneyland. Angela, who nearly died twice during her 11 years on dialysis, has returned to college to become an ultrasound technician. Her mother, Laurie Sarvo, 54, donated to Cecilia Janisiewki, an Ohio grandmother who lost four toes to complications from kidney failure but, after her transplant, was able to take a Caribbean cruise. "There's nothing better," says Laurie, a bar owner, "than watching someone's life improve."

The chain's home base is the University of Toledo Medical Center, where transplant surgeon Mike Rees performs operations and coordinates the program through his nonprofit, the Alliance for Paired Donation. People enter the chain because they need a kidney and have a friend or family member who is willing to donate, but who isn't a match. Once they enter the chain, Rees's staff inputs their names, blood types and other information into a database of other patient-and-donor pairs; the

Dr. Mike Rees (center, left) and his team perform a kidney transplant.

70 November 30, 2009 PEOPLE

PEOPLE November 30, 2009 71

- National Kidney Registry - 30 kidney transplant chain