The Theory and Practice of Market Design
(work in progress)

Nobel Lecture

December 8, 2012

“The theory of stable allocations and the practice of market design”

Plan of talk:

- How stable allocations and matching mechanisms connect to some of the markets that have the most influence on our lives
- Some additional theory: how can we help the market learn the preferences of participants, on which stability depends?
- Some applications: getting a job, getting into a good school, getting a kidney

Market Design

- What are markets and marketplaces?
  - What are they for?
  - How do they work?
  - How do they fail?
  - How can we fix them when they're broken?

Commodity markets

Fruit market

NY Stock Exchange

Commodity markets can be arms-length and anonymous

- When buying 100 shares of AT&T on the New York Stock Exchange, you don't need to worry about whether the seller will pick you—**you don't have to submit an application or engage in any kind of courtship**. Likewise, the seller doesn't have to pitch himself to you.
- **The price does all the work**, bringing the two of you together at the price at which supply equals demand. **On the NYSE, the price decides who gets what.**
- The market helps do "price discovery" to find prices that work.

But in many markets prices don't do all the work

- **Harvard and Stanford don't raise tuition until just enough applicants remain to fill the freshman class.**
- Selective colleges try to keep the tuition low enough so that *many* students would like to attend, and then they admit a fraction of those who apply.
- Colleges don't rely on prices alone to equate supply and demand
- **Labor markets and college admissions are more than a little like courtship and marriage**: each is a two-sided matching market that involves searching and wooing on both sides.

Matching markets

- *Matching* is economist-speak for **how we get the many things that we can't simply choose.**
- You can't just inform Yale that you're enrolling, or Google that you are showing up for work. You also have to be *admitted* or *hired*. Neither can Google or Yale simply choose who will come to them, any more than one spouse can simply choose another: each also has to be *chosen*.

Standing on the shoulders of Gale and Shapley ‘62 and Shapley Scarf ‘74

- Gale and Shapley ‘62: defined a notion of stability related to the core in a 2-sided market, and demonstrated that the **deferred acceptance algorithm** could use the preferences of the participants as the input needed to reach a stable matching, i.e. one with no blocking pairs.
- Shapley and Scarf ’74, for a 1-sided market, showed that the **top trading cycles algorithm** (of David Gale) could use the preferences of the participants as input to reach a core allocation

These two results raised theoretical, empirical and design questions that my colleagues and I have spent decades trying to ask and answer.

The *Deferred* Acceptance algorithm produces a stable matching(G-S 1962)

- Step 0: students and schools **privately** submit preferences to a clearinghouse
- Step 1: Each student "applies" to her first choice. Each school **tentatively** assigns its seats to its applicants one at a time in in order of the school's preferences/priorities over students. Any remaining applicants are rejected.

  …
- Step k: Each student who was rejected in the previous step applies to her next choice if one remains. Each school considers the students it has been holding together with its new applicants and **tentatively** assigns its seats to these students one at a time **in preference/priority order***. Any remaining applicants are rejected.
- The algorithm terminates when no student application is rejected, and each student is (finally) assigned her current tentative assignment.

- *note that schools take no account of in what step a student applied.

Some theory from 1982

- In a two-sided market, it's impossible to always produce a stable matching based on stated preferences in a way that always makes it safe for everyone to reveal their preferences truthfully.
- The deferred acceptance algorithm with students applying makes it safe for the students to reveal their true preferences.
- In the one-sided 'housing market,' the top trading cycles algorithm makes it safe for everyone to reveal their true preferences.

What would happen instead if you tried to give as many people as possible their first choice…?

- An ‘unsafe’ *Immediate acceptance* algorithm
- Step 1: Each student applies to her first choice. Each school **immediately** assigns its seats to its applicants one at a time in order of the school’s preferences/priorities over students. Any remaining applicants are rejected.

  …
- Step k: Each student who was rejected in the previous step applies to her next choice if one remains. Each school immediately assigns its remaining seats (i.e. seats that haven’t already been assigned to earlier applicants) to its applicants one at a time in order of the school’s preferences/priorities over students. Any remaining applicants are rejected.

The immediate acceptance algorithm makes it **unsafe** to reveal your true preferences

- If you don't get into the school you list as your first choice, you won't get into any popular school
  - Your second choice will have filled all its places with students who listed it as their first choice (even if you had a higher priority at that school)
  - So you have to be very careful to list as your first choice a school you can get into (or to list an unpopular school as your second choice…)
- The deferred acceptance algorithm avoids this problem: if you fail to get into your first choice, you have just as much chance of getting into your second choice as if you had listed it first.
  - You don't lose your priority at the school…
  - This makes it safe to reveal your true preferences

A window on marketplaces—early empirics

- History of the U.S. job market for new doctors
  - Unraveling (thin markets, diffuse, exploding offers) (1900-1945)
  - Congestion (thick markets, few, exploding offers) (1945-51)
  - Clearinghouse (1951-) successful largely in it's original form for many years…
- Roth '84: the 1950's medical algorithm is different but equivalent to Gale and Shapley's 1962 hospital proposing deferred acceptance algorithm.

This was the first of many observations that helped us refine the question: What do marketplaces do?

- we've seen many similar market failures and sometimes recoveries, once we learned to look for them.
- What have we learned about market design?
  - Thickness
  - Congestion
  - Safety and simplicity

Stability turns out to be important for a successful 2-sided market clearinghouse

Market	Stable	Still in use (halted unraveling)
• NRMP	yes	yes (new design in ’98)
• *Edinburgh ('69)*	*yes*	*yes*
• *Cardiff*	*yes*	*yes*
• *Birmingham*	*no*	*no*
• *Edinburgh ('67)*	*no*	*no*
• *Newcastle*	*no*	*no*
• Sheffield	no	no
• Cambridge	no	yes
• London Hospital	no	yes
• Medical Specialties	yes	yes (~30 markets, **1 failure**)
• Canadian Lawyers	yes	yes (Alberta, no BC, Ontario)
• Dental Residencies	yes	yes (5) (no 2)
• Osteopaths (< '94)	no	no
• Osteopaths (≥ '94)	yes	yes
• Pharmacists	yes	yes
• Reform rabbis	yes (first used in ‘97-98)	yes
• Clinical psych	yes (first used in ‘99)	yes
• Lab experiments	yes	yes
(Kagel&Roth *QJE* 2000)	no	no

Lab experiments fit nicely on the list, just more of a variety of observations that increase our confidence in the robustness of our conclusions, the lab observations are the smallest but most controlled of the markets on the list…

Redesign of the resident match: Growing problems with couples, etc.

- Increasing percentage of women docs, starting in 1970's
- Some defection of couples
  - Iron law of marriage: you can't be happier than your spouse
- Various attempts made to deal with this, including finally allowing couples to state preferences over pairs of positions
- But stable matching with couples is still a hard problem: deferred acceptance algorithm won't work, and a stable matching might not even exist
- Roth Peranson algorithm…'95 ('99)
- Recent work on markets for doctors later in their career, e.g. gastroenterologists (Niederle, Proctor, Roth…)

Stable Clearinghouses (blue -> Roth Peranson Algorithm)

NRMP / SMS:

Medical Residencies in the U.S. (NRMP) (1952)
Abdominal Transplant Surgery (2005)
Child & Adolescent Psychiatry (1995)
Colon & Rectal Surgery (1984)
Combined Musculoskeletal Matching Program (CMMP)
- Hand Surgery (1990)

Medical Specialties Matching Program (MSMP)
- Cardiovascular Disease (1986)
- **Gastroenterology (1986-1999; rejoined in 2006)**
- Hematology (2006)
- Hematology/Oncology (2006)
- Infectious Disease (1986-1990; rejoined in 1994)
- Oncology (2006)
- Pulmonary and Critical Medicine (1986)
- Rheumatology (2005)

Minimally Invasive and Gastrointestinal Surgery (2003)
Obstetrics/Gynecology
- Reproductive Endocrinology (1991)
- Gynecologic Oncology (1993)
- Maternal-Fetal Medicine (1994)
- Female Pelvic Medicine & Reconstructive Surgery (2001)

Ophthalmic Plastic & Reconstructive Surgery (1991)
Pediatric Cardiology (1999)
Pediatric Critical Care Medicine (2000)
Pediatric Emergency Medicine (1994)
Pediatric Hematology/Oncology (2001)
Pediatric Rheumatology (2004)
Pediatric Surgery (1992)
Primary Care Sports Medicine (1994)
Radiology
- Interventional Radiology (2002)
- Neuroradiology (2001)
- Pediatric Radiology (2003)

Surgical Critical Care (2004)
Thoracic Surgery (1988)
Vascular Surgery (1988)

Postdoctoral Dental Residencies in the United States
- Oral and Maxillofacial Surgery (1985)
- General Practice Residency (1986)
- Advanced Education in General Dentistry (1986)
- Pediatric Dentistry (1989)
- Orthodontics (1996)

Psychology Internships in the U.S. and CA (1999)

Neuropsychology Residencies in the U.S. & CA (2001)
Osteopathic Internships in the U.S. (before 1995)
Pharmacy Practice Residencies in the U.S. (1994)
Articling Positions with Law Firms in Alberta, CA(1993)
Medical Residencies in CA (CaRMS) (before 1970)

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British (medical) house officer positions
- Edinburgh (1969)
- Cardiff (197x)

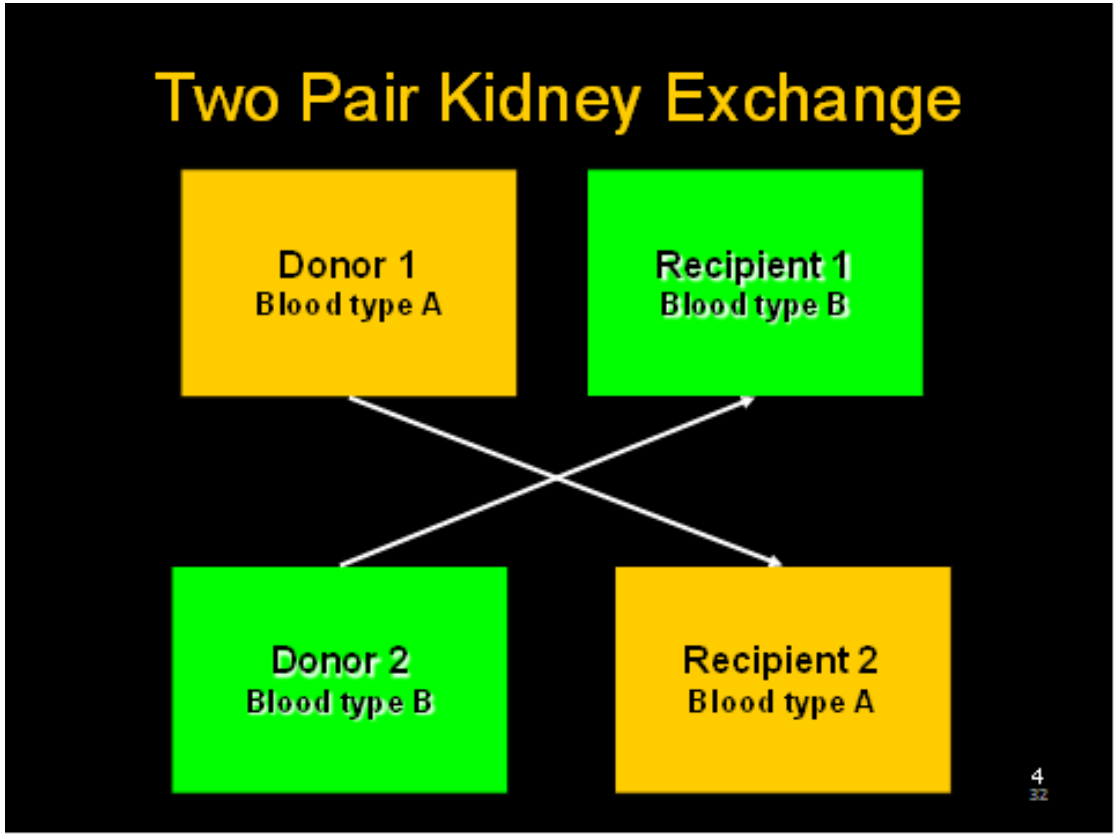
New York City High Schools (2003)
Boston Public Schools (2006)
Denver, Wasington DC (2012)

School choice

- Initially, NYC high schools (2003)
  - Abdulkadiroglu, Pathak and Roth
  - Two-sided matching—perhaps this is the application closest to what Gale and Shapley '62 might have imagined.
- Then Boston Public Schools (2004)
  - One sided allocation problem—schools aren't strategic players (Abdulkadiroglu and Sonmez; Abdulkadiroglu, Pathak, Roth and Sonmez)
- Lately Denver and New Orleans (2012)
- (with Abdulkadiroglu, Pathak, Neil Dorosin and many other education professionals)
- Initially deferred acceptance
  - But with many indifferences, leading to lots of new questions and new theory
- Also top trading cycles—in New Orleans

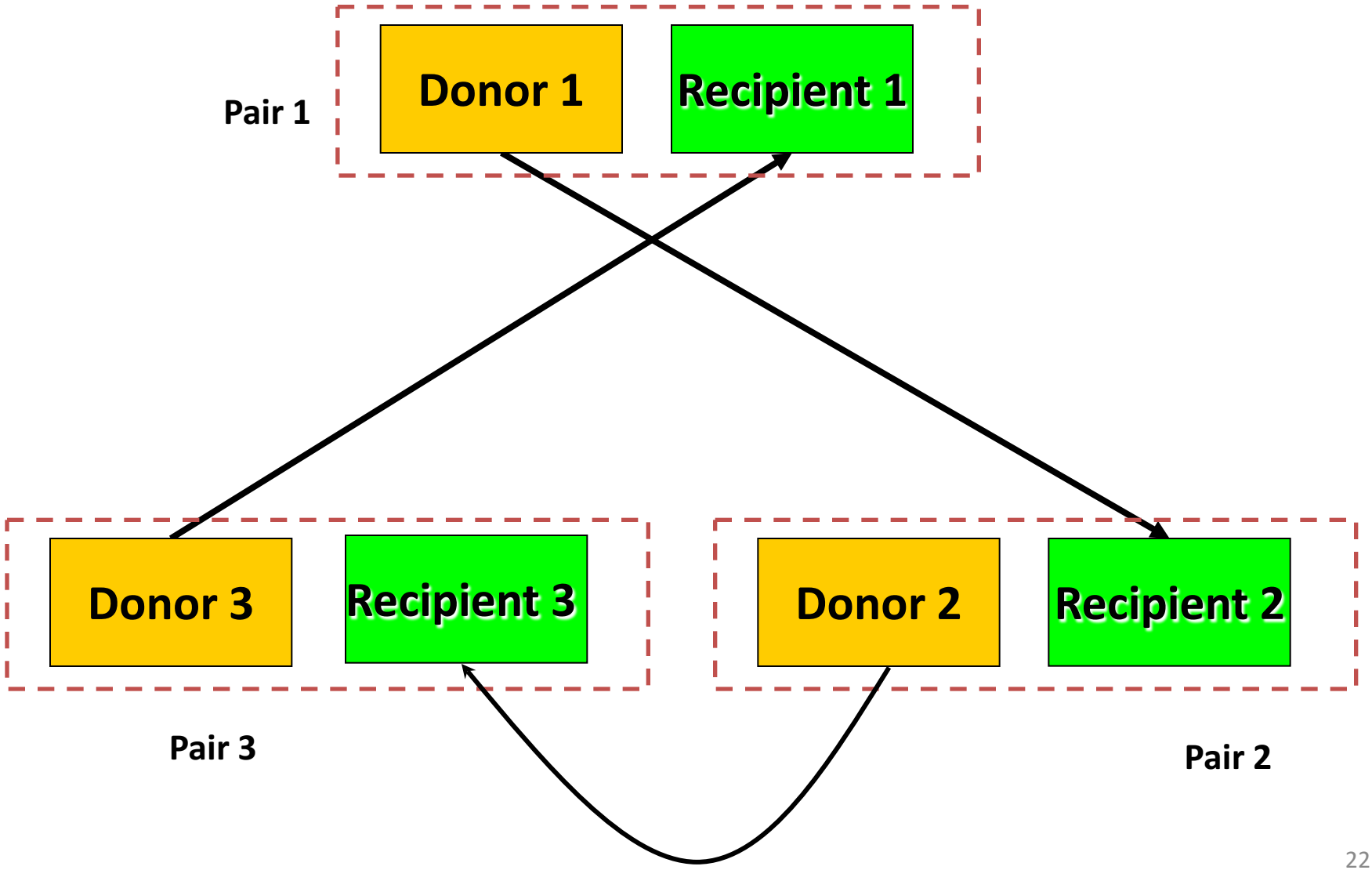
Kidney exchange: (an “in kind” exchange”

- Roth, Sonmez, and Unver; and Ashlagi, and Frank Delmonico and Susan Saidman and Mike Rees

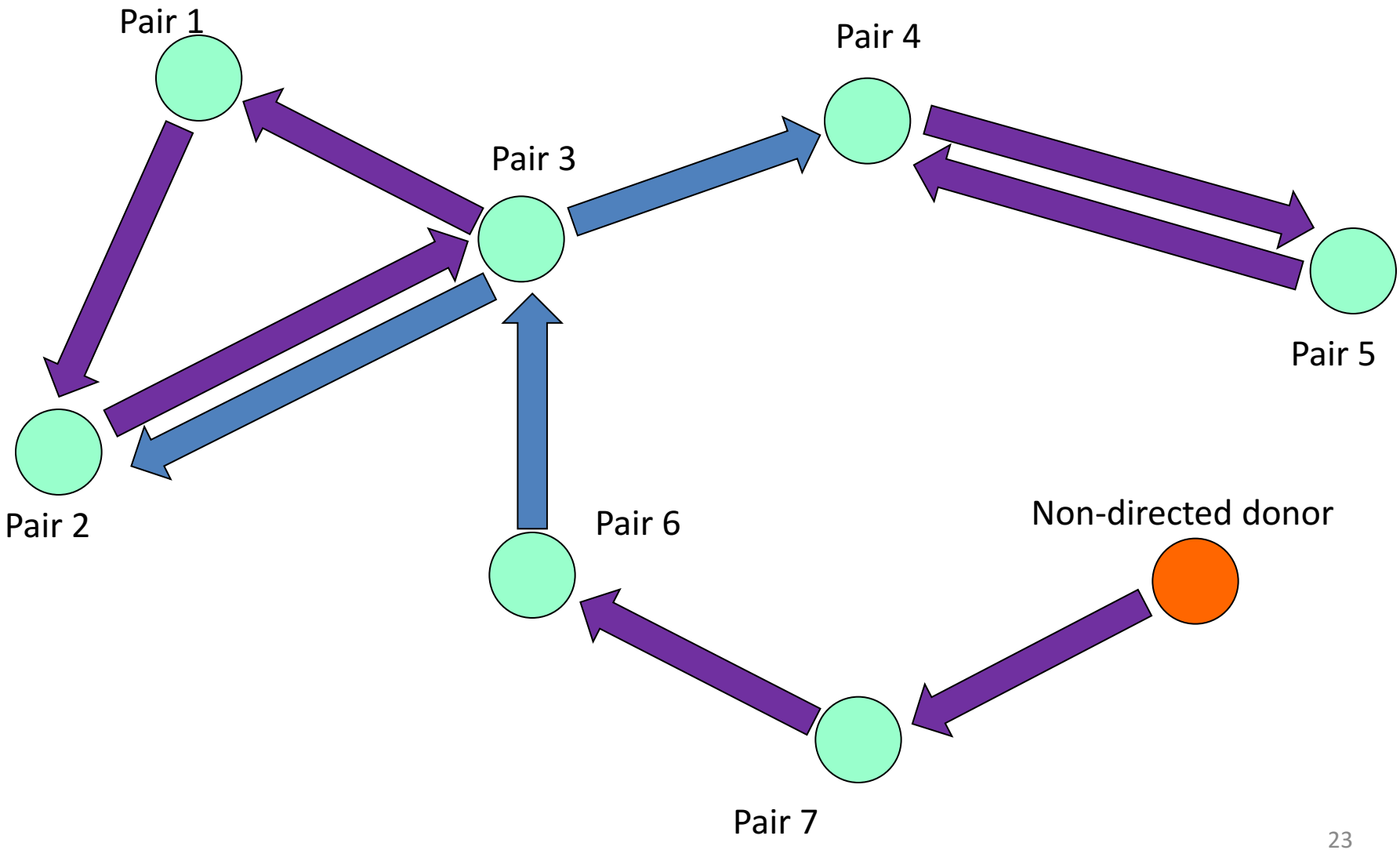


2-way exchange involves 4 *simultaneous* surgeries

3-pair exchange (6 simultaneous surgeries)



Non-directed donors: cycles plus chains



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A Nonsimultaneous, Extended, Altruistic-Donor Chain

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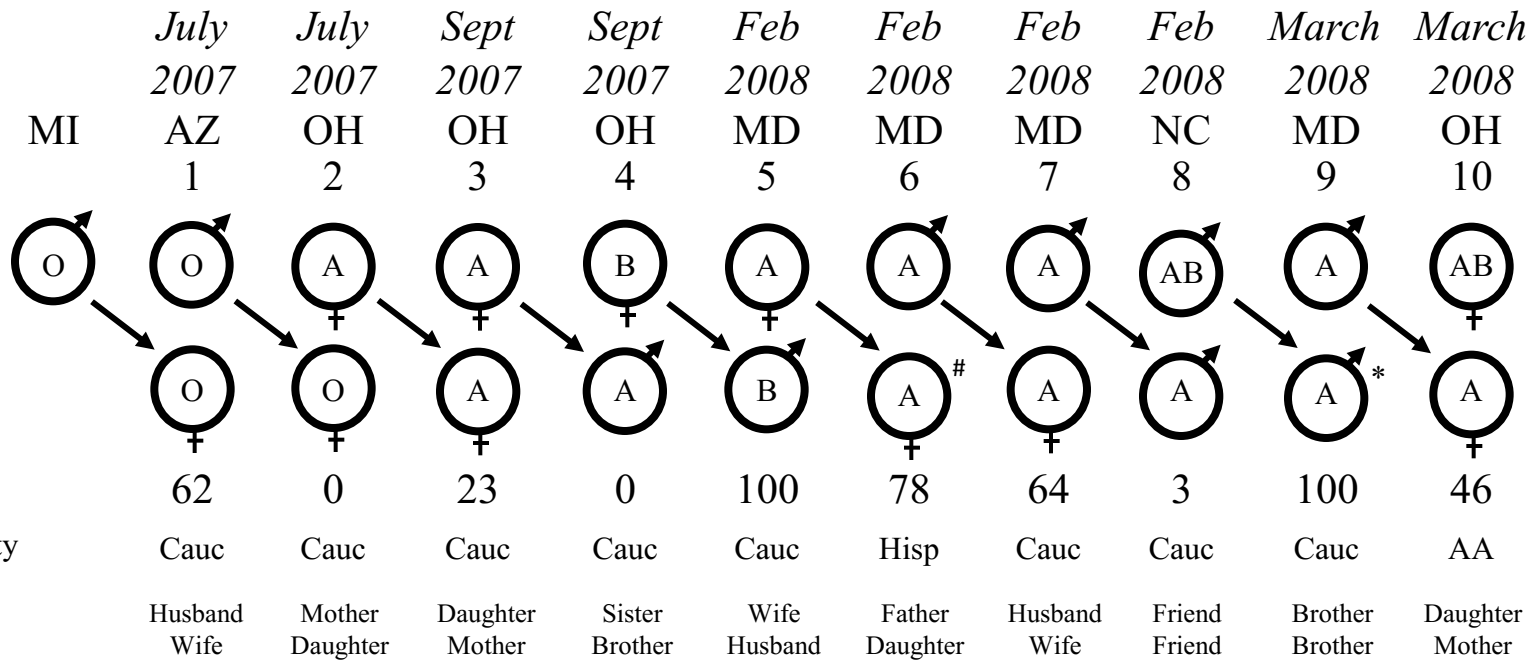
SUMMARY

We report a chain of 10 kidney transplantations, initiated in July 2007 by a single altruistic donor (i.e., a donor without a designated recipient) and coordinated over a period of 8 months by two large paired-donation registries. These transplantations involved six transplantation centers in five states. In the case of five of the transplantations, the donors and their coregistered recipients underwent surgery simultaneously. In the other five cases, "bridge donors" continued the chain as many as 5 months after the coregistered recipients in their own pairs had received transplants. This report of a chain of paired kidney donations, in which the transplantations were not necessarily performed simultaneously, illustrates the potential of this strategy.

The First NEAD Chain (Rees, APD)

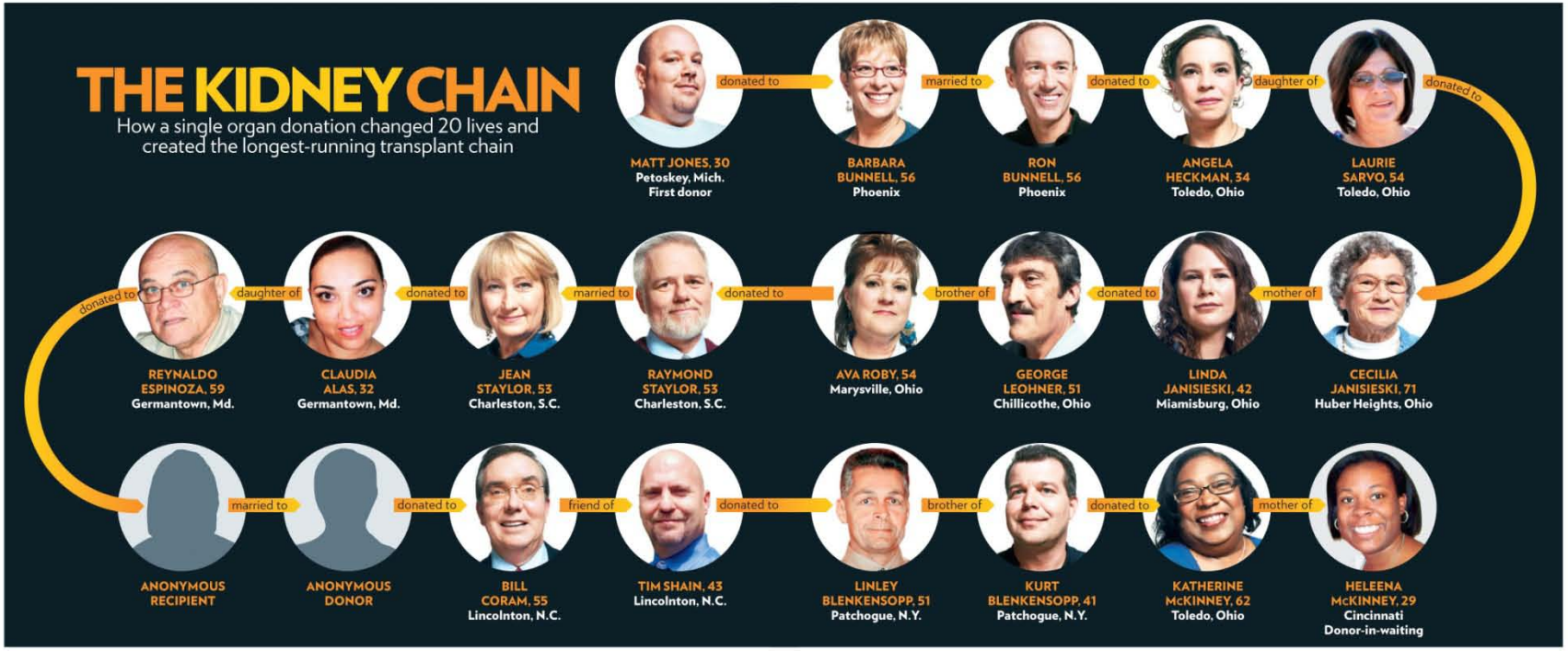


* This recipient required desensitization to Blood Group (AHG Titer of 1/8).

This recipient required desensitization to HLA DSA by T and B cell flow cytometry.

THE KIDNEY CHAIN

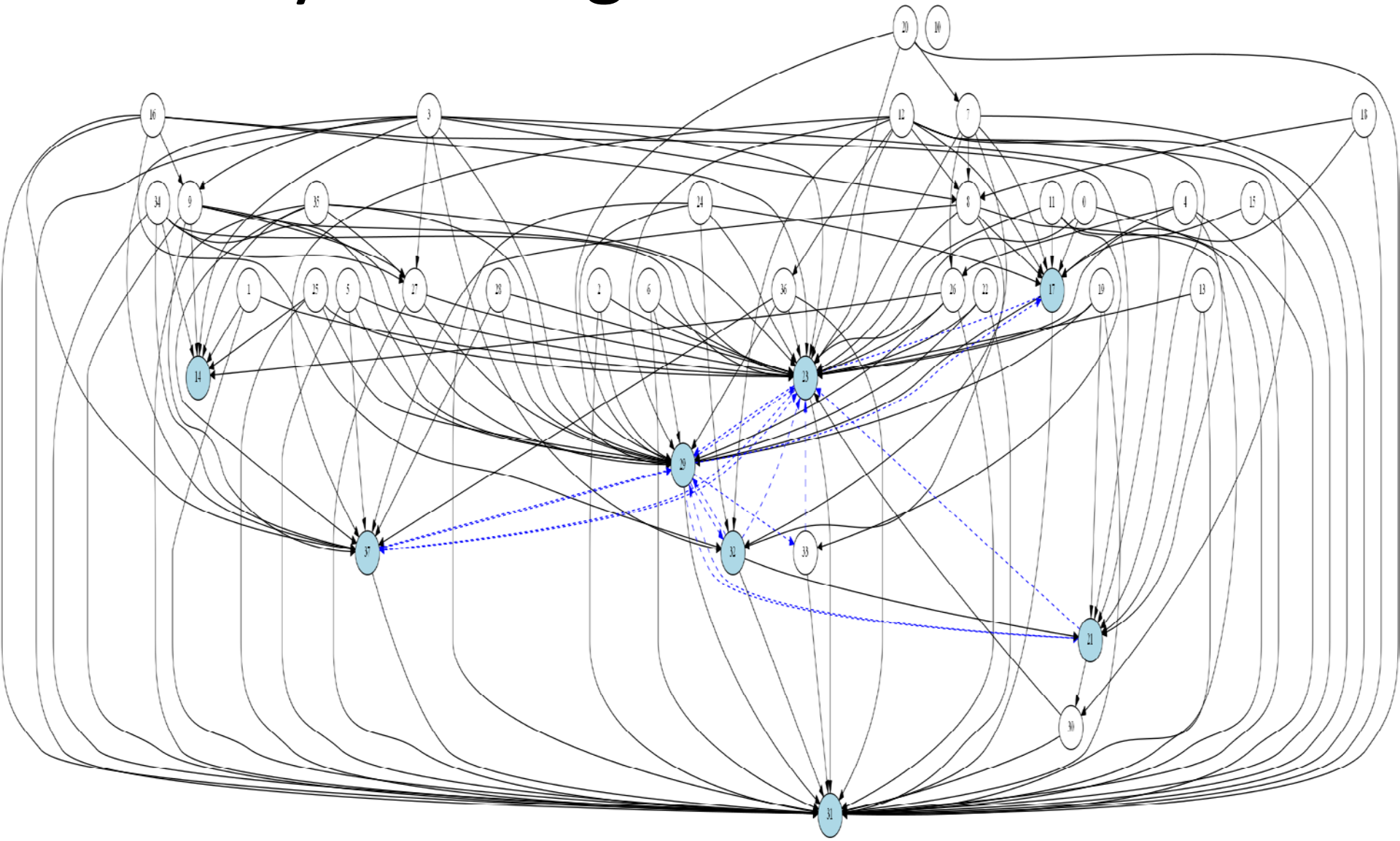
How a single organ donation changed 20 lives and created the longest-running transplant chain



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

NKR 2012

Why are long chains so useful?



Compatibility Graph induced by pairs with A patients and A donors 38 pairs, only 5 can be covered by some cycle

Should kidneys be bought and sold?

- It's a felony to buy or sell organs for transplantation
  - Some people think it would be a good idea to allow kidneys to be bought and sold, and others think it's the kind of bad idea that only bad people have…
- It got me thinking about repugnance as a constraint on markets
  - Scholars need to understand a lot more about how economic and business transactions are understood by regular folks…

What's next for market design?

- Design of *decentralized* marketplaces
  - Market for new economists: scramble and signaling (w/ Peter Coles and Muriel Niederle and…)
    - Dating websites—signaling: Soo Lee and Niederle; Coles, Kushnir and Niederle
  - (Pre-)Market for gastroenterologists
    - Rules about offers and acceptances (Niederle, Proctor and Roth)

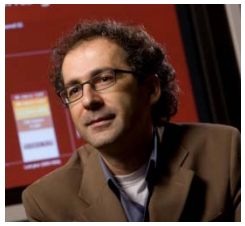
What is a free market?

- One with rules and institutions that let it operate freely…
  - Think of a wheel that can rotate freely, because it has an axle and well-oiled bearings

The economist as engineer

- **Game theory**
  - A combination of strategic and coalitional models
- Plus…
- **Empirics**: Careful observation of rules: to a game theorist, **rules are data!**
- **Computation**: sometimes we need to give advice beyond our reliable scientific knowledge
- **Controlled Experiments**: there are lots of design questions that can't be answered in small scale lab experiments, but there are also questions that can't be answered any other way
- Theory and practice interact, and lead to new kinds of theory.

Market design is a team sport that involves both academics and practitioners…and sometimes it is hard to tell which is which.



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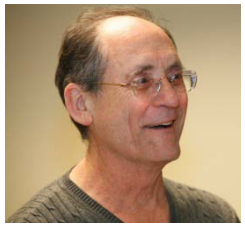

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