

APPLIED MECHANISM DESIGN FOR SOCIAL GOOD

JOHN P DICKERSON

Lecture #1 – 01/26/2021

CMSC828M
Tuesdays & Thursdays
2:00pm – 3:15pm



COMPUTER SCIENCE
UNIVERSITY OF MARYLAND

Markets come in many forms ...

... some of which don't conform to
conventional notions of markets ...

... and some in which money may play little or no role.

– excerpt from *Who Gets What – and Why*

AESTHETICALLY-DISPLEASING ONE-SLIDE COURSE SUMMARY

Mechanism design is a field in economics and game theory that takes an engineering approach to designing economic mechanisms or incentives, **toward desired objectives**, in strategic settings, where players act rationally.

AKA “reverse game theory” – we’re **designing the rules of the game**, not figuring out how to play it.

This course: can we design mechanisms for societal problems that perform well in practice, are computationally tractable, and whose workings and results are understandable by humans?

More info: <https://marketdesign.github.io/>

PREREQUISITE KNOWLEDGE

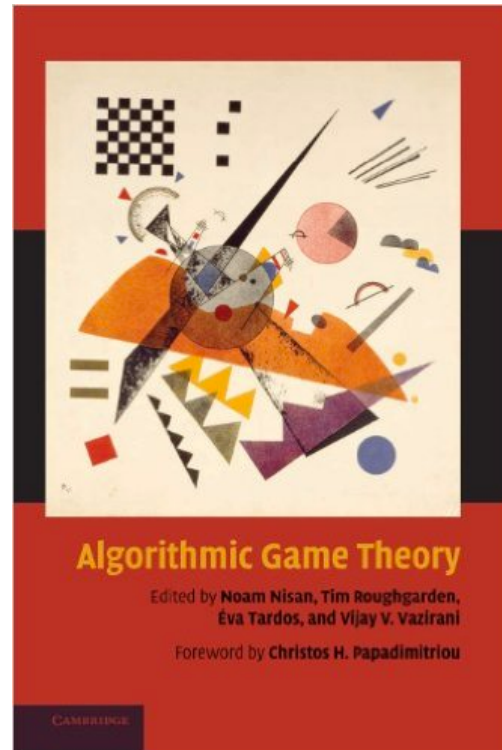
Aimed at **Ph.D. students** – but likely accessible to others with mathematical maturity and interest.

Assuming:

- Basic CS undergrad knowledge of theory (correctness proofs, NP-hardness, impossibility results)
- Basic CS/Math undergrad knowledge of optimization
 - Convex optimization, LPs, IPs – one lecture of primer, too
- Basic CS/Math undergrad knowledge of statistics and probability
- Ability to consume scientific papers (CS, Econ, OR)

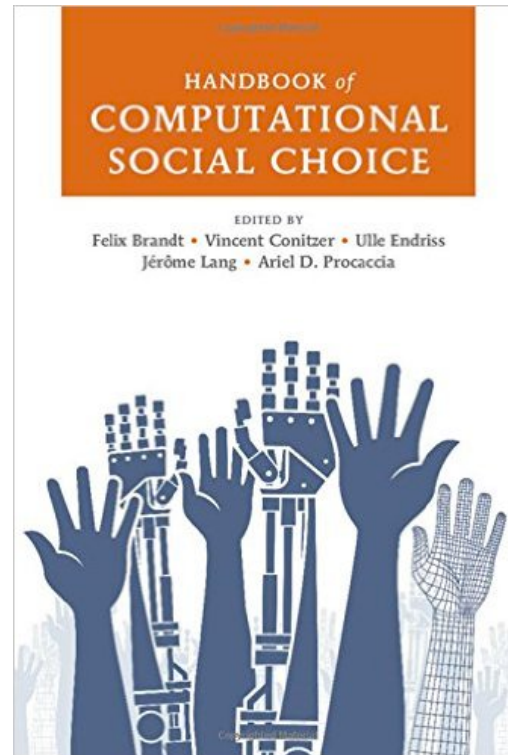
All of this can be learned on the fly! Recommended books ...

BOOK #1: “THE AGT BOOK”



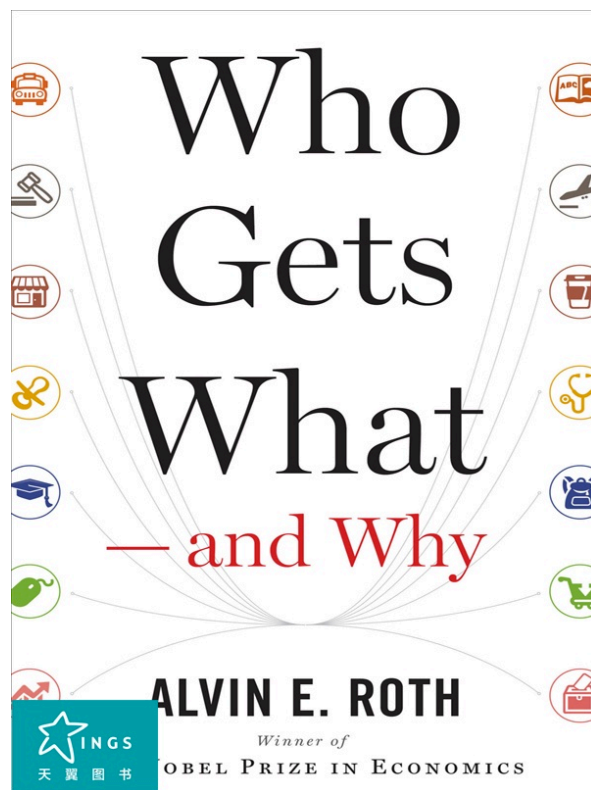
It's **free** online! Check the course webpage.

BOOK #2: “CSC HANDBOOK”



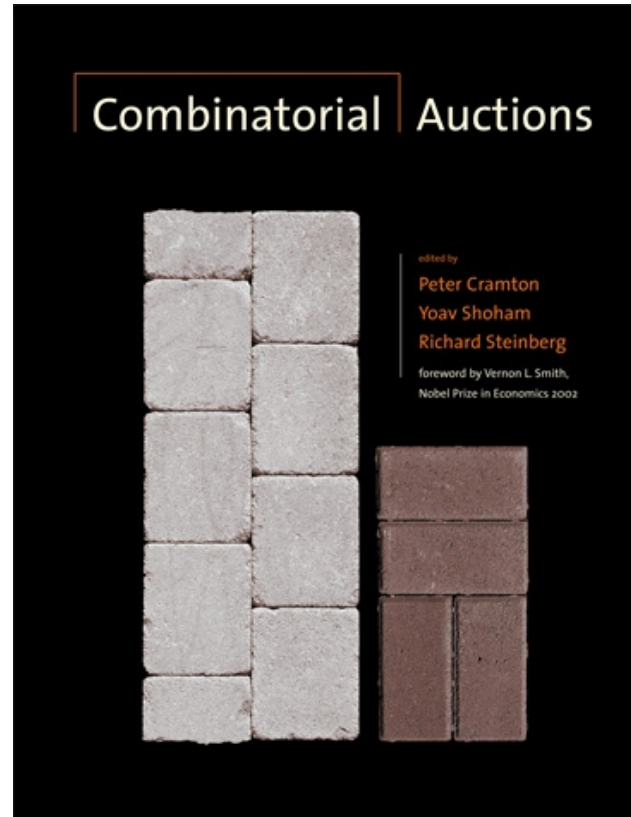
It's **free** online! Check the course webpage.

BOOK #3: “MATCHING MARKET DESIGN”



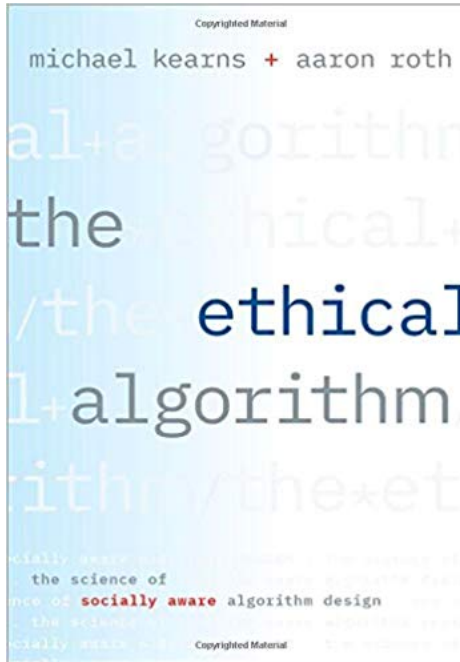
It's **not free** online! UMD has one copy.

BOOK #4: “COMBINATORIAL AUCTIONS”



It's **free** online! Check the course webpage.

BOOK #5: “THE ETHICAL ALGORITHM”

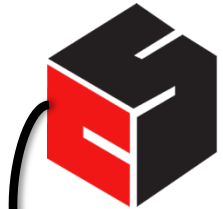


It's **not free** online! UMD might have a copy?

SINGLE-SLIDE VERSION OF JOHN

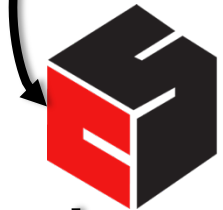


UNITED NETWORK FOR ORGAN SHARING



COMPUTER SCIENCE
UNIVERSITY OF MARYLAND 2004 – 2008

Carnegie Mellon University
School of Computer Science 2010 – 2016



COMPUTER SCIENCE
UNIVERSITY OF MARYLAND 2016 – ∞



APPLIED MATHEMATICS &
STATISTICS, AND SCIENTIFIC
COMPUTATION PROGRAM



**OPTIMIZED
MARKETS**



facebook research 2018 – 2020

{ Advisory roles in UMD alumni's startups } 2017 – now

{ Advisory role to a US regulatory agency } Late 2019 +



**THE DIAN FOSSEY
GORILLA FUND
INTERNATIONAL**

WHO ARE YOU?

Area?

Interest in this course?

Goals in life? And goals
for this course?



PhD/MSc/BSc?

Background in: CS, game
theory, mechanism
design, HCI?

Advisor?

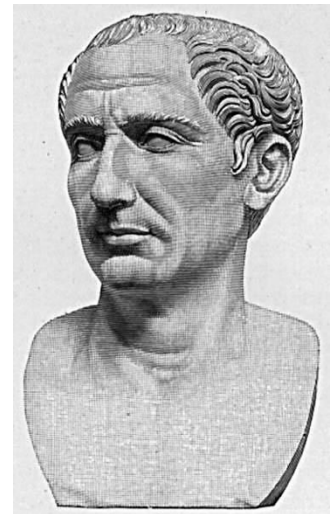
I'm probably going to use Slack instead of Piazza – thoughts?

COURSE STRUCTURE

First 5-6 lectures: primers in GT/MD and optimization

Next 23 lectures: theory + application areas

- Security games
- Healthcare markets (organ allocation, financing R&D)
- Food allocation
- Learning for mechanism design
- Combinatorial assignment (bidding on courses)
- Incentive auctions (FCC spectrum allocation)
- Fair Division (allocating rooms to schools)
- Voting
- School choice (assigning kids to schools)
- Prediction markets
- 2-3 lectures of “floating topics” – ideas?



Ambitious ...

GRADE #1: PROJECT

Students will complete a **semester-long course project** on something related to market and mechanism design.

- Individual or small group
- 100% theory, 100% applied, or convex combination

Goal: create something **publishable!**

Important dates:

- Project proposals will be due in early March
- ~~Project presentations will be during the last 2-3 lectures~~
- Project writeups—formatted as, say, a NeurIPS conference paper or similar—will be due by the exam date for this course (Monday, May 17 at 10:30AM).

A FEW PROJECTS FROM RECENT YEARS ...

Some projects from recent years that have been published:

- Faez Ahmed: diverse b-matching (IJCAI-17, [arXiv](#))
- Neal Gupta: competition in dynamic matching markets (IJCAI-18)
- Duncan McElfresh: a new fairness metric for kidney exchange (AAAI-18, [arXiv](#))
- Elissa Redmiles: behavioral economics and two-factor authentication (EC-18 & CCS-18, [arXiv](#))
- Candice Schumann: diversity and multi-armed bandits (AAMAS-19 & NeurIPS-19, [arXiv](#) & [arXiv](#))
- Many projects in the works from last year / under submission / I'm sure many that I don't know about!

GRADE #2: PRESENT A PAPER (ON ZOOM/YOUTUBE/ETC)

Students will pick a paper (or papers, or chapter, or topic, or ...) to present, and will create a small video recording (let's say 15 minutes, but this is flexible) that we can post online!

- Good for you!
- Good for your fellow classmates!

Check out the course webpage for topics

- Also: feel free to suggest a topic you like!

Logistics:

- We'll figure this out in second week



GRADE #3: TAKE-HOME EXAMS

The majority of students want this to be an MSc/PhD qualifier

- So this course is an **AI qualifier** for CMSC grad students

What this means:

- “... the courses' written exam(s) which must account for at least 30% of the grade.” – *UMD graduate handbook*

Implementation:

- One take-home **midterm**; 24 hours to do it
- One take-home **final**; 48 hours to do it
- I'll let you pick when you take exams (within reason; see site)



CLASS PARTICIPATION

Please please please please please read the paper(s) before coming to class!

- I want to speak **with** you, not at you ...
- Also, looking forward to your video presentations!

Participate on Slack, help brainstorm project ideas, ask questions in class, answer questions in class, etc.

GRADE BREAKDOWN | QUALIFIER APPROVAL

55% course project:

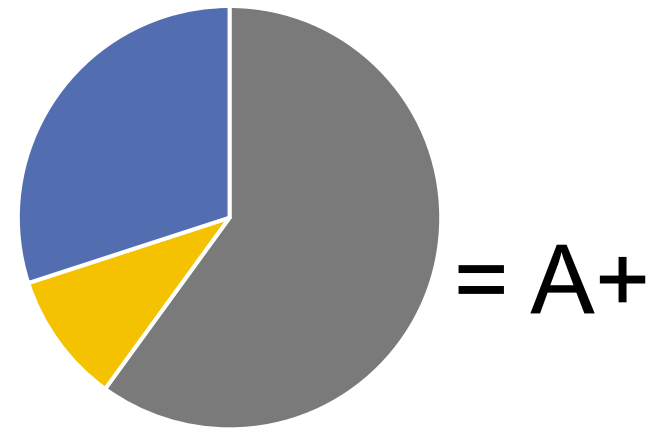
- 5% project proposal (early March)
- 5% project checkup (April)
- 45% course project writeup (mid-May)

15% presenting/summarizing a paper

30% examinations:

- Better of 10%/20% or 15%/15% midterm/final

Your Grade



■ Project ■ Paper Present ■ Examinations

IMPORTANT WALLS OF TEXT

ANTI-HARASSMENT

(Adapted from ACM SIGCOMM's policies)

The **open exchange of ideas and the freedom of thought and expression** are central to our aims and goals. These require an environment that recognizes the inherent worth of every person and group, that fosters dignity, understanding, and mutual respect, and that embraces diversity. For these reasons, we are dedicated to providing a harassment-free experience for participants in (and out) of this class.

Harassment is unwelcome or hostile behavior, including speech that intimidates, creates discomfort, or interferes with a person's participation or opportunity for participation, in a conference, event or program.

ACADEMIC INTEGRITY

(Text unironically stolen from Hal Daumé III)

Any assignment or exam that is handed in must be your own work (unless otherwise stated). However, talking with one another to understand the material better is strongly encouraged. Recognizing the distinction between cheating and cooperation is very important. If you copy someone else's solution, you are cheating. If you let someone else copy your solution, you are cheating (this includes *posting solutions online in a public place*). If someone dictates a solution to you, you are cheating.

Everything you hand in must be in your own words, and based on your own understanding of the solution. If someone helps you understand the problem during a high-level discussion, you are not cheating. **We strongly encourage students to help one another understand the material presented in class, in the book, and general issues relevant to the assignments.** When taking an exam, you must work independently. Any collaboration during an exam will be considered cheating. Any student who is caught cheating will be given an F in the course and referred to the University Office of Student Conduct. Please don't take that chance – if you're having trouble understanding the material, please let me know and I will be more than happy to help.

EXAMPLE APPLICATION AREAS

MANY OF WHICH WE'LL COVER IN FUTURE CLASSES

EXAMPLE: MATCHING MARKETS

In matching problems, prices do not do all – or any – of the work

Agents are **paired** with other (groups of) agents, transactions, or contracts

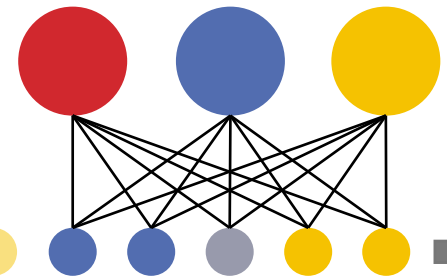
- Workers to firms
- Children to schools
- Residents to hospitals
- Patients to deceased donors
- Advertisements to viewers
- Riders to rideshare drivers



UNCERTAINTY IN MATCHING MARKETS

- Does a matched edge truly exist?
- How valuable is a match?
- Will a better match arrive in the future?

upwork™
formerly oDesk



COMPETITION IN MATCHING MARKETS

Rival matching markets compete over the same agents

- How does this affect global social welfare?
- How to differentiate?



CADENCE OF MATCHING MARKETS

How quickly do new edges form?

How frequently does a market clear?

Is clearing centralized or decentralized?

Can agents reenter the market?



EXAMPLE: RESIDENT-HOSPITAL ASSIGNMENT

1940s: decentralized resident-hospital matching

- Market “unraveled”, offers came earlier and earlier, quality of matches decreased

1950s: NRMP introduces hospital-proposing **deferred acceptance** algorithm

1970s: couples increasingly don't use NRMP

1998: matching with couple constraints

- (**Stable matching** may not exist anymore ...)

Take-home message

Looks like: M.D.s aren't the only type of doctor who help people!



EXAMPLE: COMBINATORIAL COURSE ALLOCATION

[IMAGES FROM BUDISH ET AL. WORKING PAPER 2016]

BIDDING

COURSE MATCH UTILITY SELECTION

Dept	Instructor	Day	Time	Cu	Qtr	Show Positive
MGMT691408 LGSST806408 OPIM691408	NEGOTIATIONS DIAMOND S R 3:00 PM - 6:00 PM (8/27/14 - 12/9/14) This course CANNOT be taken Pass/Fail.			1.00	S	80 LGSST806408
MGMT721001	CORP DEV. MERG & ACQUIS FELDMAN E MW 9:00 AM - 10:30 AM (8/27/14 - 12/9/14) This course CANNOT be taken Pass/Fail.			1.00	S	80
MGMT721002	CORP DEV. MERG & ACQUIS FELDMAN E MW 12:00 PM - 1:30 PM (8/27/14 - 12/9/14) This course CANNOT be taken Pass/Fail.			1.00	S	80
OPIM673002	GLOBAL SUPPLY CHAIN MGMT FISHER M TR 1:30 PM - 3:00 PM (10/18/14 - 12/9/14)			0.50	2	85
LGST611002	RESP IN GLOBAL MGMT PETKOSKI D M 3:00 PM - 6:00 PM (10/20/14 - 12/4/14) This course CANNOT be taken Pass/Fail.			0.50	2	90
LGST612003	RESP IN PROF'L SERVICES ZARING D MW 10:30 AM - 12:00 PM (8/27/14 - 10/8/14) This course CANNOT be taken Pass/Fail.			0.50	1	90
MGMT789001	GOV & MGMT. OF CHIN FRMS ZHAO M TR 10:30 AM - 12:00 PM (8/27/14 - 12/9/14)			1.00	S	90
OPIM614001	INNOVATION TERWIESCH C			0.50	1	90

My Settings

My Utility Distribution

- LCST806410
- MCMT772001
- OPIM690401
- MCMT701002
- OPIM673001
- MCMT691411
- LGST611001
- OPIM690402
- OPIM690403
- MCMT701001
- OPIM614002
- LCST612001
- OPIM614003

My Adjustments

My Top Schedules

DYNAMIC EXCLUSIONS

COURSE MATCH Course Match closing: Mon Aug 17 12:00 PM FALL 2015 MBA Courses

MY TOP SCHEDULES

Schedule Value: 392.5

Schedule Value: 382.5

Schedule Value: 345

Schedule Value: 342.5

Schedule Value: 335

Schedule Value: 322.5

My Settings

My Utility Distribution

My Adjustments

My Utilities

Course	Utility
FNCE72601	100
ACCT74202	95
HCMG85002	95
LGST220401	85
LGST620401	LGST620401
FNCE721404	80
REAL721404	REAL721404
BEPP770401	70
BEPP201401	BEPP770401
ACCT742003	40
BEPP823401	20
BEPP322401	BEPP823401

Showing 1 to 8 of 8.

“Funny money” used for bidding

EXAMPLE: VOTING

Set of **voters** N and a set of **alternatives**:

{Joe Biden, Bernie Sanders, Donald Trump}

Each voter ranks the candidates:

v_1 : Donald Trump > Bernie > Joe Biden

v_2 : Joe Biden > Bernie > Donald Trump

...

A **preference profile** is the set of all voters' rankings

Can we choose a **voting rule** – that is, a function that takes preference profiles and returns a winning alternative – that:

- “Behaves well”
- Isn't manipulable by strategic agents



EXAMPLE: FAIR ALLOCATION

Divisible goods:

- Splitting land, cutting cake

Indivisible goods:

- Splitting up assets after divorce (house, cars, pets)



<http://spliddit.org>

A chief concern: defining and guaranteeing the fairness of the final allocation

An allocation is **envy free** if each player values her own allocated set of goods at least as highly as any other player's allocated set

When do envy-free allocations exist? How can we compute them? What can we do when they don't exist?

EXAMPLE: FOOD BANK ALLOCATION

Food banks supply nutrition to the needy for free or at a reduced cost

- Much of that food comes from donors (e.g. supermarkets, manufacturers)

Distribution is overseen by a large non-profit organization, Feeding America

- Previously: **centralized allocation** based on perceived need of food banks
- Currently: food banks bid in an **online auction** using a fake currency for loads of donated food.



EXAMPLE: SECURITY GAMES

Where should we deploy security forces (checkpoints, cop cars, dogs, troops), assuming a rational adversary who can observe our deployment strategy?

- Checkpoints at airports
- Patrol routes on the water on the borders
- **Anti-poacher teams near big game**

Rangers Use Artificial Intelligence to Fight Poachers

Emerging technology may help wildlife officials beat back traffickers.

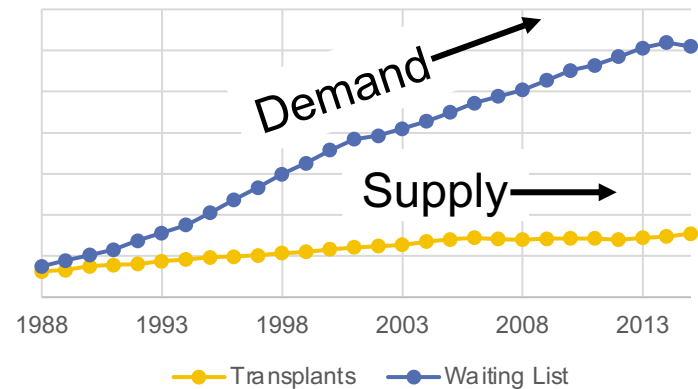


How do we compute these strategies?

What if the adversary isn't rational?

EXAMPLE: KIDNEY TRANSPLANTATION

- **US waitlist: over 100,000**
 - 36,157 added in 2014
- **4,537 people died while waiting**
- **11,559 people received a kidney from the deceased donor waitlist**
- **5,283 people received a kidney from a living donor**
 - Some through **kidney exchanges** [Roth et al. 2004]
 - (We work extensively with the UNOS exchange.)



EXAMPLE: DECEASED-DONOR ALLOCATION

Online bipartite matching problem:

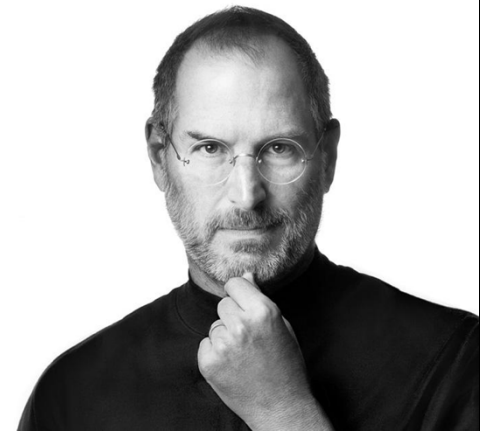
- Set of patients is known (roughly) in advance
- Organs arrive and must be dispatched **quickly**

Constraints:

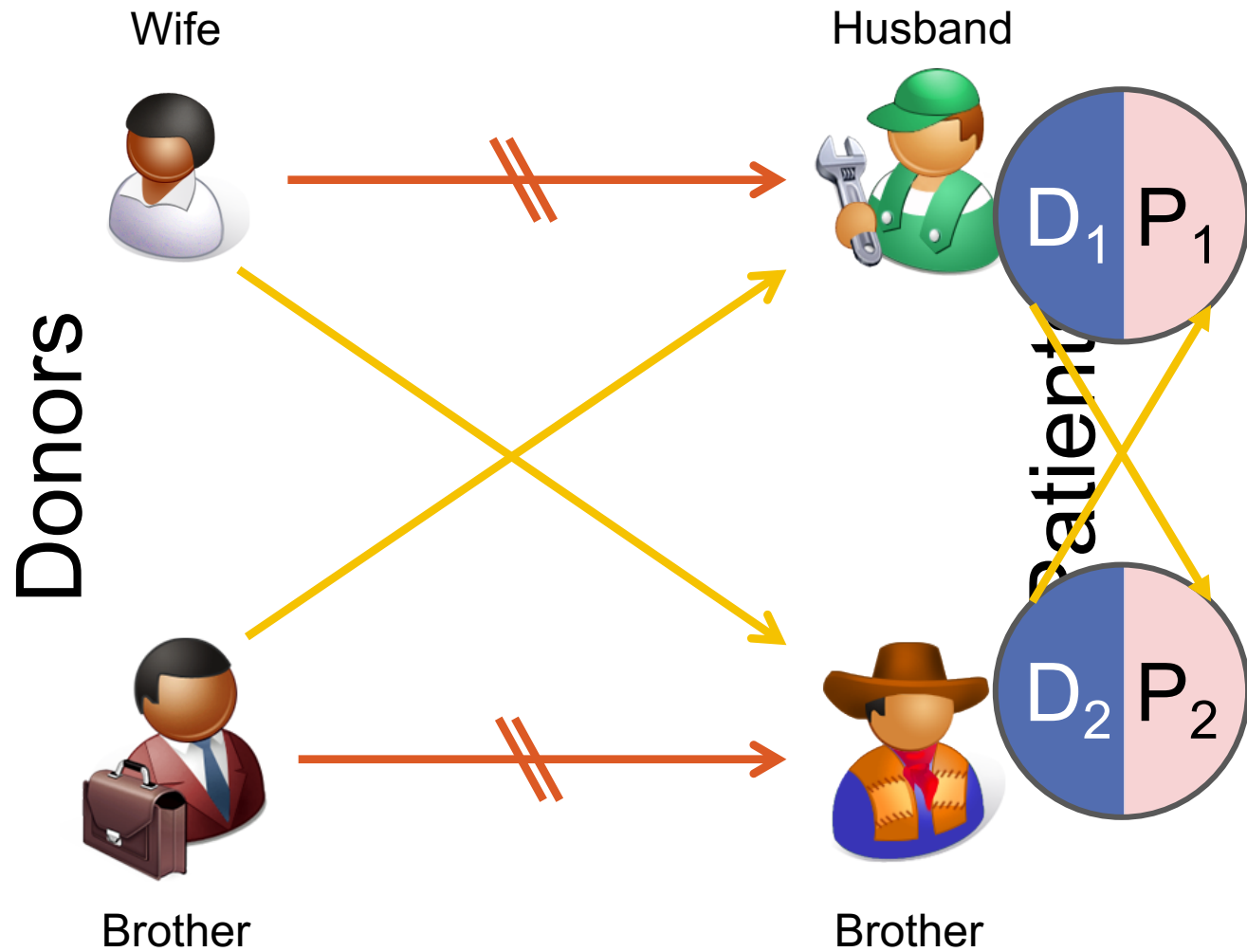
- Locality: organs only stay good for 24 hours
- Blood type, tissue type, etc.

Who gets the organ? Prioritization based on:

- Age?
- QALY maximization?
- Quality of match?
- Time on the waiting list?



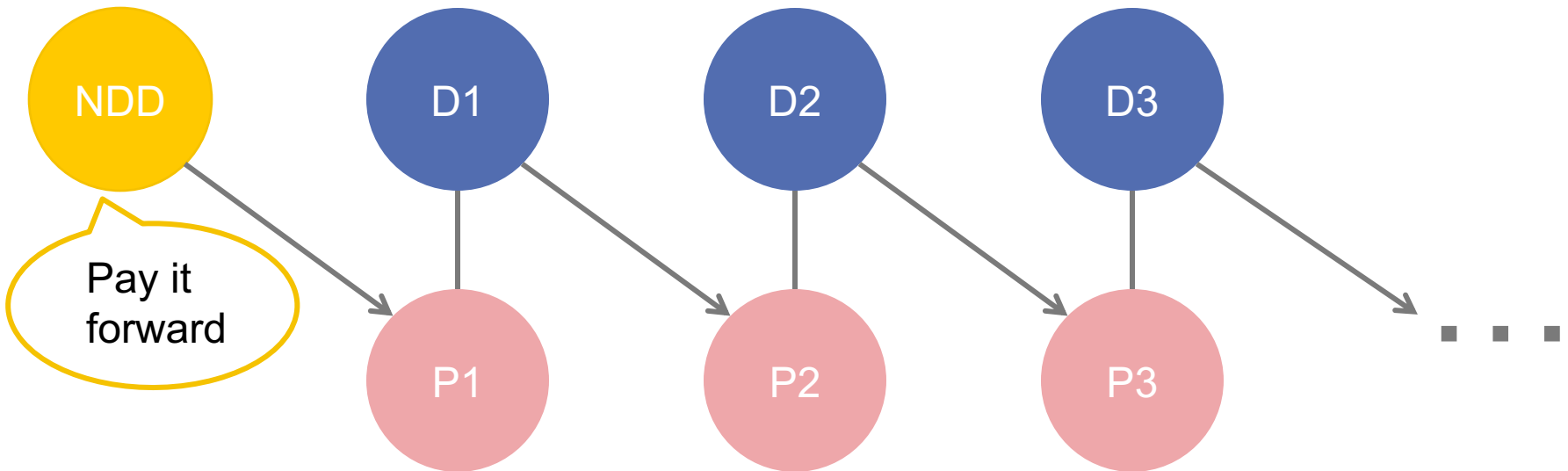
EXAMPLE: KIDNEY EXCHANGE



(2- and 3-cycles, all surgeries performed simultaneously)

NON-DIRECTED DONORS & CHAINS

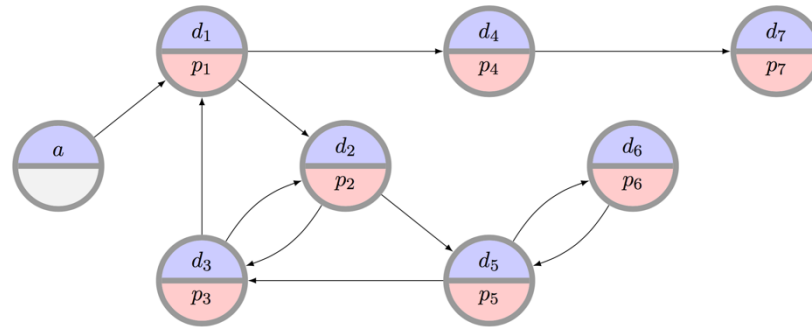
[Rees et al. 2009]



Not executed simultaneously, so no length cap required based on logistic concerns ...

... but in practice edges fail, so some finite cap is used!

EXAMPLE: KIDNEY EXCHANGE



What is the “best” matching objective?

- Maximize matches right now or over time?
- Maximize transplants or matches?
- Prioritization schemes (i.e. fairness)?
- Modeling choices?
- Incentives? Ethics? Legality?

Can we design a mechanism that **performs well in practice**, is **computationally tractable**, and is **understandable by humans**?

TECHNIQUES WE'LL USE

*(NEXT THREE LECTURES WILL COVER THESE,
IN THE CONTEXT OF MECHANISM DESIGN)*

COMBINATORIAL OPTIMIZATION

Combinatorial optimization lets us select the “best element” from a set of elements.

Some **PTIME** problems:

- Some forms of matching
- 2-player zero-sum Nash
- Compact LPs

Some **PPAD-** or **NP-hard** problems:

- More complex forms of matching
- Many equilibrium computations

Some **> NP-hard** problems:

- Randomizing over a set of all feasible X , where all feasible X must be enumerated (#P-complete)

C.O. FOR KIDNEY EXCHANGE: THE EDGE FORMULATION

[Abraham et al. 2007]

Binary variable x_{ij} for each edge from i to j

Maximize

$$u(M) = \sum w_{ij} x_{ij}$$

Flow constraint

Subject to

$$\sum_j x_{ij} = \sum_j x_{ji}$$

for each vertex i

$$\sum_j x_{ij} \leq 1$$

for each vertex i

$$\sum_{1 \leq k \leq L} x_{i(k)i(k+1)} \leq L-1$$

for paths $i(1) \dots i(L+1)$

(no path of length L that doesn't end where it started – cycle cap)

C.O. FOR KIDNEY EXCHANGE: THE CYCLE FORMULATION

[Roth et al. 2004, 2005,
Abraham et al. 2007]

Binary variable x_c for each feasible cycle or chain c

Maximize

$$u(M) = \sum w_c x_c$$

Subject to

$$\sum_{c: i \text{ in } c} x_c \leq 1 \text{ for each vertex } i$$

C.O. FOR KIDNEY EXCHANGE: COMPARISON

Tradeoffs in number of variables, constraints

- IP #1: $O(|E|^L)$ constraints vs. $O(|V|)$ for IP #2
- IP #1: $O(|V|^2)$ variables vs. $O(|V|^L)$ for IP #2

IP #2's relaxation is weakly tighter than #1's. Quick intuition in one direction:

- Take a length $L+1$ cycle. #2's LP relaxation is 0.
- #1's LP relaxation is $(L+1)/2$ – with $1/2$ on each edge

Recent work focuses on balancing tight LP relaxations and model size

[Constantino et al. 2013, Glorie et al. 2014, Klimentova et al. 2014, Alvelos et al. 2015, Anderson et al. 2015, Mak-Hau 2015, Manlove&O'Malley 2015, Plaut et al. 2016, ...]:

- We will discuss (9/29) new compact formulations, some with tightest relaxations known, all amenable to failure-aware matching

GAME THEORY & MECHANISM DESIGN

We assume participants in our mechanisms are:

- Selfish utility maximizers
- Rational (typically – sometimes relaxed)

Game theory & M.D. give us the language to describe desirable properties of mechanisms:

- Incentive compatibility
- Individual rationality
- Efficiency

A dark blue rectangular box containing white text that reads: "A STRANGE GAME. THE ONLY WINNING MOVE IS NOT TO PLAY. HOW ABOUT A NICE GAME OF CHESS?"

MACHINE LEARNING

Predicting supply and demand

Computing optimal matching/allocation policies:

- MDPs
- RL
- POMDPs, if you're feeling brave/masochistic

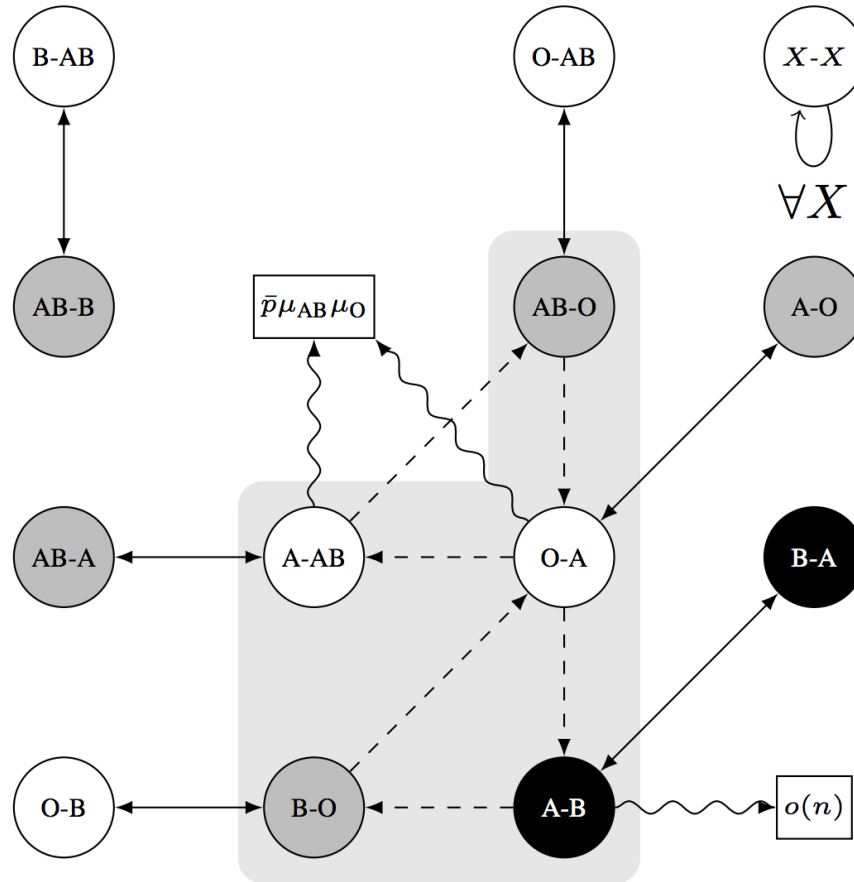
Aside: recent work looks at fairness and discrimination in machine learning – could be an interesting project.

- “... when a search was performed on a name that was “racially associated” with the black community, the results were much more likely to be accompanied by an ad suggesting that the person had a criminal record—regardless of whether or not they did.”

CAN COMPUTERS BE RACIST?

Big data, the internet, and the law

RANDOM GRAPH THEORY



**NEXT CLASS:
GAME THEORY PRIMER**