CS 598:
AI Methods for Market Design

Lecture 1: Introduction

Xintong Wang

Spring 2024

Outline

- Course overview
- Examples of market failure / inefficiency
- Administrivia
- Illustrative topics

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Today’s Markets

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Computational systems where *participants* interact with each other to pursue their goals at an unprecedented complexity, speed, and scale.

Our Lens: *"EconCS"*

- Economics

"The study of decision making by multiple actors, each with individual preferences, capabilities, and information, and motivated to act in regard to these preferences."

(Parkes & Seuken)

Our Lens: *"EconCS"*

- Computer Science

"The study of the types of computation that can be carried out efficiently, under time, resource and communication constraints."

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Our Lens: *"EconCS"*

- Computer Science

"The study of the types of computation that can be carried out efficiently, under time, resource and communication constraints."

(Parkes & Seuken)

- Artificial Intelligence

"The study of agents that receive percepts from the environment and perform actions to achieve specified tasks or goals."

(Russell and Norvig)

Our Lens: *"EconCS"*

"The analysis and design of systems whose performance depends on achieving good incentive properties and good computational properties."

(Parkes & Seuken)

Course Goal

- Learn how to model, analyze, and design computational, multi-agent systems where *incentives* matter
  - Model the decision making of participants who are free agents
  - Analyze the relation between rules in the marketplace and market outcomes
  - Redesign market to promote desirable behaviors and achieve system-wide objectives

Course Goal

- Appreciate the way in which systems both influence and are influenced by user behavior

- Get to know some of the cutting-edge research topics and papers on AI for market design

Course Agenda

What we will cover

- Topics listed in syllabus on course website
- Basics of game theory, equilibrium computation, auctions, mechanism design, matching, information elicitation, prediction market, cryptoeconomics…
- Research papers on how AI can advance topics above
- Incentives and game-theoretic aspects in learning settings (e.g., adversarial learning, recommender system, performative prediction, federated learning)

Course Agenda

What we will *not* cover

- Recipe to implement and train ML/DL algorithms
- Recipe to predict stock prices and make profits
- How to use ML platform/framework, e.g., TensorFlow, PyTorch (though you may need them for the class project of your choice)
- How to beat state-of-the-art algorithms on benchmark datasets or RL games

Outline

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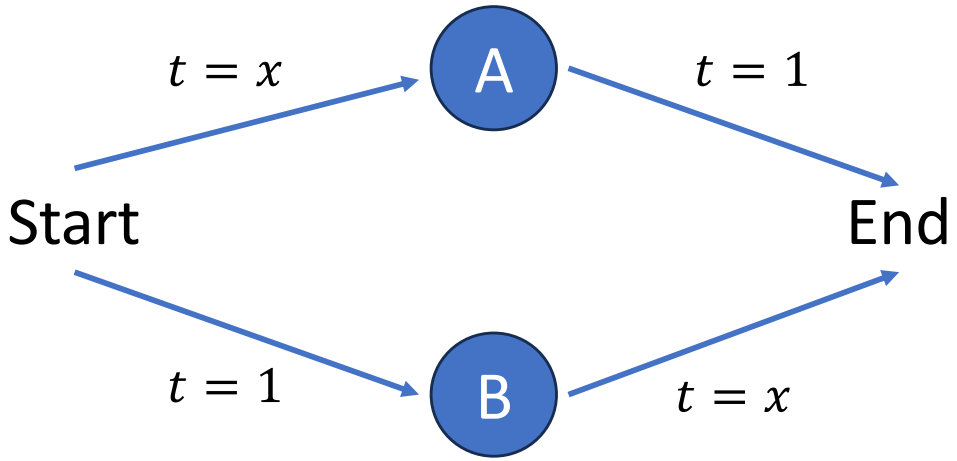
Example 1: Braess' paradox

- Transportation systems
- Power transmission networks
- Many more…

Example 1: Transportation System

- A unit mass of people commute to work everyday from point “Start” to point “End”.
- Every driver has to choose a path, without seeing what others do.



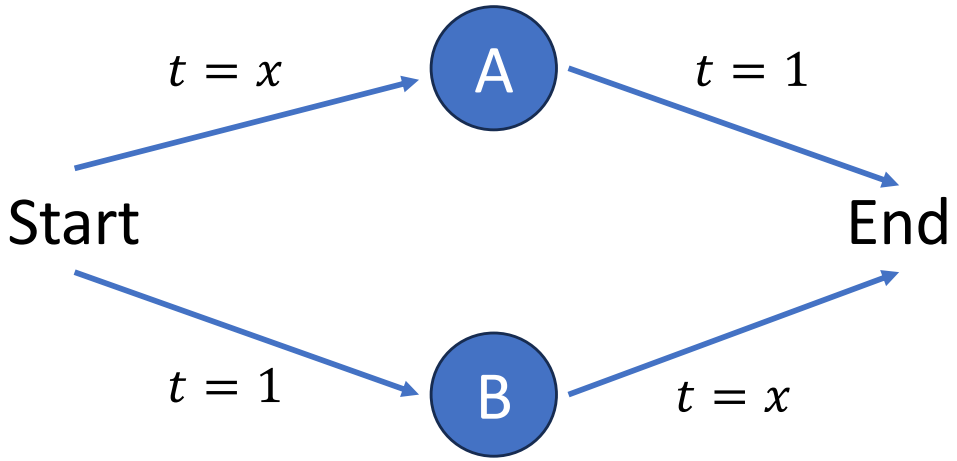
Example 1: Transportation System

- Optimal (min max delay):

  0.5 via A and 0.5 via B with 1.5 hours delay.

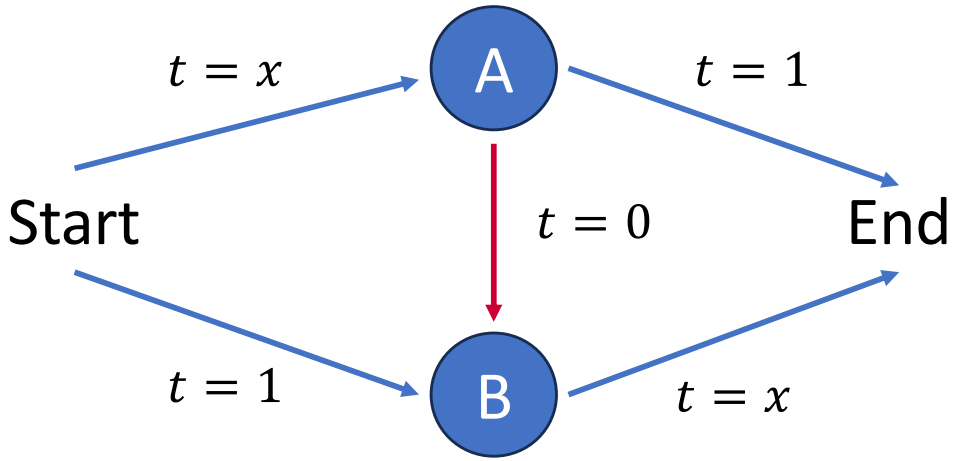
- Also the *"Equilibrium"*:

  Everyone prefers their path to switching paths.



Example 1: Transportation System

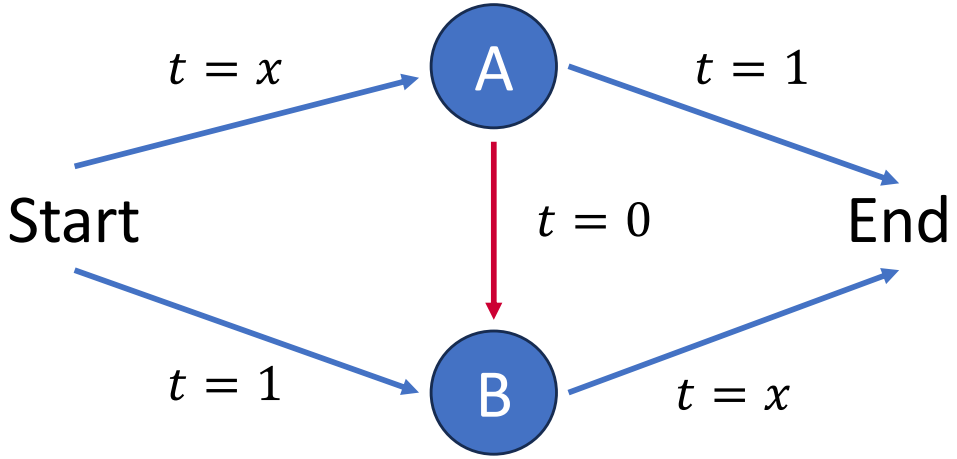
- Add super highway!



Example 1: Transportation System

- Add super highway!
- Optimal (min max delay):

  0.5 via A and 0.5 via B with 1.5 hours delay.
- *What about the new equilibrium?*



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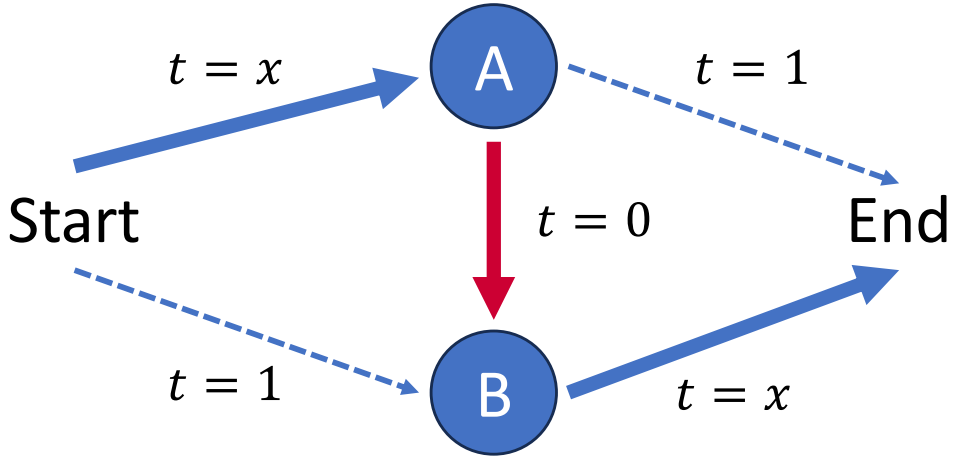

S->A->B and A->B->E each take at most 1 hour!

Example 1: Transportation System

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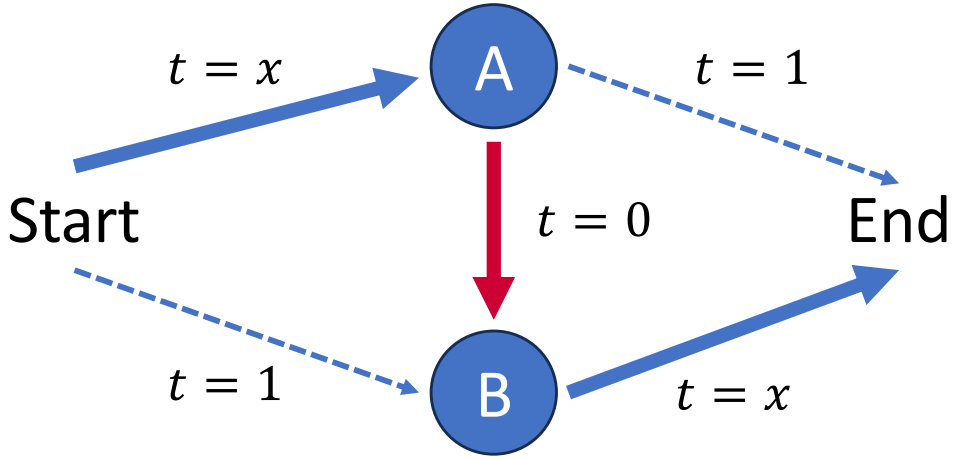

S->A->B->E is a dominant strategy.

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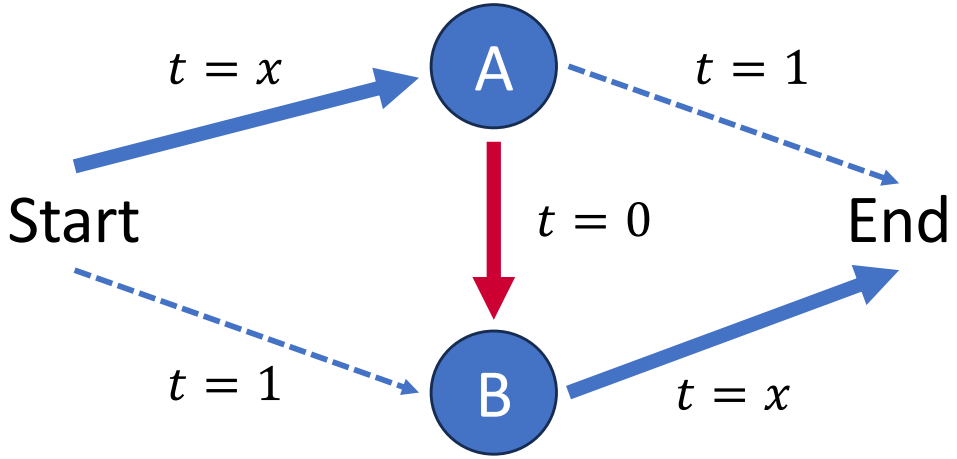
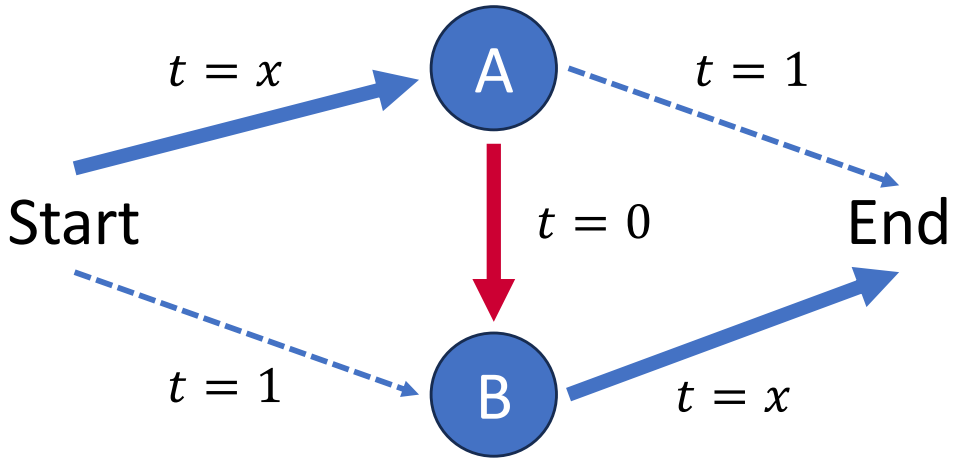
- *What about the new equilibrium?*



A mass of 1 via S->A->B->E with 2 hours delay!

Example 1: Transportation System

- Braess' Paradox: Super highway reduces the system's performance under rational behavior.
- Seemingly helpful design may lead to inefficient outcomes!



Example 1: Transportation System

- Braess' Paradox

The New York Times

Mayor Plans to Close Parts of Broadway to Traffic

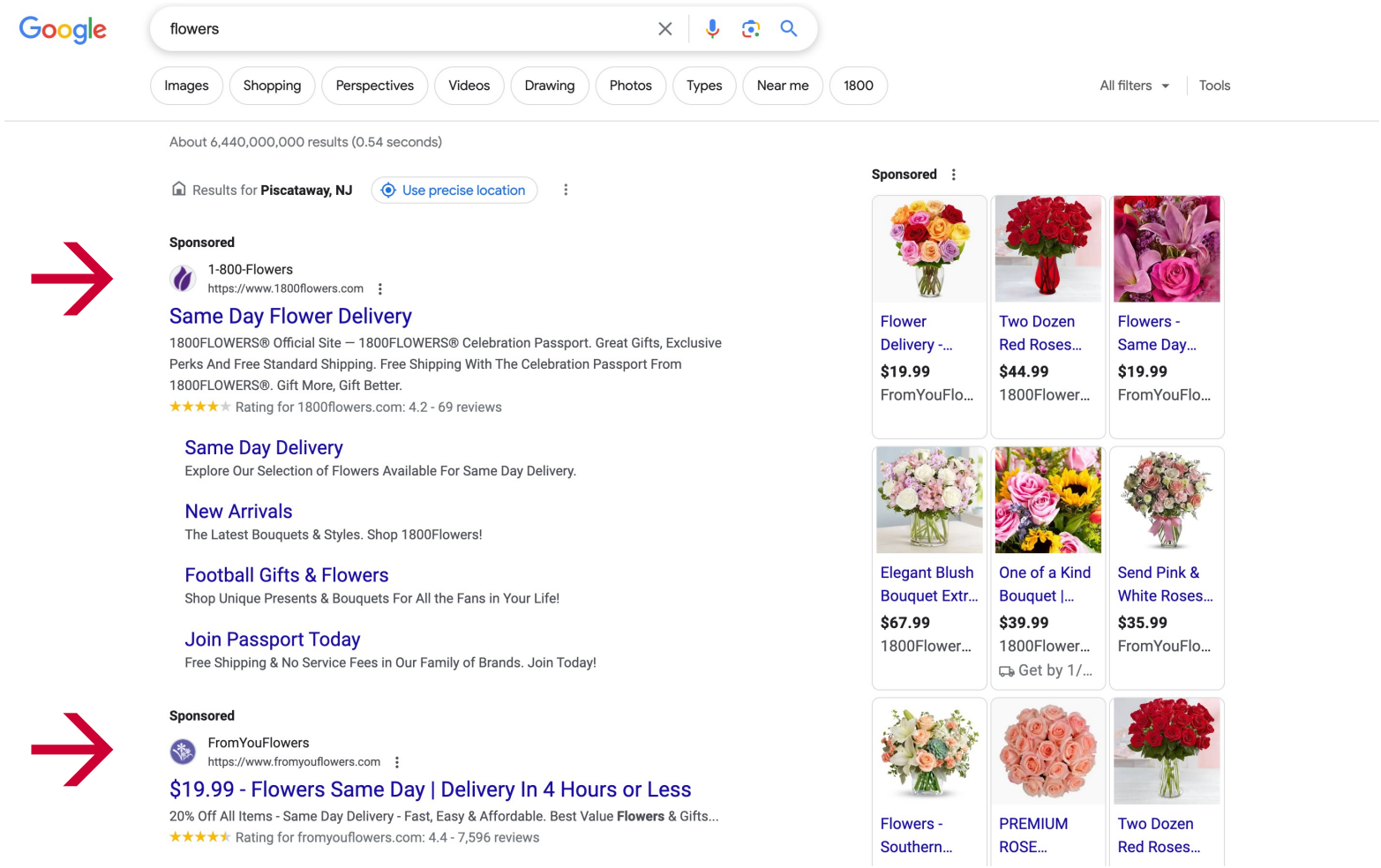
Share full article

By William Neuman and Michael Barbaro

Feb. 25, 2009

The article claims that "Traffic along Seventh Avenue, for example, moved 4 percent faster," and that "Travel times along that avenue [the Avenue of the Americas] improved by 15 percent, according to the city's data." Additionally, "northbound travel times improved by 17 percent," according to "numbers [which] encompassed 1.1 million Midtown taxi trips taken between Fifth and Ninth Avenues in Midtown".

Example 2: Sponsored Search Auctions



Example 2: Sponsored Search Auctions

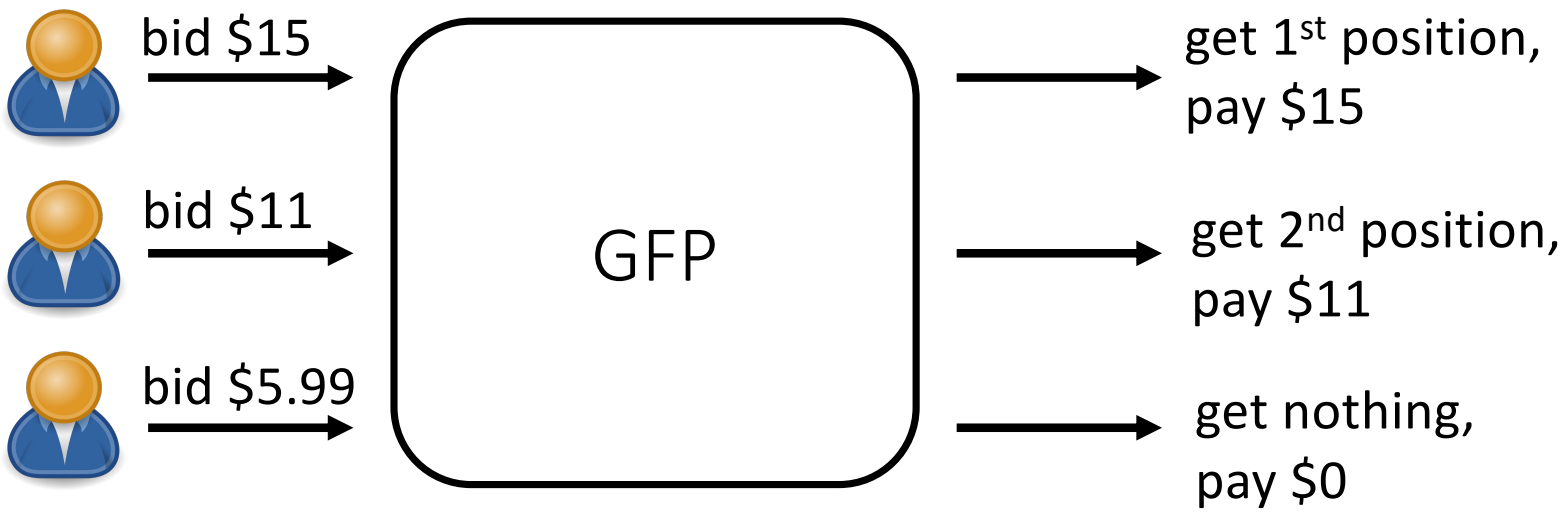
- Two ad positions with distinct *clickthrough rate** (CTR)
  - ❑ $CTR_1 = 0.1, CTR_2 = 0.02$
- Three advertisers (or bidders) with different *value per click* and submit their *bid per click*
  - ❑ $\mathrm{v}_1 = \$15, v_2 = \$11, v_3 = \$5.99$
- Expected profit for an impression in position *j* for advertiser *i:*

$$CTR_j(\underbrace{v_i - b_i}_{\text{Profit per click}})$$

clickthrough rate: the fraction of times that an impression leads to a click.

Example 2: Sponsored Search Auctions

- Early design (Overture, 1990s): Generalized First Price Auction



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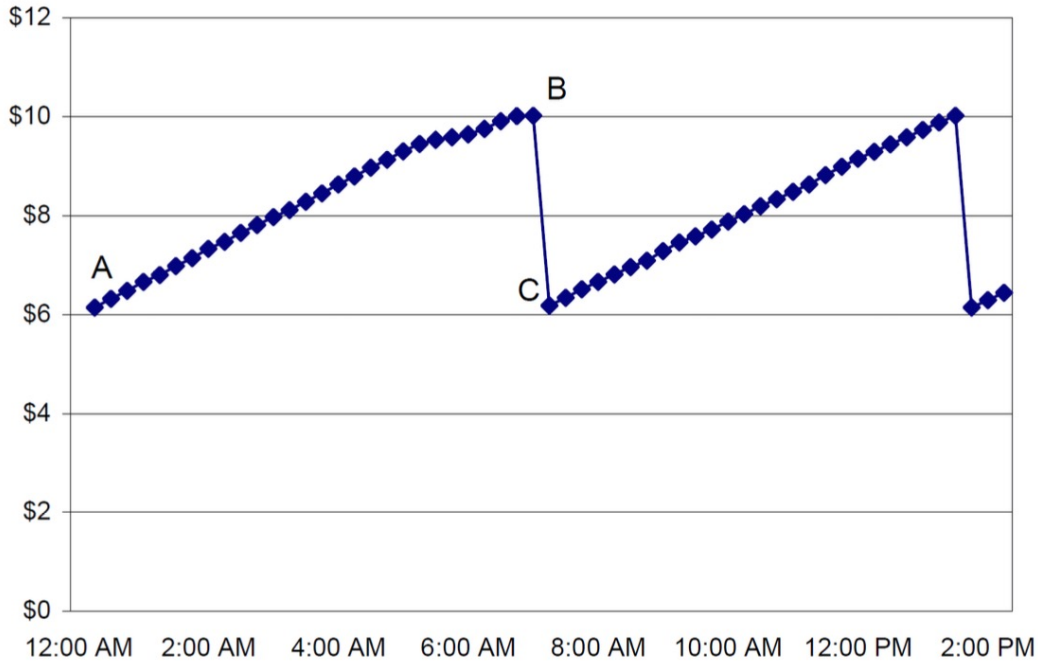

Bidding wars by automated bidding robots!
(Edelman & Ostrovsky, 2007)

0.1($11-$6.02) > 0.02($11-$6)

0.1($11-$10.01) < 0.02($11-$6)

advertiser \ round	1	2	3	4	5	...	*					
b_1	6.01	6.01	**6.03**	6.03	**6.05**	...	**9.98**	9.98	**10.00**	10.00	**6.01**	...
b_2	6.00	**6.02**	6.02	**6.04**	6.04	...	9.97	**9.99**	9.99	**6.00**	6.00	...
b_3	5.99	5.99	5.99	5.99	5.99	...	5.99	5.99	5.99	5.99	5.99	...

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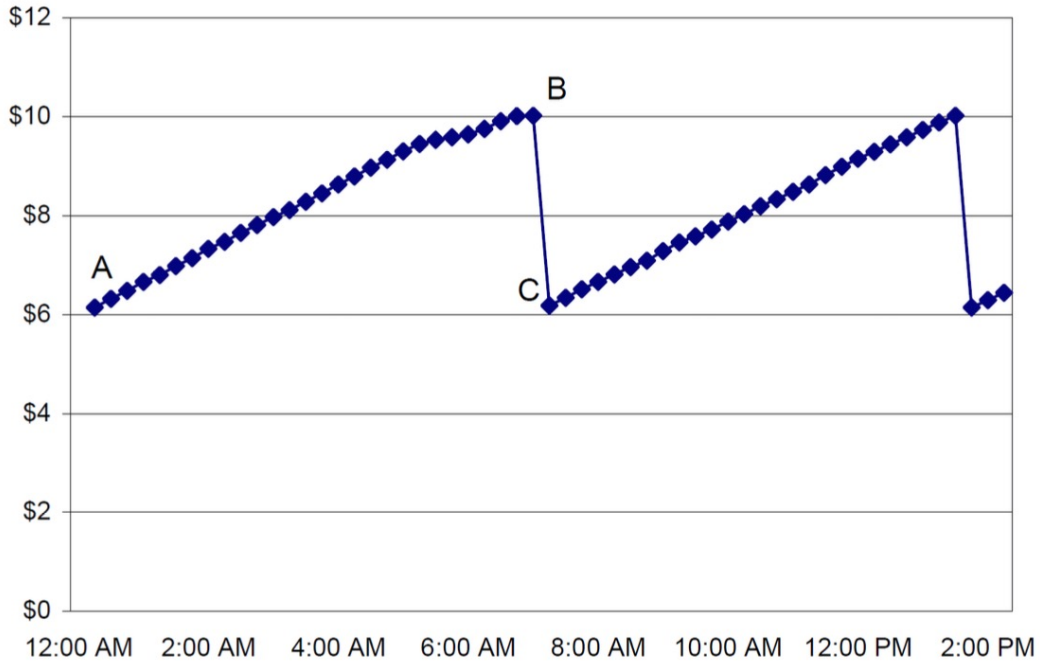
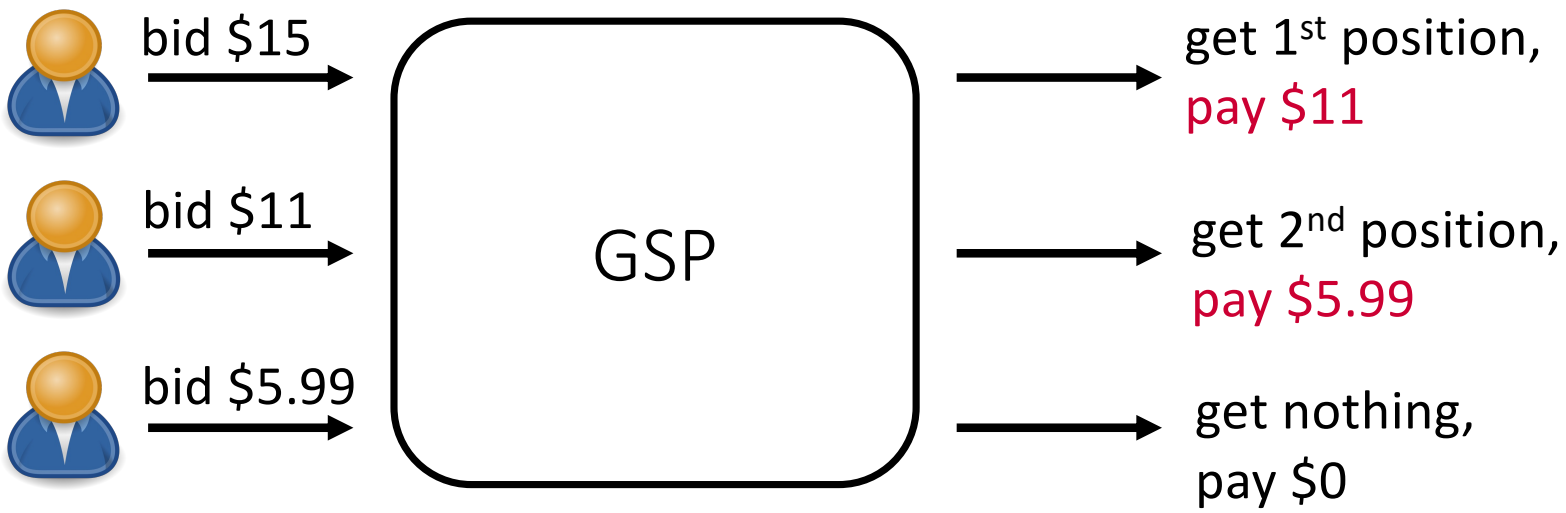


Bidding wars by automated bidding robots!
(Edelman & Ostrovsky, 2007)

- Inefficient allocation and volatile prices
- Wasted investments in gaming and competition

Example 2: Sponsored Search Auctions

- Later fix (Google, 2002): Generalized Second Price Auction



Price stability!

Inspired by W. Vickrey (1961)

Sell to the highest bidder for the second-highest bid price

Example 3: Financial Markets

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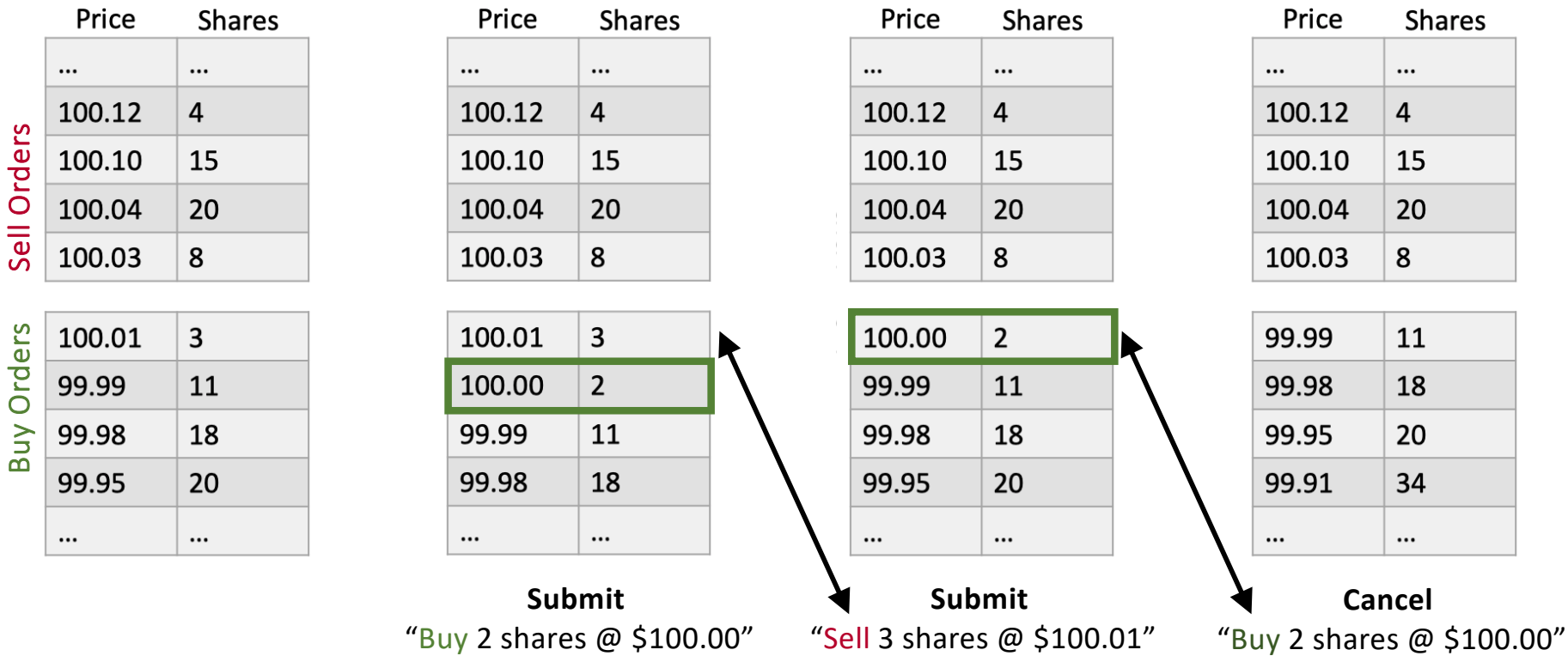
- Continuous double auction (CDA) & the limit order book



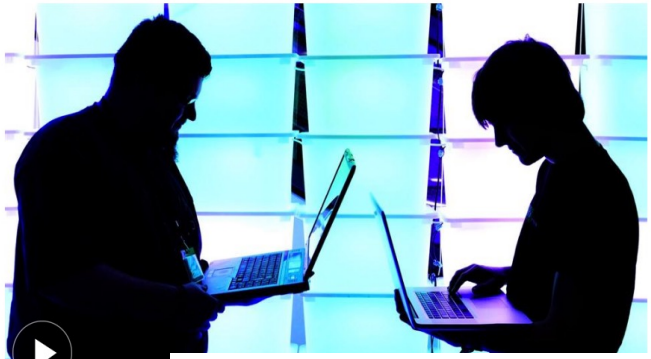
Example 3: Financial Markets

- Spoofing the limit order book

MARKETS

As 'Spoof' Trading Persists, Regulators Clamp Down

Bluffing Tactic That Dodd-Frank Banned in 2010 Can Distort Markets



WSJ's Bradley Hope expla
designed to trick other in
Getty

US seals first prosecution against stock market trader for 'spoofing'

Prosecutors said Michael Coscia wanted to lure other traders to markets by creating an illusion of demand so that he could make money on smaller trades Photo: AP

Flash Crash Trader E-Mails Show Spoofing Strategy, U.S. Says

by Tom Schoenberg Tschoenberg22 Suzi Ring journosooz Janan Hanna

September 3, 2015 – 4:03 PM EDT *Updated on* September 4, 2015 – 9:32 AM EDT

er Singh Sarao leaves Westminster Magistra
rapher: Chris Ratcliffe/Bloomberg Photogra

UBS, Deutsche Bank and HSBC to pay millions in spoofing settlement, CFTC says

Liz Moyer

Published 2:29 PM ET Mon, 29 Jan 2018 | Updated 8:32 AM ET Wed, 31 Jan 2018

CNBC

Deutsche Bank

Example 3: Financial Markets

- Spoofing the limit order book

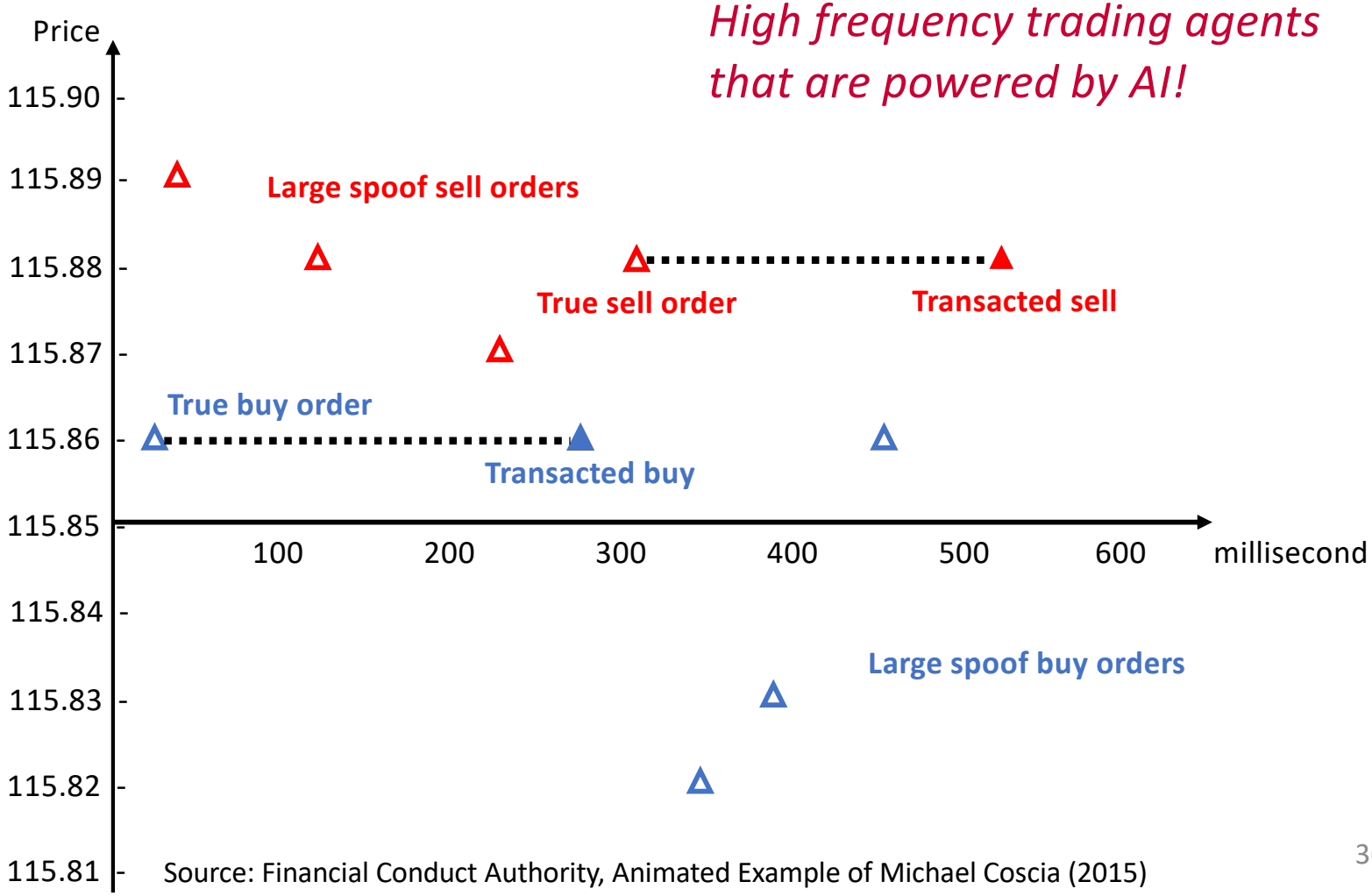
2010 Dodd-Frank Act, §747

> "Spoofing is the practice of placing orders with the intent *not* to trade, […] but to mislead others about market demand or supply"

Example 3: Financial Markets

- Spoofing the limit order book

High frequency trading agents that are powered by AI!



Source: Financial Conduct Authority, Animated Example of Michael Coscia (2015)

Many More Strategic Settings…

INSIDER

Drivers Collude to Trigger "Surge" Prices

Uber drivers are able to trigger surge pricing by turning their apps off and on simultaneously … they can double a ride from $10 to $20

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Market Design: Why Game Theory?

Single-Agent Decision Making

- Choose an action $x \in X$ to optimize for utility $f(x)$
- Treat as an optimization problem:

  min / max $f(x)$

  subject to $x \in X$

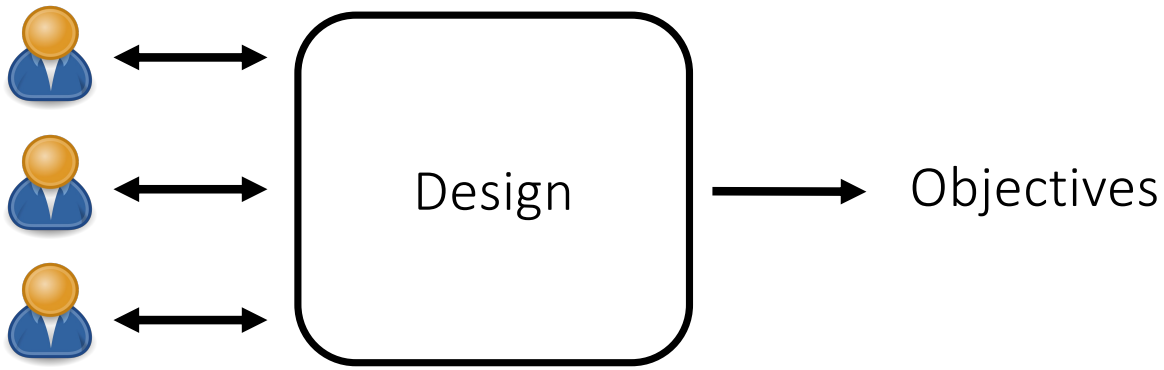
Multi-Agent Decision Making

- Agent i chooses an action $x_i \in X_i$ to get $f_i(x_i, x_{-i})$
- No longer an optimization problem, need game theory:

  Agent's utility depends on their own action x_i *AND* other agents' actions x_{-i}

Market Design: Why Artificial Intelligence?

Given system-wide objectives, design rules / mechanisms that incentivize individuals with own goals to act in ways that lead to the objectives



Heterogeneity in types
Diverse preferences & beliefs
Large information state

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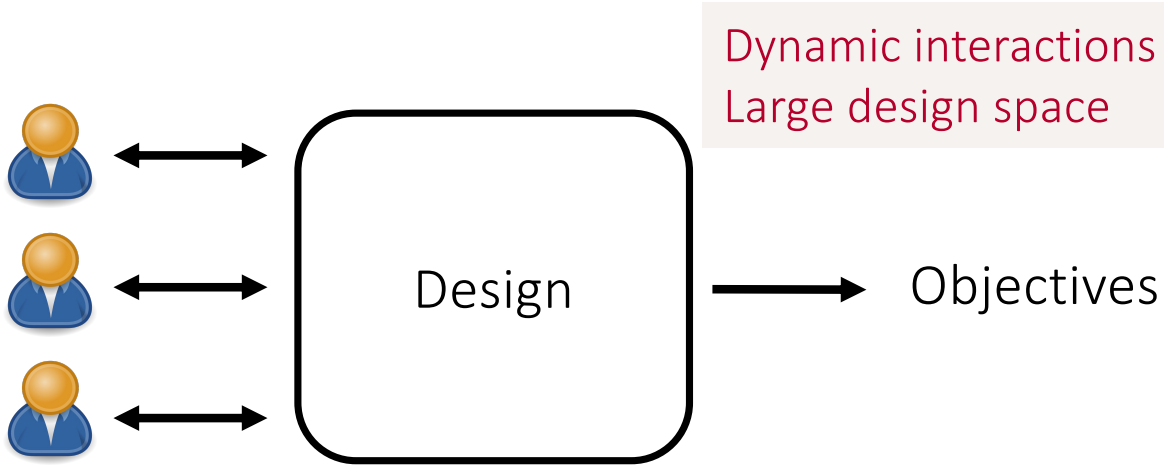

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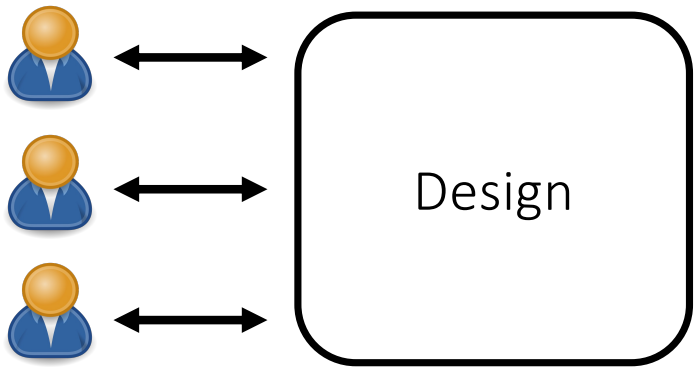


Objectives

Dynamic interactions
Large design space

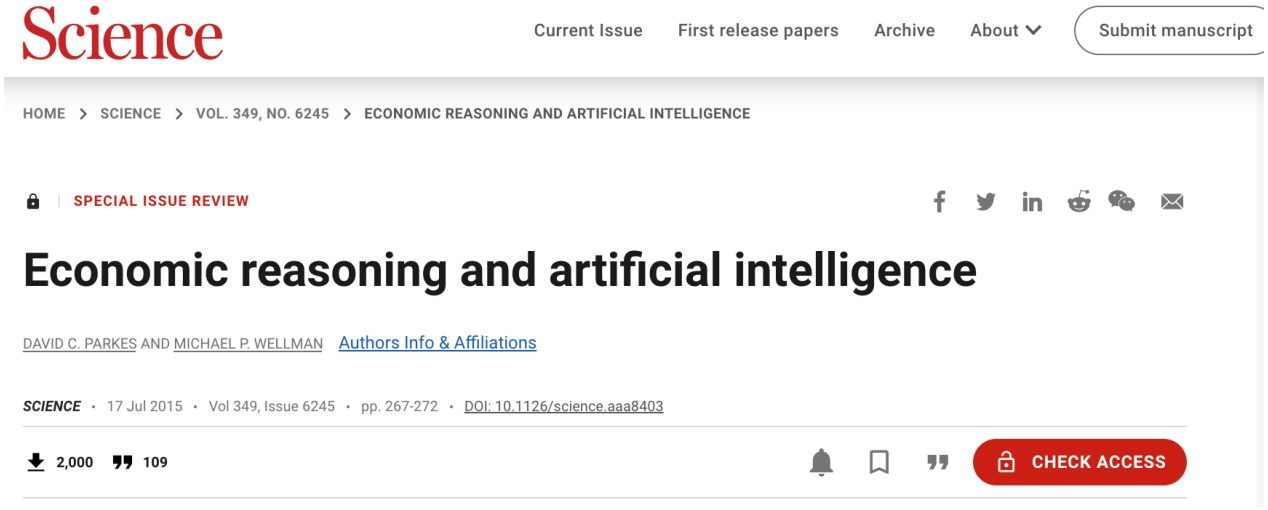
Society's value (fairness, diversity, market stability, sustainability…)

Heterogeneity in types
Diverse preferences & beliefs
Large information state

Market Design: Why Artificial Intelligence?

- "…hyper-rationality may actually be [an] appropriate model for software agents… The whole framework of game theory and mechanism design may well find its most exciting and practical application with computerized agents rather than human agents."

(Varian 1995)



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Basic Information

- Time: Fridays, 10:20 am – 1:20 pm (~20min break)
- Lecture: In person, attendance is highly recommended
- Instructor: Xintong Wang
  - Email: xintong.wang@rutgers.edu (please indicate 598 in subject)
  - Office hours: CoRE 319, 2:00 – 3:00 pm (via Zoom today)
  - Additional hours for paper presentations and class projects
- Course website: https://xintongemilywang.github.io/CS598.html
- Course materials:
  - Links to chapters and papers on website, accessible via Canvas; No official textbooks
  - Slides will be posted *after* lectures

Prerequisites

- Mathematics: calculus, linear algebra, probability
- Computer Science:
  - Data structure and algorithm analysis (complexity classes, algorithm design)
  - Enrolled students must have taken a machine learning or AI course
- Economics: helpful but not necessary
- Research: read and appreciate, critical thinking…

Informally, mathematical maturity, a reasonable level of understanding in AI/ML, and willingness to learn as you go!

Course Structure

- Lectures to cover fundamental concepts

- Research papers to discuss recent advances
  - A selected list of ~15 papers
  - Seminar style with discussions

Course Schedule (tentative)

- 1/19: Introduction
- 1/26: Intro to game theory
- 2/2: Eq. computation
- 2/9: Auctions
- 2/16: Mechanism design
- 2/23: Ad markets
- 3/1: Matching
- 3/8: Info. elicitation
- 3/15: Spring break
- 3/22: Prediction markets
- 3/29: Cryptoeconomics
- 4/5: Buffer/project advising
- 4/12: GT in learning I
- 4/19: GT in learning II
- 4/26: Project presentations

Pre-class Reading

- Reading before each class is important
- Do *not* need to understand everything!
- Goal: familiarize with new terms/concepts, prepare to ask questions and participate in discussions
- Complete short comprehension questions or paper commentaries (~15mins)
  - Skip at most two pre-class questions

Paper Presentation

- Students will work in pairs to present a paper and lead the discussion
- Each student should present at least one paper
- Before your presentation
  - Sign up a time slot to sync your slides with me
  - Prepare one or two pre-class questions that you'd like your audience to think about
- More information on paper bidding and presentation guidelines to follow

Problem Sets

- 2 – 3 problem sets over the course
- Check basic understanding and ability to apply and combine concepts
- At least a week to work on each
- You can work in pairs, if you wish

Final Project

- Goal:
  - Explore independent interests, develop a deeper understanding of a specific topic
  - Encourage and practice teamwork (a group of 2 or 3)
  - Aim at a conference publication!
- Can be theoretical, computational, experimental, empirical…
- Timeline (tentative)
  - Project proposal: March 8
  - Presentation: April 26 (last class)
  - Project report: May 6 (no extension)
- More office hours for project advising
- More information on project guidelines to follow

Grading

- Class participation: 20%
  - In-class participation: 10%
  - Pre-class questions: 10%
- Problem sets: 20%
- Paper presentation: 15%
- Class project: 45%
  - Proposal: 10%
  - Presentation: 15%
  - Final report: 20%

Don’t need to worry about grade if you do invest time!

Collaboration Policy

- You and your partners should discuss and work on the problem together
- Please state what you each contributed
- You can consult with other groups, without sharing code or answers, and should list names of students from other groups whom you have discussed with

Generative AI & Citation Policy

- No LLMs for pre-class CQs and problem sets
- For your final project, you may use LLMs as a tool to help with your writing
- Cite any tools, web sources, papers, textbooks you consult/use
- You are responsible for the content of your writing, including its correctness and that it does not plagiarize other sources

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(Algorithmic) Game Theory

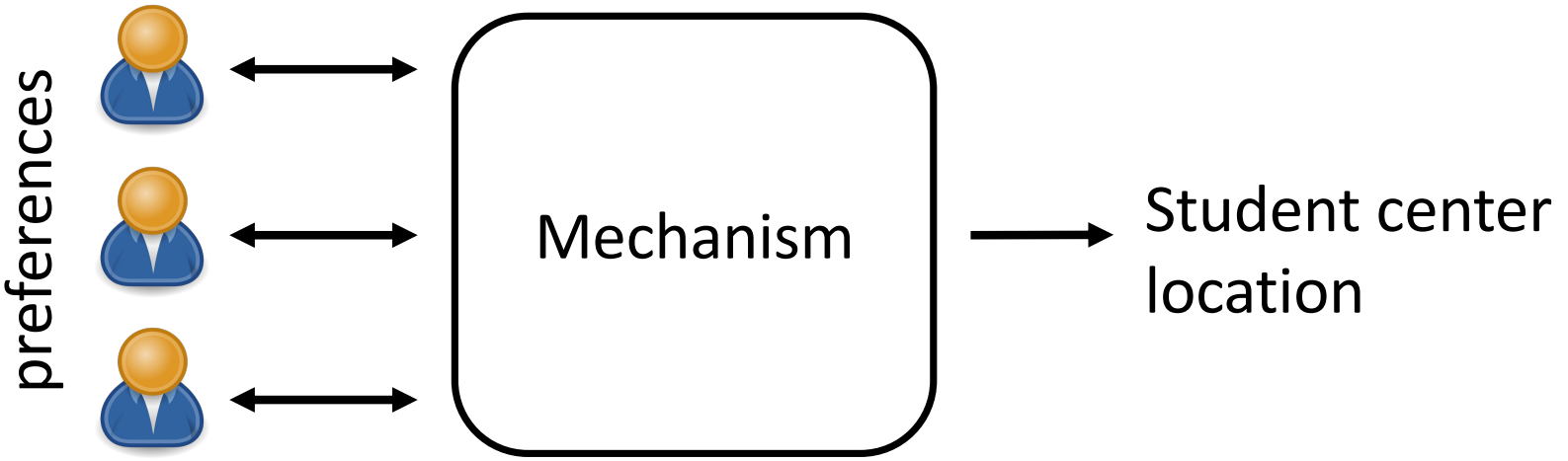
A \ B	B stays silent	B betrays
A stays silent	-1, -1	0, -3
A betrays	-3, 0	-2, -2

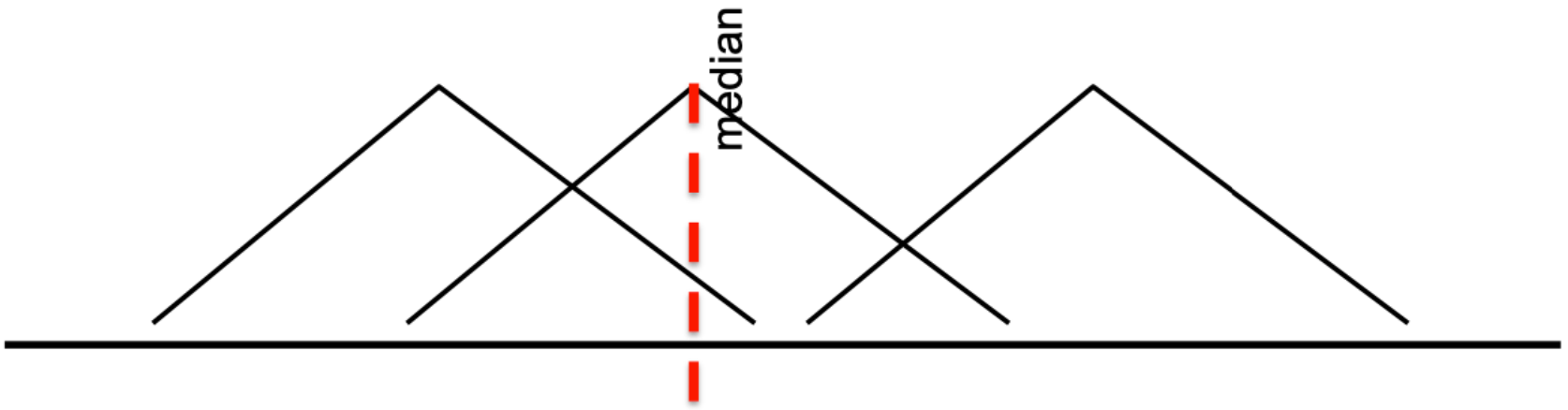
- How to represent a game?
- How to compute a Nash equilibrium?
- What are other solution concepts?
- How to extend to large-scale games?
- How to extend to policy space and MARL?

Auction Designs

- What are different forms of auctions?
- What are some of the design goals?
- How are AI algorithms used to optimize bid and to find optimal auction design?

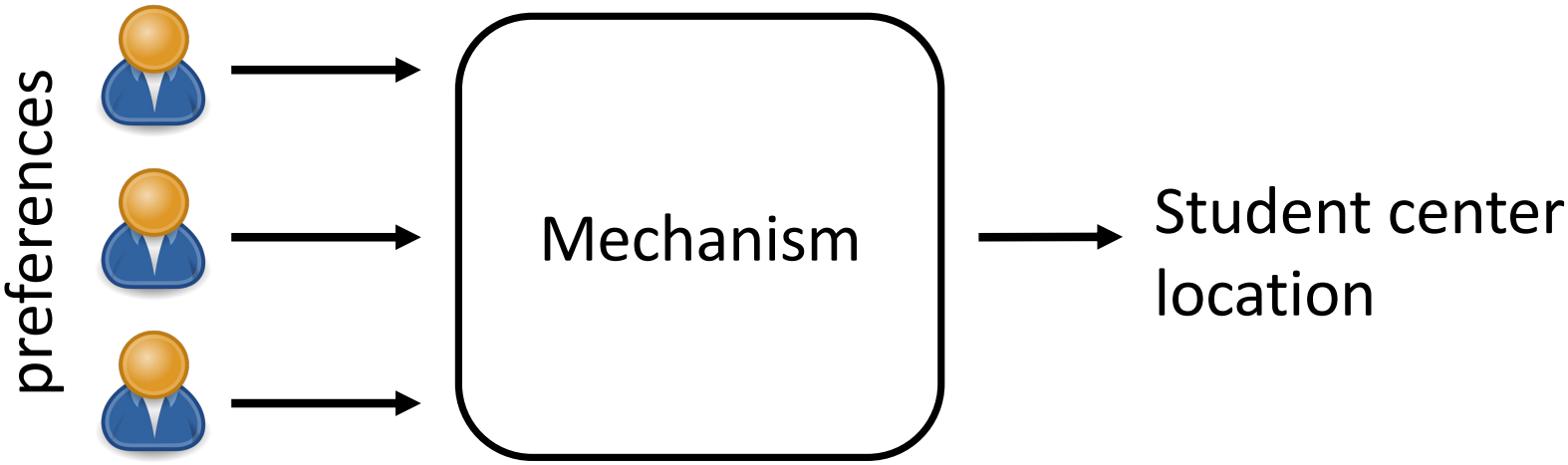
Mechanism Design





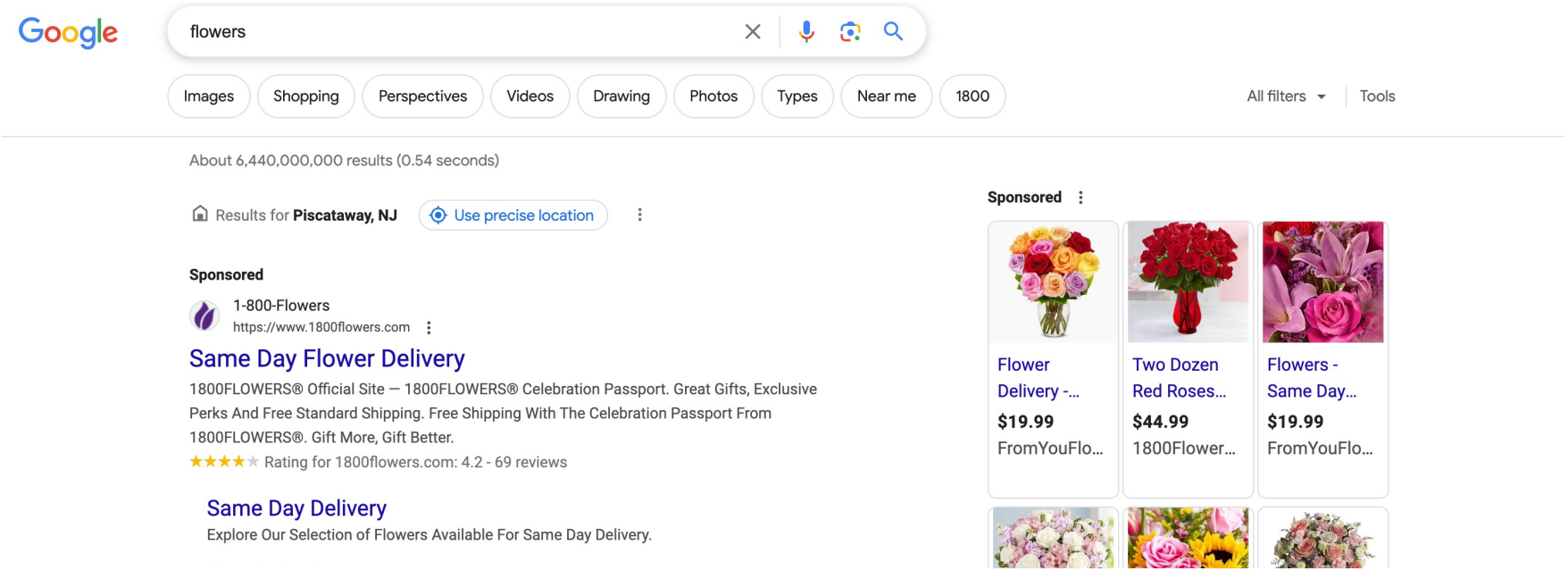
Median mechanism: *truthful*, immune to manipulation

Mechanism Design



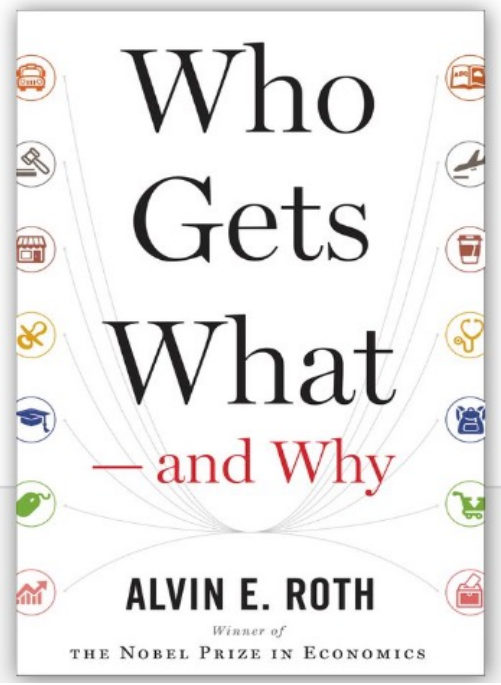
- What are desirable properties of a mechanism?
- Can we achieve these properties simultaneously?
- How are AI algorithms used to enforce properties and find optimal design?

Online Advertising Markets



- Apply auction theory and mechanism design to online advertising markets
- How are AI algorithms used by both bidding agents and the market designer?

Matching



Medical students to hospital residency positions

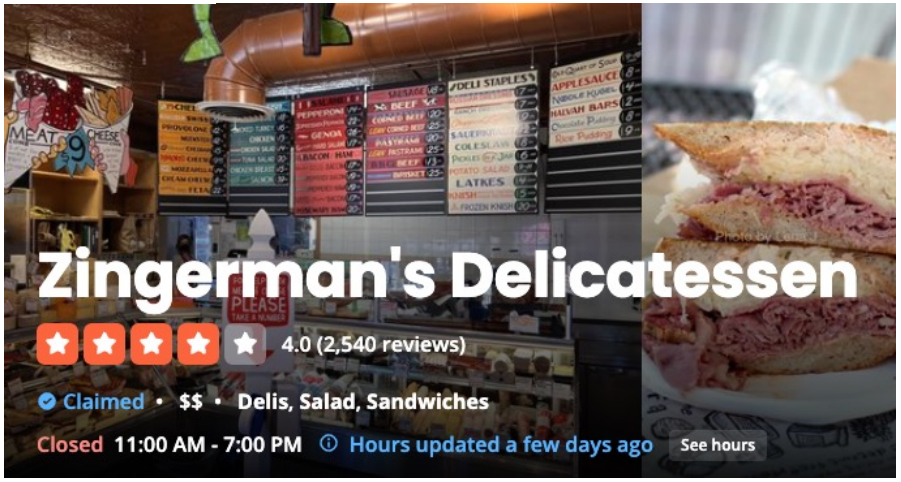
Students to public high schools

Patients with donors for organ transplant

…

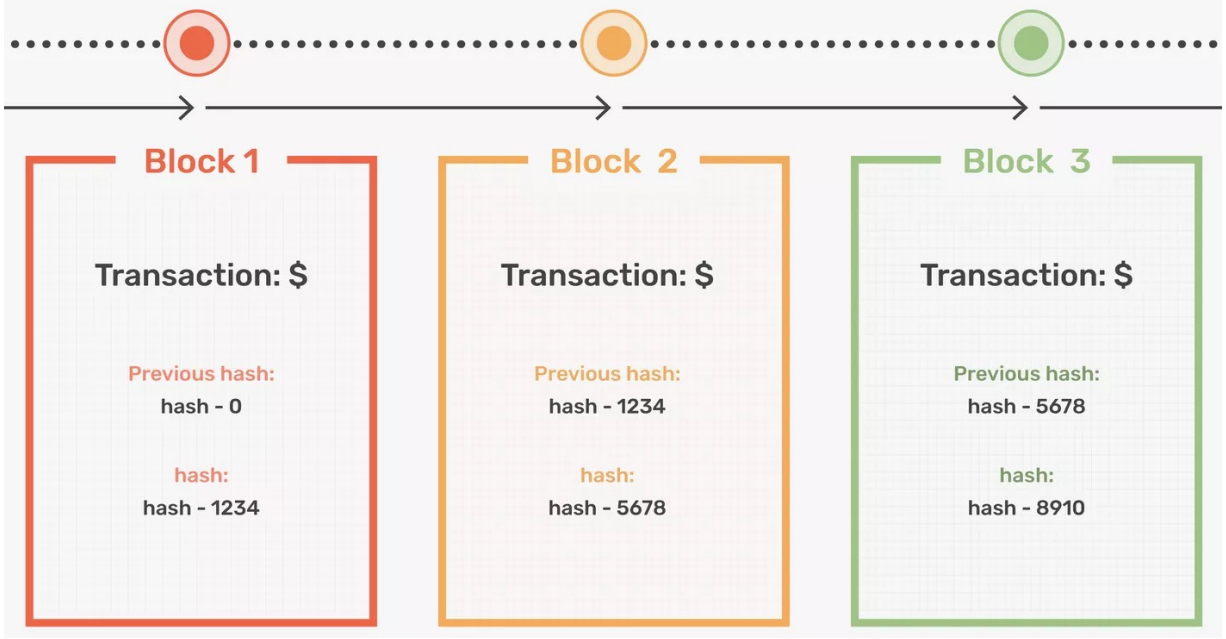
- How to find efficient and equitable methods of matching?
- Can ML help to achieve good tradeoff between desirable properties?

Information Elicitation & Prediction Markets



- How to incentivize honest opinion and achieve “the wisdom of crowds”?
- How to balance *market expressiveness*, prediction accuracy, and computational efficiency?

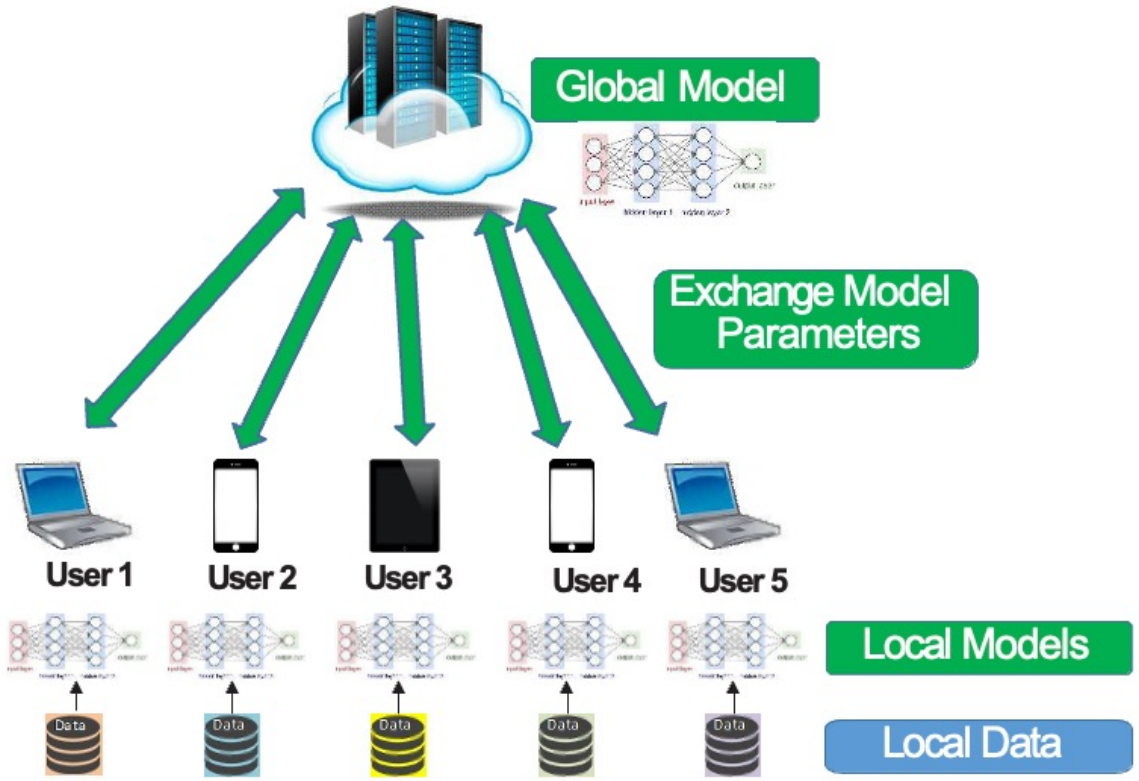
Cryptoeconomics



- How does blockchain enable the operation of a digital currency?
- What are some of the incentive issues and potential attacks in this new economic system?

Incentives & Game-Theoretic Aspects in Learning Settings

- Federated Learning

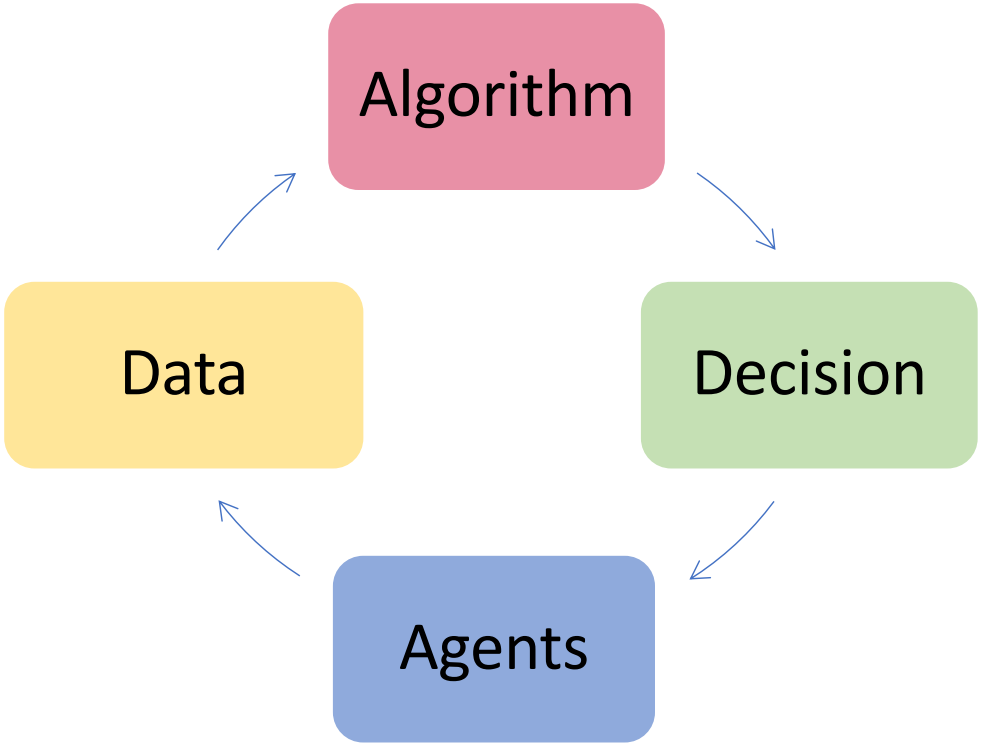


Liu, Bo, et al. "When machine learning meets privacy: A survey and outlook." *ACM Computing Surveys (CSUR)* 54.2 (2021): 1-36.

Incentives & Game-Theoretic Aspects in Learning Settings

- Performative Prediction: when predictions support decisions, we change the distribution of future data

Credit default risk
Recommender systems
…



Perdomo, Juan, et al. "Performative prediction." ICML 2020.

“Homework” for This Week

- Complete class survey (if haven’t already)
- Start to think about which topic you would like to present a paper and do project for (don’t need to be the same) and start to find your teammates
- Reading and pre-class questions for next lecture

Thank you!