

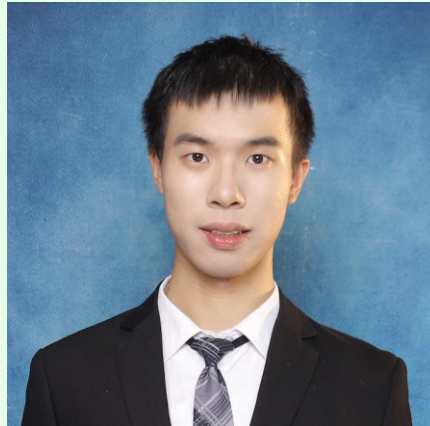
# 15-326

# Computational Microeconomics

<https://www.cs.cmu.edu/~15326-s26/>

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# History



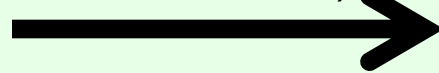
*John von  
Neumann*

computer architecture  
(von Neumann  
architecture)



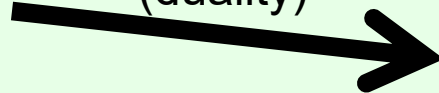
***Computer Science  
& Engineering***

game theory  
(minimax theorem)

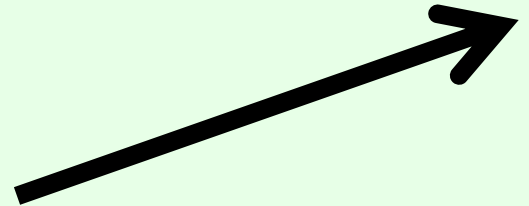
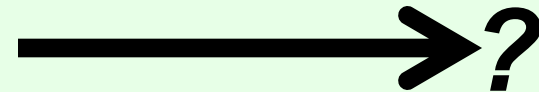
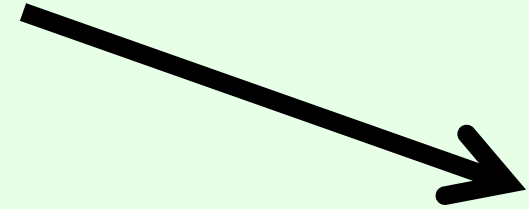


***Economic Theory***

linear programming  
(duality)



***Mathematical  
Optimization &  
Operations  
Research***

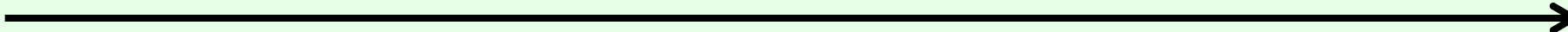


?

1900

1950

2000





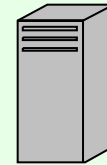
# What is Economics?

- “a social science that studies the production, distribution, and consumption of goods and services.” [\[Wikipedia, Jan. 2026\]](#)
- Some key concepts:
  - Economic **agents** or **players** (individuals, households, firms, bots, ...)
  - Agents’ current **endowments** of goods, money, skills, ...
  - Possible **outcomes** ((re)allocations of resources, tasks, ...)
  - Agents’ **preferences** or **utility functions** over outcomes
  - Agents’ **beliefs** (over other agents’ utility functions, endowments, production possibilities, ...)
  - Agents’ possible **decisions/actions**
  - **Mechanism** that maps decisions/actions to outcomes



# An economic picture

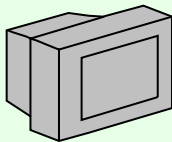
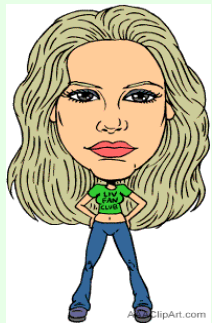
$$v(\text{server}) = 200$$



\$ 800

$$v(\text{monitor}) = 100$$

$$v(\text{laptop}) = 400$$



\$ 600

$$v(\text{laptop}) = 200$$

$$v(\text{server}, \text{monitor}) = 400$$



\$ 200





# After trade (a more efficient outcome)

$$v(\text{server}) = 200$$

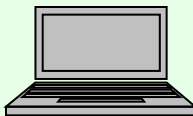
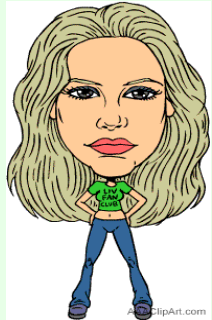


\$ 1100

*... but how do we  
get here?  
Unstructured trade?  
Auctions?  
Exchanges?*

$$v(\text{monitor}) = 100$$

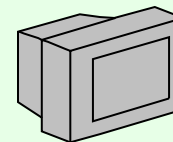
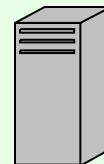
$$v(\text{laptop}) = 400$$



\$ 400

$$v(\text{laptop}) = 200$$

$$v(\text{server}, \text{monitor}) = 400$$



\$ 100





# Some distinctions in economics

- **Descriptive** vs. **normative** economics
  - Descriptive:
    - seeks only to describe real-world economic phenomena
    - does not care if this is in any sense the “right” outcome
  - Normative:
    - studies how people “should” behave, what the “right” or “best” outcome is
- **Microeconomics** vs. **macroeconomics**
  - Microeconomics: analyzes decisions at the level of individual agents
    - deciding which goods to produce/consume, setting prices, ...
    - “bottom-up” approach
  - Macroeconomics: analyzes “the sum” of economic activity
    - interest rates, inflation, growth, unemployment, government spending, taxation, ...
    - “big picture”



# What is Computer Science?

- “Computer science is the study of computation, information, and automation. Included broadly in the sciences, computer science spans theoretical disciplines (such as algorithms, theory of computation, and information theory) to applied disciplines (including the design and implementation of hardware and software).” [\[Wikipedia, Jan. 2026\]](#)
- A **computational problem** is given by a function  $f$  mapping inputs to outputs
  - For integer  $x$ , let  $f(x) = 0$  if  $x$  is prime, 1 otherwise
  - For initial allocation of resources + agent utilities  $x$ , let  $f(x)$  be the (re)allocation that maximizes the sum of utilities
- An **algorithm** is a fully specified procedure for computing  $f$ 
  - E.g., sieve of Eratosthenes
  - A **correct algorithm** always returns the **right** answer
  - An **efficient algorithm** returns the answer **fast**
- Computer science is also concerned with building **larger artifacts** out of these building blocks (e.g., personal computers, spreadsheets, the Internet, the Web, search engines, artificial intelligence, ...)

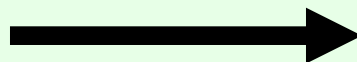
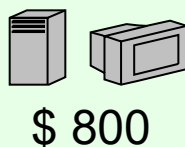


# Resource allocation as a computational problem (*Part 1 of the course*)

*input*

*output*

$v(\text{server, monitor}) = \$400$   
 $v(\text{laptop}) = \$600$

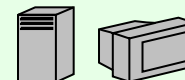


\$ 750

$v(\text{server, monitor}) = \$500$   
 $v(\text{laptop}) = \$400$



\$ 400



\$ 450

Here, gains from trade (\$300)  
are divided evenly  
(not essential)



# Economic mechanisms

***“true” input***

***agents’ bids***

***result***

$$v(\text{server, monitor}) = \$400$$
$$v(\text{laptop}) = \$600$$

agent 1’s  
bidding  
algorithm

$$v(\text{server, monitor}) = \$500$$
$$v(\text{laptop}) = \$501$$

exchange  
mechanism  
(algorithm)



\$ 800

$$v(\text{server, monitor}) = \$500$$
$$v(\text{laptop}) = \$400$$

agent 2’s  
bidding  
algorithm

$$v(\text{server, monitor}) = \$451$$
$$v(\text{laptop}) = \$450$$



\$ 400

*Exchange mechanism designer  
does not have direct access to  
agents’ private information*

*Agents will selfishly respond to  
incentives*



\$ 800



\$ 800



\$ 400



\$ 400



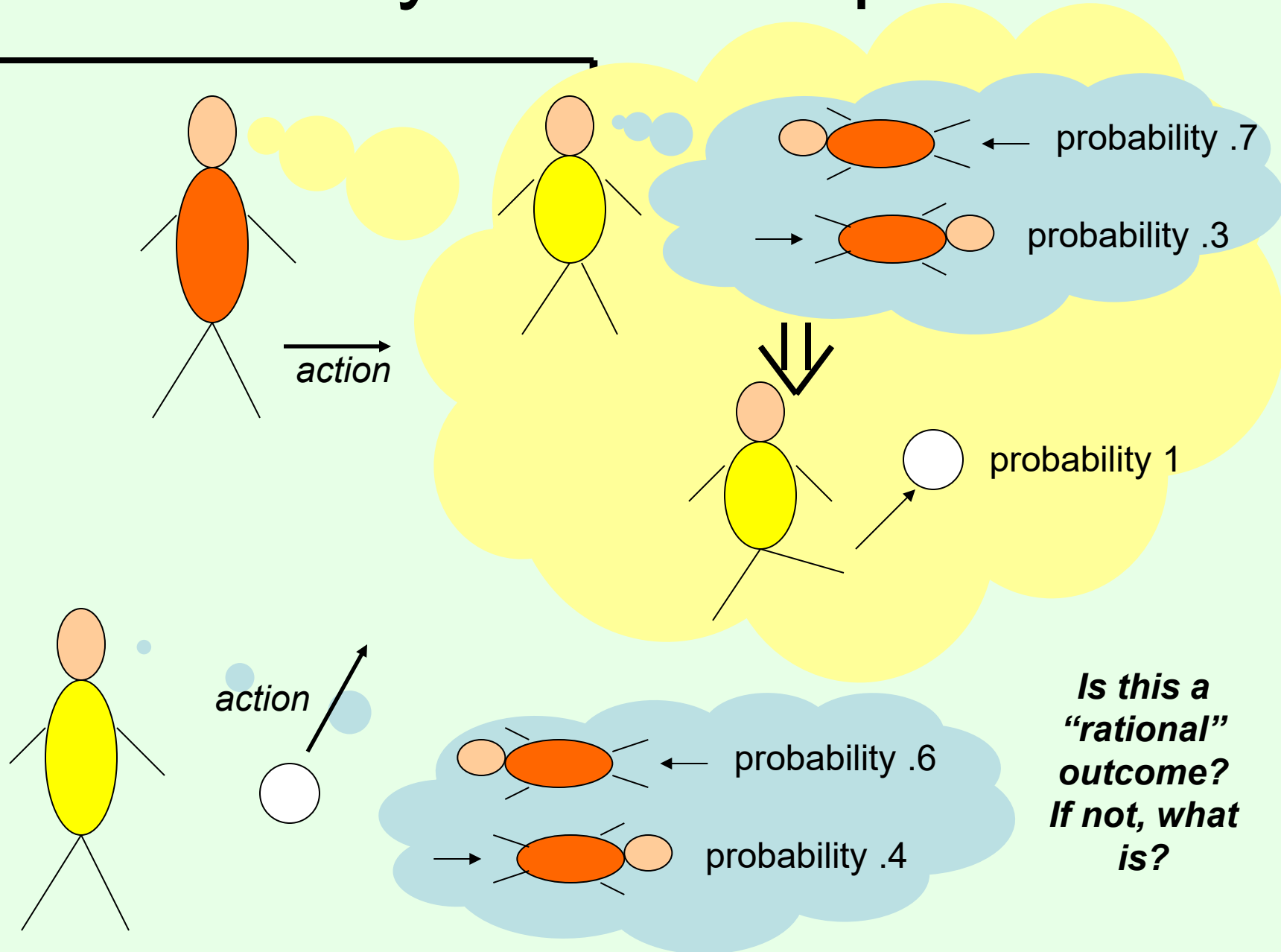
# Game theory

## *(Part 2 of the course)*

- Game theory studies settings where agents each have
  - different preferences (utility functions),
  - different actions that they can take
- Each agent's utility (potentially) depends on all agents' actions
  - What is optimal for one agent depends on what other agents do
    - Very circular!
- Game theory studies how agents can rationally form beliefs over what other agents will do, and (hence) how agents should act
  - Useful for acting as well as predicting behavior of others



# Penalty kick example

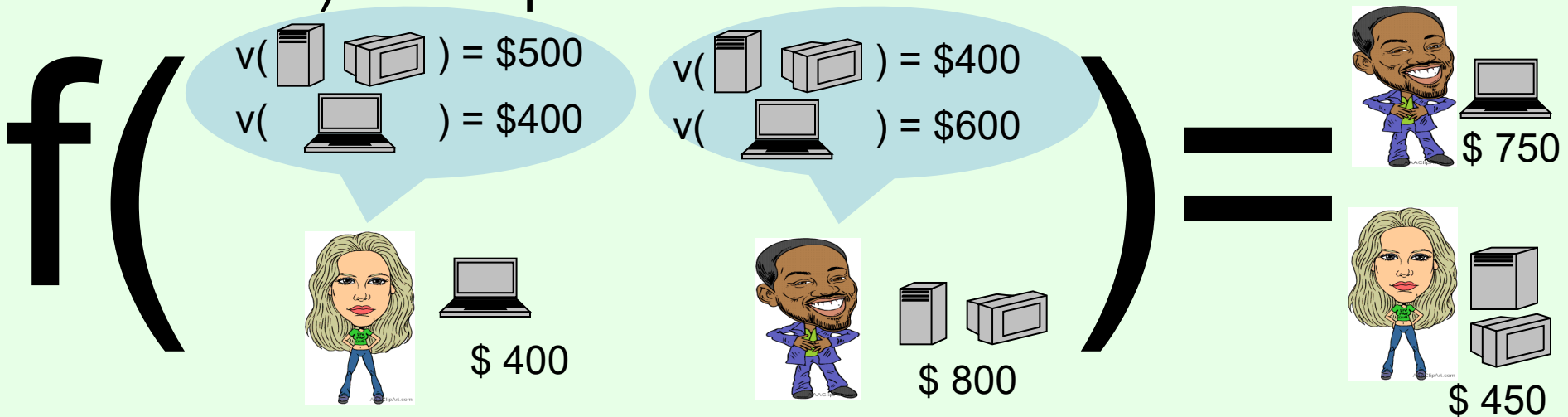




# Mechanism design

## (Part 3 of the course)

- **Mechanism** = rules of auction, exchange, ...
- A **function** that takes **reported preferences** (bids) as input, and produces **outcome** (allocation, payments to be made) as output

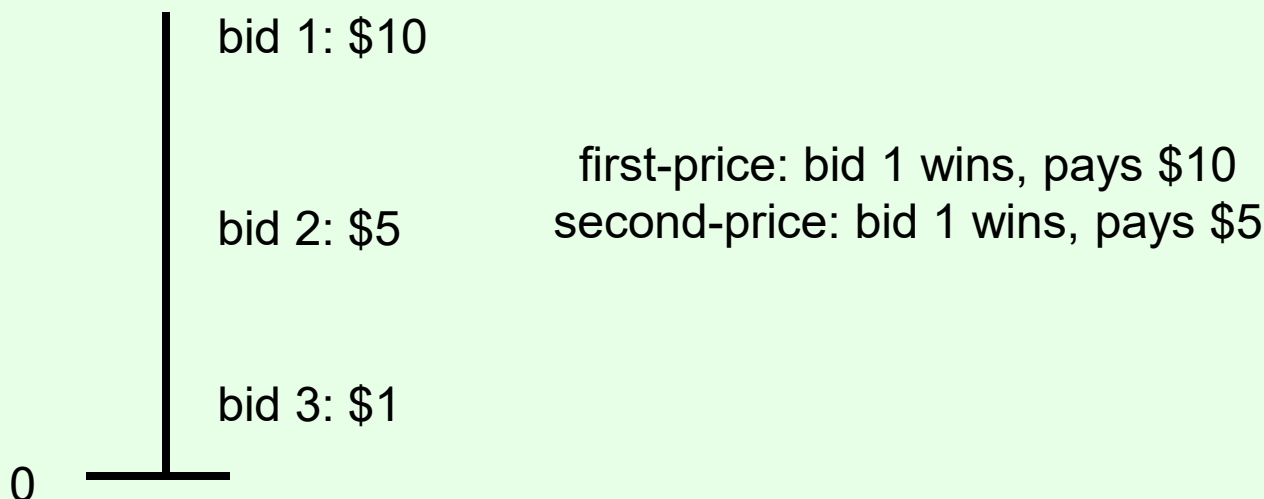


- The **entire function**  $f$  is **one** mechanism
- E.g., the mechanism from part 1: find allocation that maximizes (reported) utilities, distribute (reported) gains evenly
- Other mechanisms choose different allocations, payments



# Example: (single-item) auctions

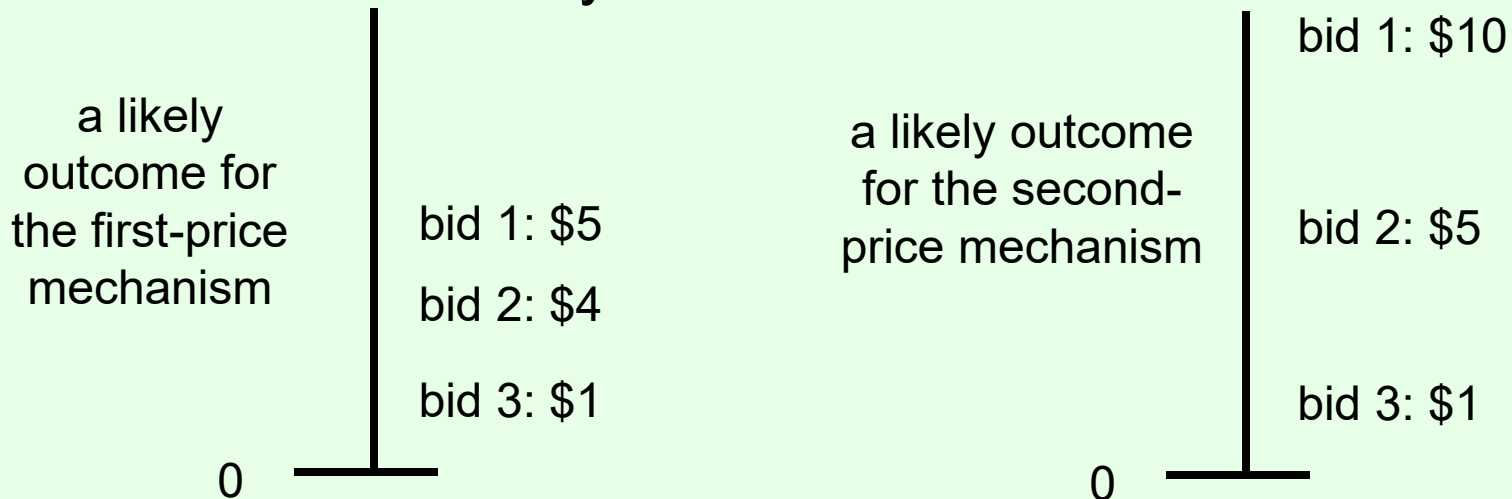
- **Sealed-bid** auction: every bidder submits bid in a sealed envelope
- **First-price** sealed-bid auction: highest bid wins, pays amount of own bid
- **Second-price** sealed-bid auction: highest bid wins, pays amount of second-highest bid





# Which auction generates more revenue?

- Each bid depends on
  - bidder's **true valuation** for the item (utility = valuation - payment),
  - bidder's **beliefs** over what others will bid ( $\rightarrow$  game theory),
  - and... the **auction mechanism** used
- In a first-price auction, it does not make sense to bid your true valuation
  - Even if you win, your utility will be 0...
- In a second-price auction, (we will see later that) it always makes sense to bid your true valuation



*Are there other auctions that perform better? How do we know when we have found the best one?*



# Mechanism design...

- Mechanism = game
- → we can use game theory to predict what will happen under a mechanism
  - if agents act strategically
- When is a mechanism “good”?
  - Should it result in outcomes that are good for the **reported** preferences, or for the **true** preferences?
  - Should agents ever end up **lying** about their preferences (in the game-theoretic solution)?
  - Should it always **generate the best allocation**?
  - Should agents ever **burn money**?(!?)
- Can we solve for the optimal mechanism?



# How are we going to solve these problems? (*Part 0*)

- This is **not** a programming course
- Will use optimization software
  - GNU Linear Programming Kit (GLPK)
  - Linear programming, mixed integer linear programming



# Uses of LP, MIP in this course

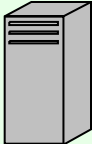
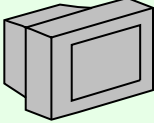
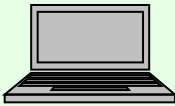
	<b>Linear programming</b>	<b>Mixed integer linear programming</b>
Part 1 (expressive marketplaces)	Winner determination in auctions, exchanges, ... with partially acceptable bids	Winner determination in auctions, exchanges, ... without partially acceptable bids
Part 2 (game theory)	Dominated strategies Minimax strategies Correlated equilibrium Optimal mixed strategies to commit to	Nash equilibrium
Part 3 (mechanism design)	Automatically designing optimal mechanisms that use randomization	Automatically designing optimal mechanisms that do not use randomization



Other settings/applications



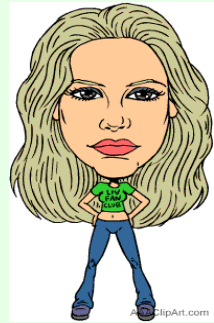
# Combinatorial auctions (in Part 1)

Simultaneously for sale:  ,  , 



*bid 1*

$$v(\text{server}, \text{cabinet}) = \$500$$



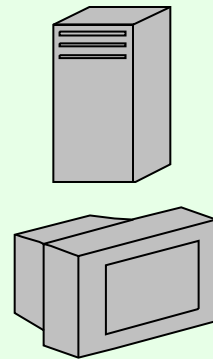
*bid 2*

$$v(\text{laptop}, \text{cabinet}) = \$700$$



*bid 3*

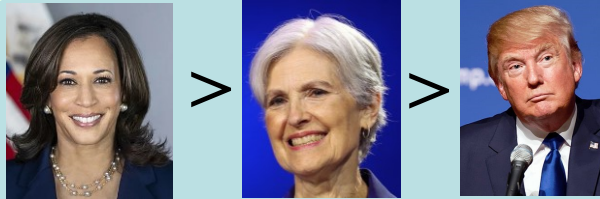
$$v(\text{laptop}) = \$300$$



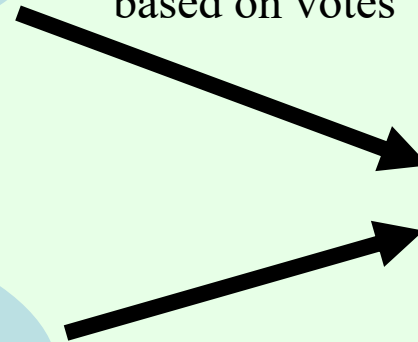
used in truckload transportation, industrial procurement, radio spectrum allocation, ...



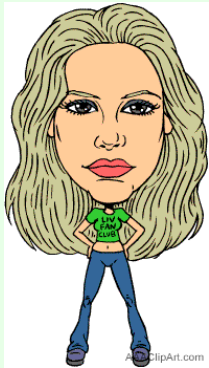
# Voting (in Part 1)



voting rule  
(mechanism)  
determines winner  
based on votes



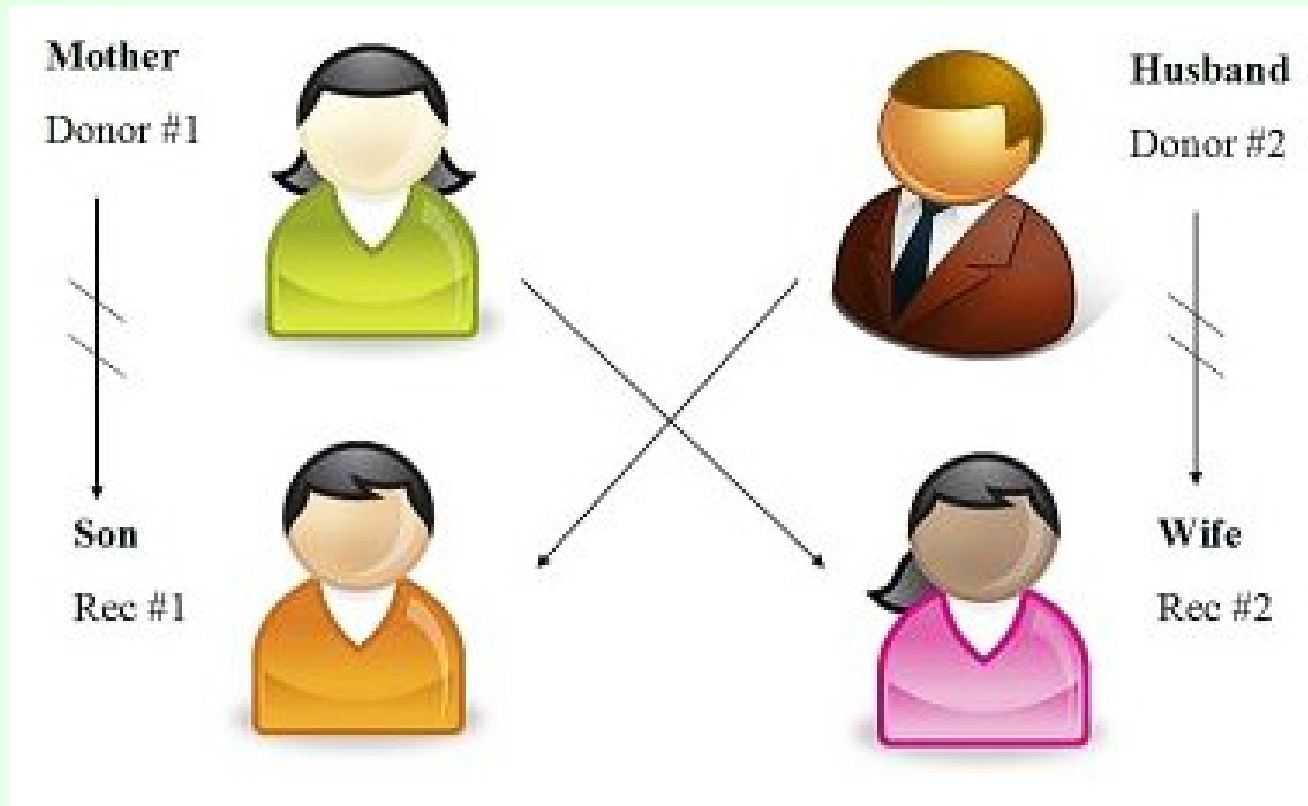
- Can vote over other things too
  - Where to go for dinner tonight, other joint plans, ...
- Many different rules exist for selecting the winner





# Kidney exchange (in Part 1)

- Kidney exchanges allow patients with willing but incompatible live donors to swap donors





# Kidney exchange (in Part 1)

Q | POPULAR | LATEST | FEATURED

QUARTZ

OBSESSIONS | EMAILS | EDITIONS | ⓘ

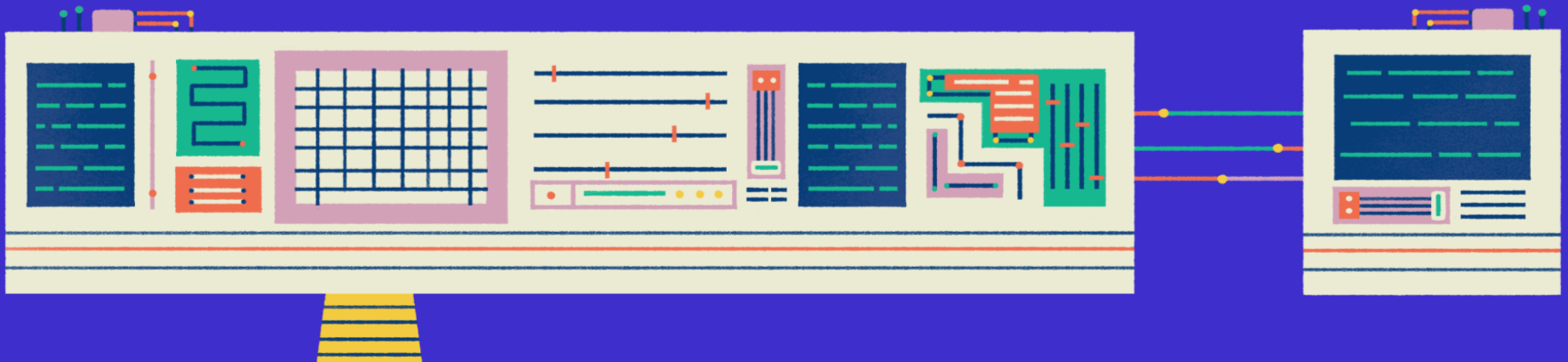
## Prescription AI

This series explores the promise of AI to personalize, democratize, and advance medicine—and the dangers of letting machines make decisions.

THE BOTPERATING TABLE

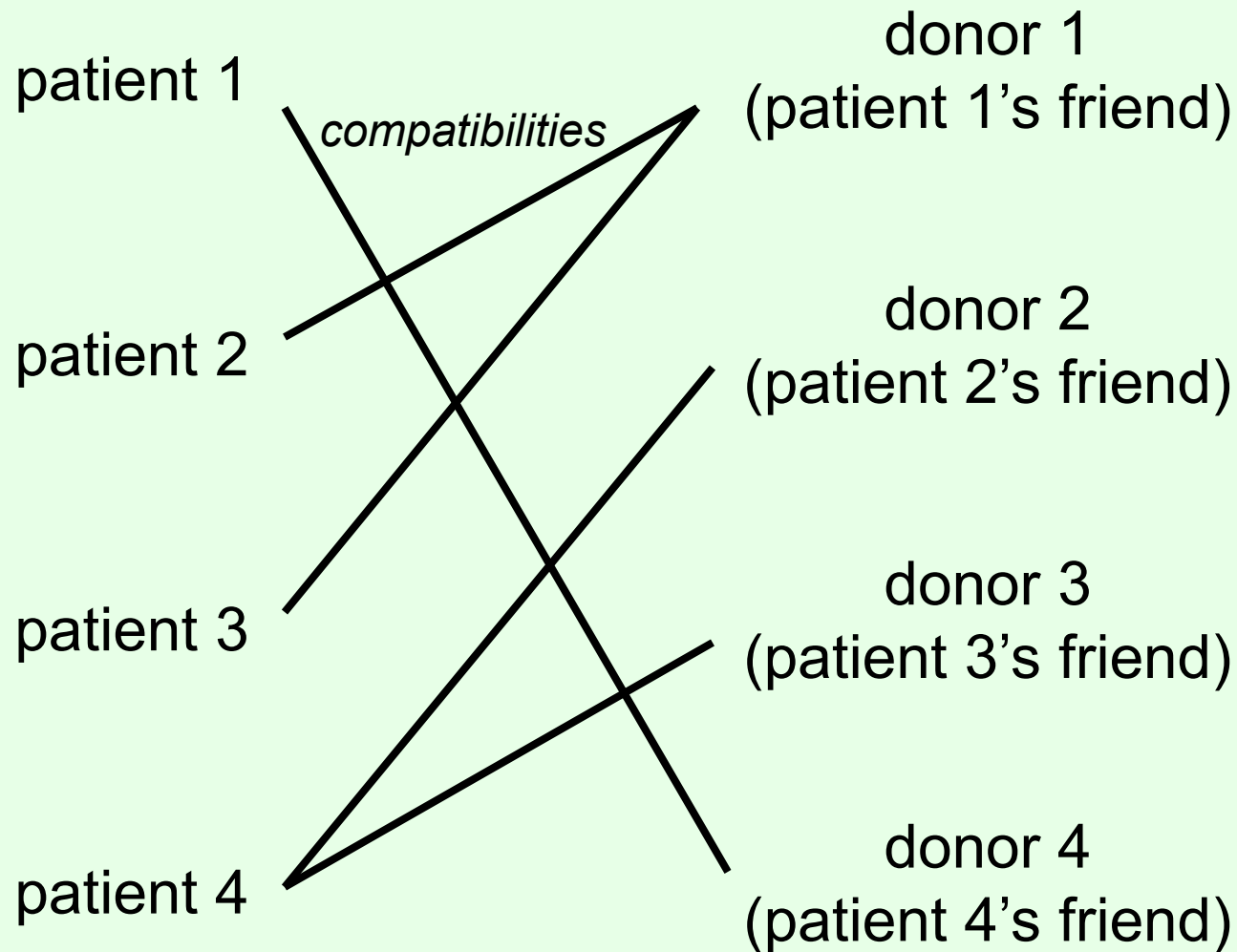
# How AI changed organ donation in the US

By [Corinne Purtill](#) • September 10, 2018





# Kidney exchange (in Part 1)

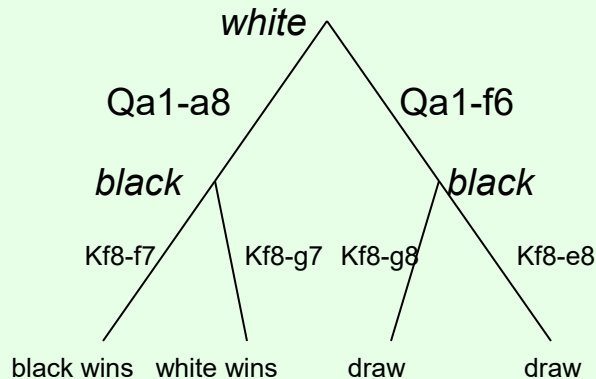




# Game playing & AI (in Part 2)

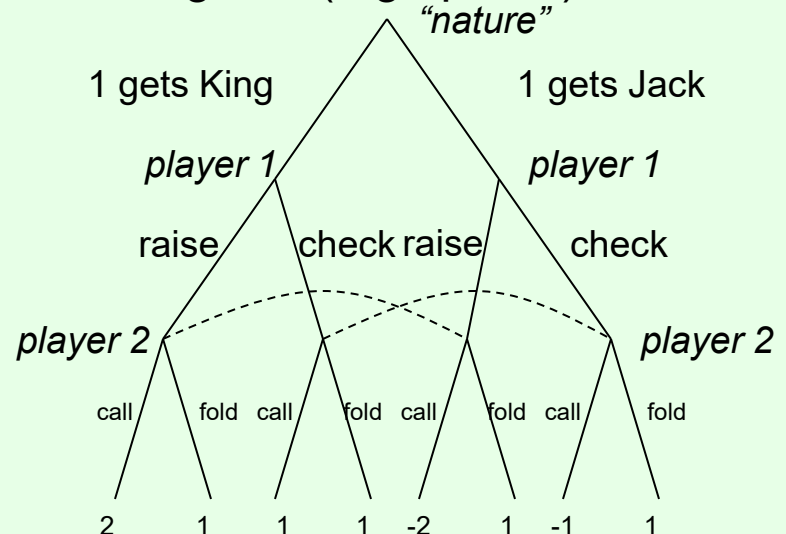
perfect information games:

no uncertainty about the state of the game (e.g. tic-tac-toe, chess, Go)



imperfect information games:

uncertainty about the state of the game (e.g., poker)



- Player 2 **cannot distinguish** nodes connected by dotted lines
  - Backward induction fails; need more sophisticated game-theoretic techniques for optimal play
- Small poker variants can be solved optimally
- ~~• Humans still better than top computer programs at full-scale poker (at least most versions)~~
- Top computer ~~(heads-up)~~ poker players are based on techniques for game theory

- Optimal play: value of each node = value of optimal child for current player (**backward induction**, minimax)
- For chess and Go, tree is too large
  - Use other techniques (heuristics, limited-depth search, alpha-beta, deep learning, ...)
- Top computer programs better than humans in chess, ~~not yet in Go~~



# Science

## 2019 BREAKTHROUGH OF THE YEAR

Darkness made visible

## RUNNERS-UP

- Face to face with the Denisovans
- Quantum supremacy attained
- Microbes combat malnourishment
- A killer impact and its aftermath
- A close-up of a far-out object
- A 'missing link' microbe emerges
- In a first, drug treats most cases of cystic fibrosis
- Hope for Ebola patients, at last
- Artificial intelligence masters multiplayer poker

## BREAKDOWNS

- The Amazon ablaze
- Measles resurgent
- Bird counts dwindling
- An eleventh hour climate awakening?

## RELATED ITEMS

- Video
- Editorial
- Podcast

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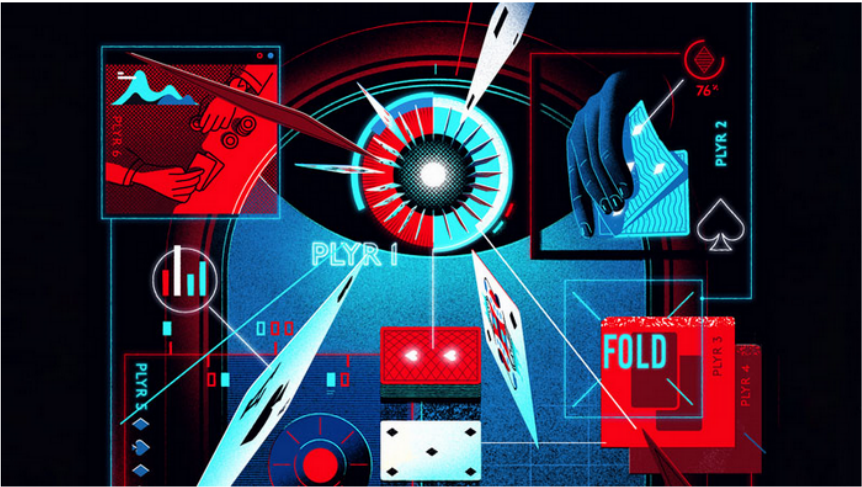
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# Artificial intelligence masters multiplayer poker



JASON SOLO/THE JACKY WINTER GROUP

This year, an artificial intelligence (AI) program beat some of the world’s best players in the most popular version of poker, no-limit Texas Hold ‘em. The landmark result marks the first time AI has prevailed in a multiplayer contest in which players have only imperfect information about the state of the game.

AI has been trouncing humans in games at a spectacular rate. In 2007, computer scientists developed a program guaranteed not to lose at checkers. In 2016, another team developed an AI program that defeated the best humans at Go, a board game with vastly more configurations than checkers.

Poker presents a stiffer challenge, as players cannot see their opponents’ cards and thus have limited information. In 2017, computer scientists developed an AI program unbeatable at a two-player version of Hold ‘em—in which each player forms a hand from five cards laid face up on the table and two more each holds privately.

Now, AI has bested world-class players in the full multiplayer game, as computer scientists at Carnegie Mellon University in Pittsburgh, Pennsylvania, announced in August. By playing 1 trillion games against itself, their program, **Pluribus**, developed a basic strategy for various kinds of situations—say, playing for an inside straight. For each specific hand, it could also think through how the cards would likely play out. In 20,000 hands with six players it outperformed 15 top-level players, as measured by average winnings per hand.







# Real-world security applications (in Part 2)



## Airport security

Where should checkpoints, canine units, etc. be deployed?



## US Coast Guard

Which patrol routes should be followed?



*Prof. Milind Tambe's TEAMCORE group (USC → Harvard); see also Prof. Fei Fang at CMU*

## Federal Air Marshals

Which flights get a FAM?



## Wildlife Protection

Where to patrol to catch poachers or find their snares?





# Global Presence of Security Games Efforts



PELIND TAMBIE'S ARMOR AND ITS MANY ITERATIONS ARE USED AROUND THE WORLD TO PROTECT AGAINST TERRORISM, POACHERS, ILLEGAL FISHING AND OTHER THREATS.

## DEPLOYED

### Perth — PROTECT

PROTECT intelligently connects U.S. Coast Guard forces to optimize border and coastal security missions such as drug and fish seizures.

### PROTECT is employed at:

Port of New York and New Jersey  
Port of Seattle  
Port of Los Angeles  
Port of Los Angeles Long Beach

### Shanghai Island Forre — PROTECT

PROTECT provides protection to the Shuang Island Ferry, which carries up to a 1,000 passengers at peak times.

### Los Angeles International Airport — ARMOR

ARMOR intelligently monitors thousands of checkpoints along the airport's roads that lead into the airport.

### U.S. Air Traffic — TMS

Airport state management of traffic is a major security risk. To improve this, Security Games has been able to help the FAA with a project called Air Traffic Traffic, which intelligently monitors and detects suspicious flight patterns to make them more visible and manageable to security operations.



## SUCCESSFULLY TESTED

### Gulf of Mexico (Near Corpus Christi, Texas) — ARMOR-TSM

ARMOR-TSM intelligently connects resources for U.S. Coast Guard and its partners to detect the illegal fishing of overfished stock and other suspicious behavior.

### Los Angeles Metro — TMS

The Los Angeles Sheriff's Department, which LA Metro administers for security, wanted TMS to intelligently coordinate patrol schedules to stop drug activities. The Sheriff's Department has now implemented a project to help coordinate patrol schedules to stop drug activities and improve on LA Metro's (2017-2021).

### England — PROTECT

England's range is a major PROTECT at Queen Elizabeth National Park to intelligently coordinate patrols to protect the integrity of the park, including the English, which is a major threat to the park's integrity.

### Malaysia — ARMOR

ARMOR, an ARMOR is connected to monitoring the network of agents and other wild areas. In cooperation with the national group ARMOR, Japan's ARMOR is a major threat to the park's integrity. In addition, it is able to provide effective patrol to the park's integrity.

## POSSIBLE FUTURE TEST SITES

Vietnam, Cambodia, Bangladesh, Indonesia — ARMOR

### Madagascar — PAWS

ARMOR is a major threat to the park's integrity. In addition, it is able to provide effective patrol to the park's integrity.

### Portuguese Coast (PCC) Region to monitor

ARMOR is a major threat to the park's integrity. In addition, it is able to provide effective patrol to the park's integrity.



# Prediction markets

(Jan. 11, 2026)



BuySell

Market

Yes 49c

No 53c

Amount

\$0

+\$1


+\$20

+\$100

Max

Trade

By trading, you agree to the [Terms of Use](#).

- AllIranGeopoliticsPoliticsMiddle East
- 

Nothing Ever Happens: Khamenei

57%
- 

Iran coup attempt by June 30?

40%
- 

US recognizes Reza Pahlavi as leader of Iran in 2026?


30%

Order Book





# Prediction markets


(Jan. 11, 2026)


 Polymarket


[How it works](#)


 Trending


 Breaking


 New


 Politics


 Sports


 Crypto


 Finance


 Geopolitics


 Earnings

 Tech

 Culture

 World

 Economy

 Climate

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Description of the Site and Features



# Financial securities (in Part 1)

- Tomorrow there must be one of   
- Agent 1 offers \$5 for a security that pays off \$10 if  or 
- Agent 2 offers \$8 for a security that pays off \$10 if  or 
- Agent 3 offers \$6 for a security that pays off \$10 if 
- Can we accept some of these at offers **at no risk?**



# How to incentivize a weather forecaster (in Part 3)

$$P(\text{☀}) = .5$$

$$P(\text{☁}) = .3$$

$$P(\text{⚡}) = .2$$

$$P(\text{☀}) = .8$$

$$P(\text{☁}) = .1$$

$$P(\text{⚡}) = .1$$



- Forecaster's bonus can depend on
  - Prediction
  - Actual weather on predicted day
- Reporting true beliefs should maximize expected bonus



# Sponsored search / ad auctions (in Part 3)

The screenshot shows a Google search interface with the query 'prediction markets proper scoring'. The search results include an advertisement for PredictIt, followed by several scholarly articles. The advertisement is highlighted with a black box. The scholarly articles are marked with green checkmarks.

Google

prediction markets proper scoring

All News Images Videos Shopping More Settings Tools

About 714,000 results (0.43 seconds)

**A Political Prediction Market - Join PredictIt Today - predictit.org**

Ad [www.predictit.org/](http://www.predictit.org/) ▼

Buy and sell shares on political outcomes with PredictIt. Let's Play Politics!  
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**Scholarly articles for prediction markets proper scoring** ✓

**Prediction markets:** Does money matter? - [Servan-Schreiber](#) - Cited by 337  
Logarithmic **markets** coring rules for modular ... - [Hanson](#) - Cited by 275  
... new understanding of **prediction markets** via no-regret ... - [Chen](#) - Cited by 81

**[PDF] Geometric Charaterization of Proper Scoring Rules and Hanson ... - ...** ✓

[www.mit.edu/~pengshi/papers/2009-05-csurf-geometry.pdf](http://www.mit.edu/~pengshi/papers/2009-05-csurf-geometry.pdf) ▼

One problem in implementing a **prediction market** is provid- ing liquidity, and ... a **proper scoring** rule can be a tedious process, and the re- lationship between ...

**[PDF] Proper Scoring Rules with Additional Properties - MIT** ✓

[www.mit.edu/~pengshi/papers/2009-04-psr-characterization.pdf](http://www.mit.edu/~pengshi/papers/2009-04-psr-characterization.pdf) ▼

of market-scoring rules and **prediction markets**. In this pa- per, we present a geometric interpretation to a previously known characterization of **proper scoring** ...

**[PDF] Logarithmic Market Scoring Rules for Modular ... - Robin Hanson** ✓

[hanson.gmu.edu/mktscore.pdf](http://hanson.gmu.edu/mktscore.pdf) ▼

by R Hanson - 2002 - [Cited by 275](#) - [Related articles](#)  
cannot even **predict** the direction in which others will disagree with them (Hanson, .... For a non-**proper**

- Choice of ads (if any) to show determined by:
  - Advertiser bid
  - Predicted likelihood of click



# Cutting across all the parts: How does all this change with modern AI (especially large language models)?

- More natural expression of preferences in markets and mechanisms?
- Generating ads?
- Can these systems play games well? Do they play like human beings?
- Can they help us design better mechanisms, for example with their own programming ability?
- ...