

15-326

# Computational Microeconomics

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

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# History



*John von  
Neumann*

computer architecture  
(von Neumann  
architecture)

game theory  
(minimax theorem)

linear programming  
(duality)

***Computer Science  
& Engineering***

***Economic Theory***

***Mathematical  
Optimization &  
Operations  
Research***

1900

1950

2000

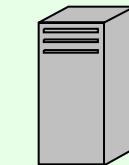


# What is Economics?

- “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

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



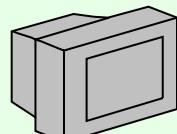
\$ 800

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

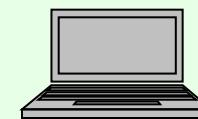
$$v( \text{laptop} ) = 400$$

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

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



\$ 600



\$ 200



AAAClipArt.com

# After trade (a more efficient outcome)

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



\$ 1100

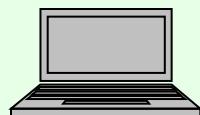
*... but how do we  
get here?  
Unstructured trade?  
Auctions?  
Exchanges?*

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

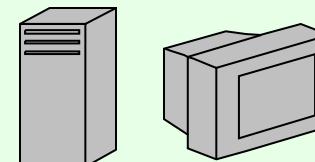
$$v(\text{Laptop}) = 400$$

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

$$v(\text{Server}, \text{Monitor}) = 400$$



\$ 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”

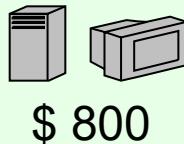
# What is Computer Science?

- “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*

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



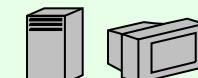
$$v(\text{[server, monitor]}) = \$500$$
$$v(\text{[laptop]}) = \$400$$



*output*



\$ 750



\$ 450

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

# Economic mechanisms

**“true” input**

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



 \$ 800

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



 \$ 400

agent 1's  
bidding  
algorithm

**agents' bids**

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



 \$ 800

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



 \$ 400

**result**



 \$ 800



 \$ 400

exchange  
mechanism  
(algorithm)

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

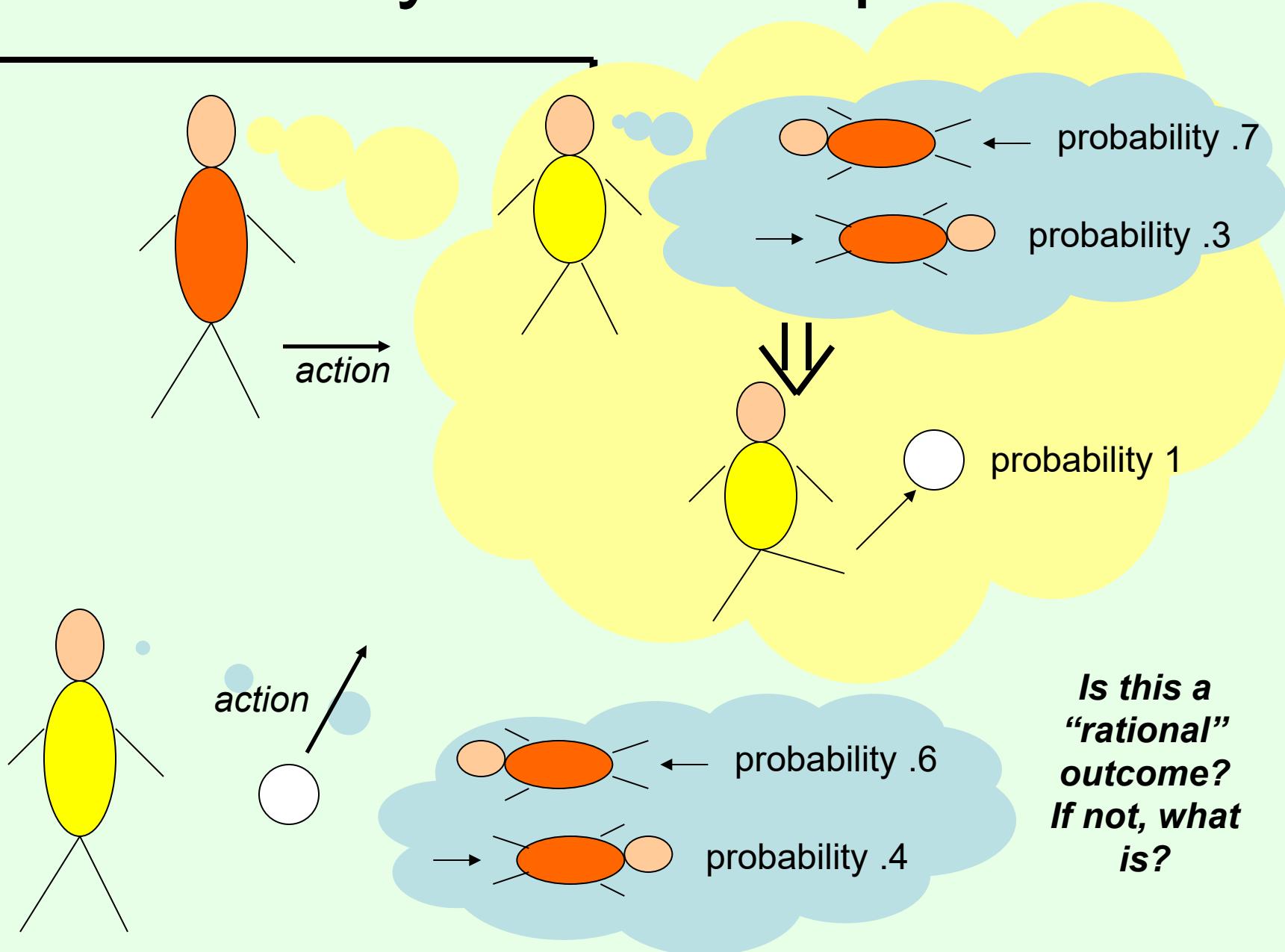
*Agents will selfishly respond to  
incentives*

# 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

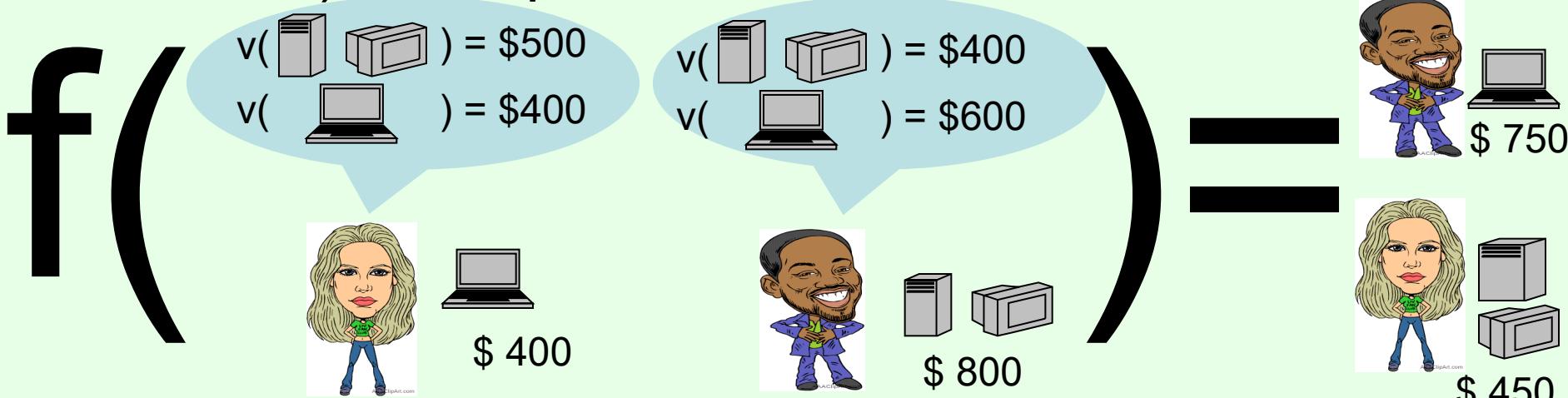
# Penalty kick example



# Mechanism design

## (Part 3 of the course)

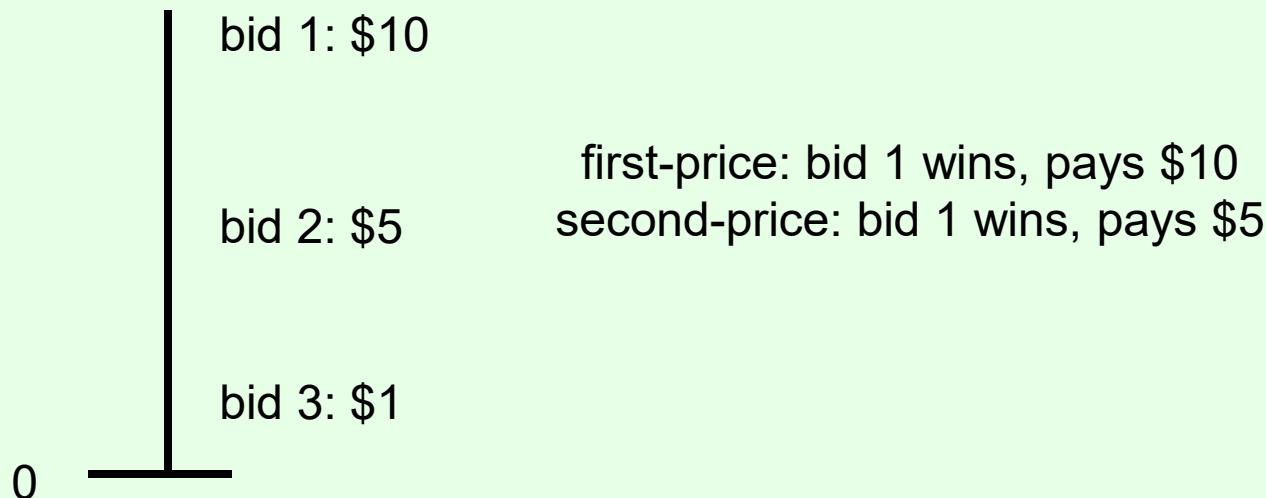
- Mechanism = rules of auction, exchange, ...
- A function that takes reported preferences (bids) as input, and produces outcome (allocation, payments to be made) as output



- 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

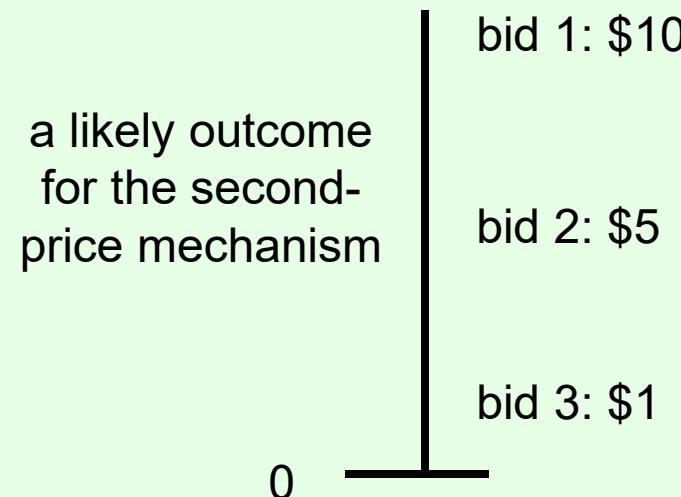
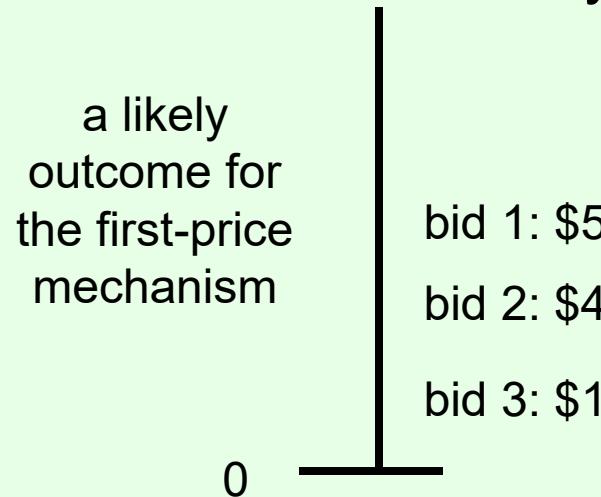
# Example: (single-item) auctions

- **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

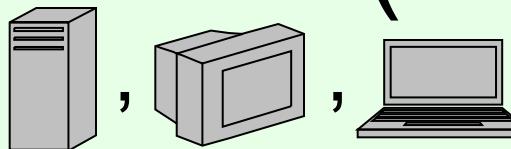
# Uses of LP, MIP in this course

	<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*

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



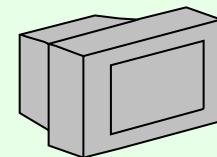
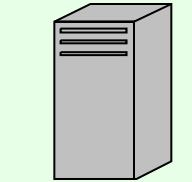
*bid 2*

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



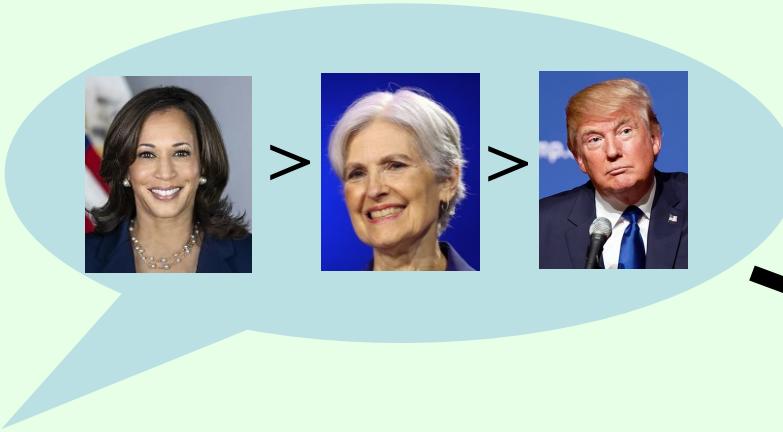
*bid 3*

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



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

# Voting (in Part 1)



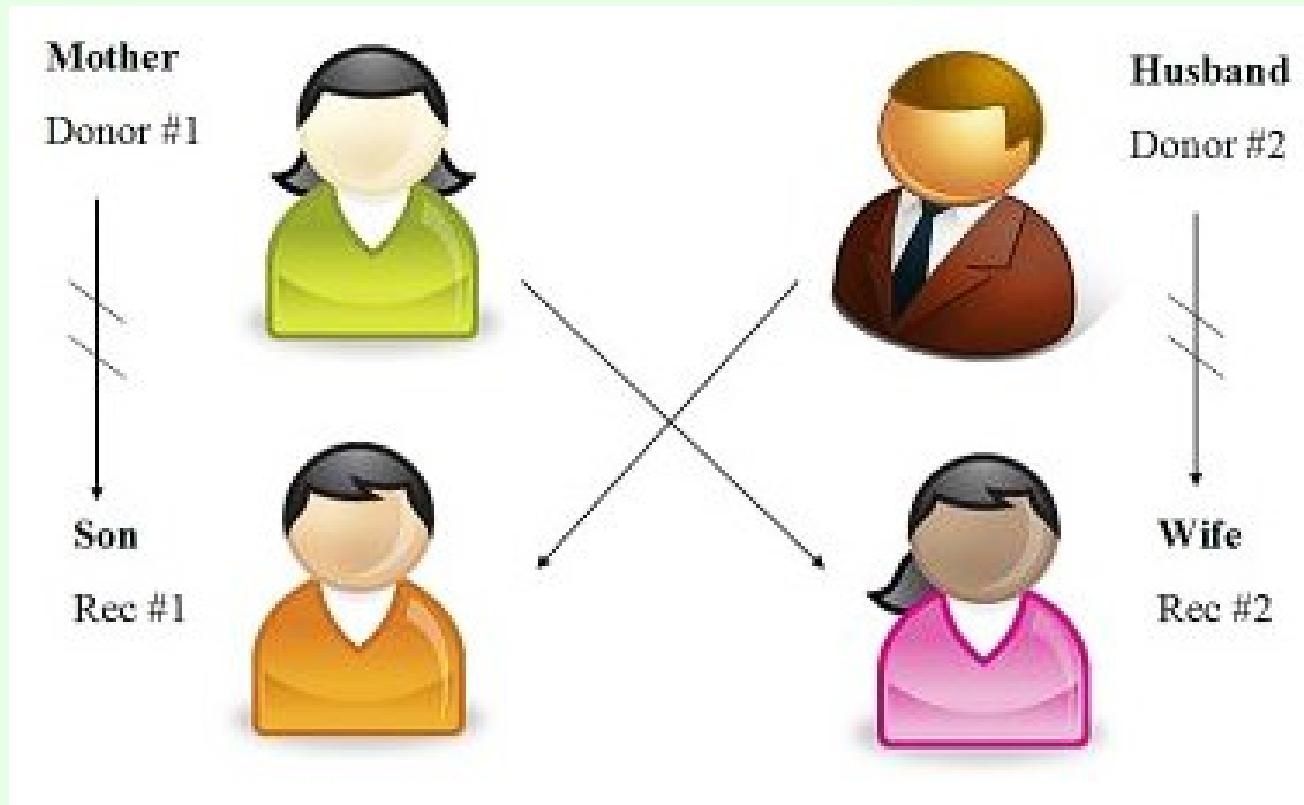
voting rule  
(mechanism)  
determines winner  
based on votes



- 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 | ⓘ

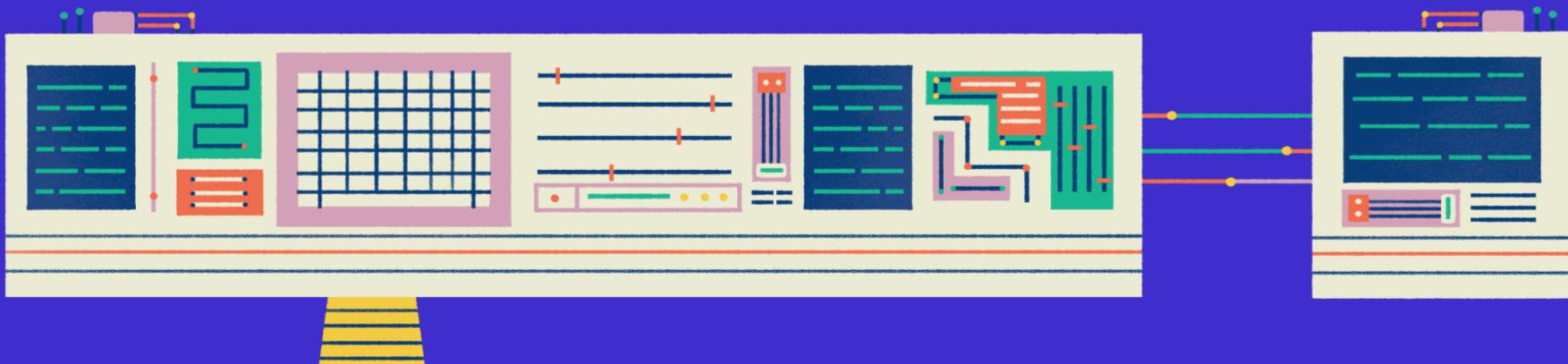
## Prescription AI

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

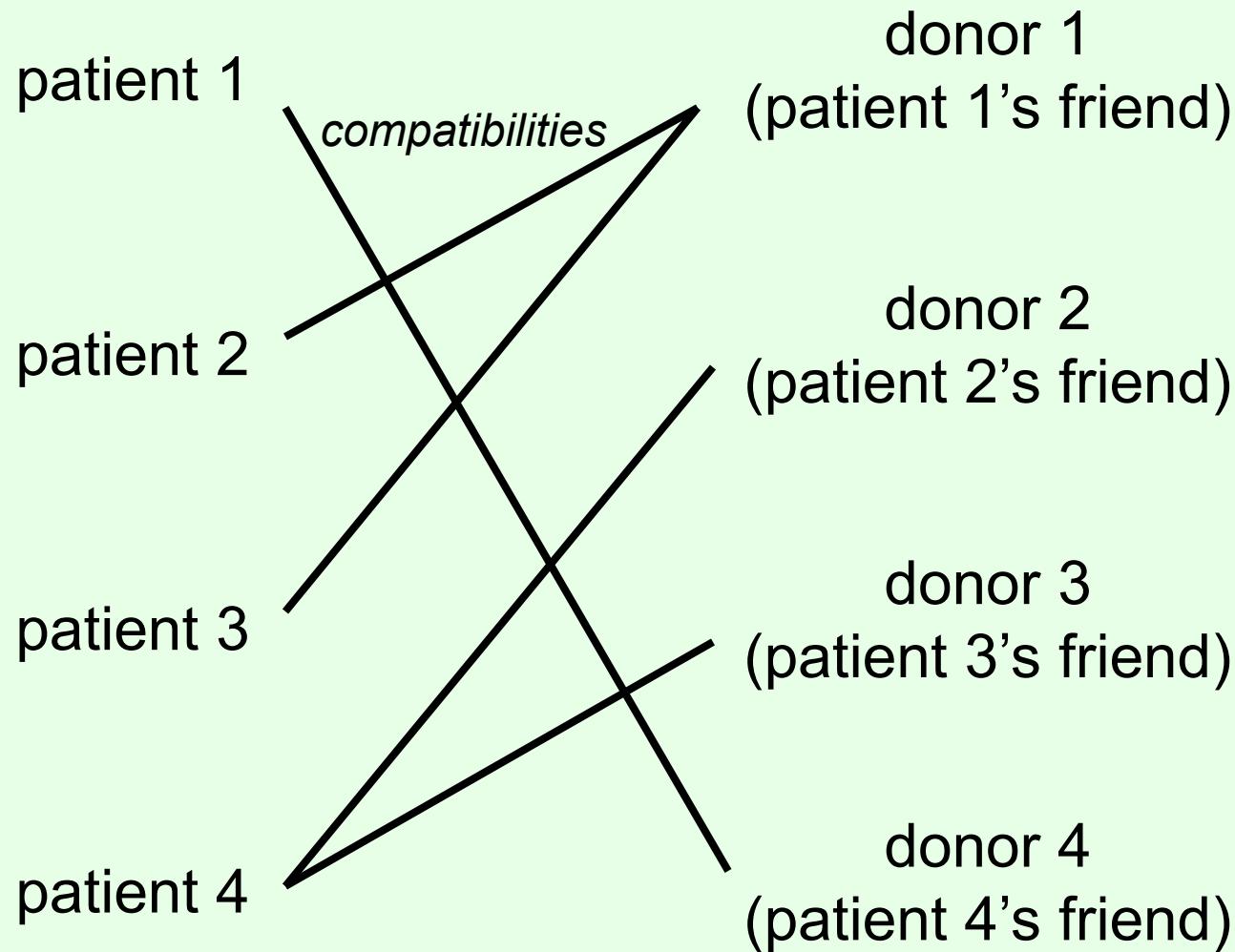
THE BOTPERATING TABLE

# How AI changed organ donation in the US

By Corinne Purtill • September 10, 2018



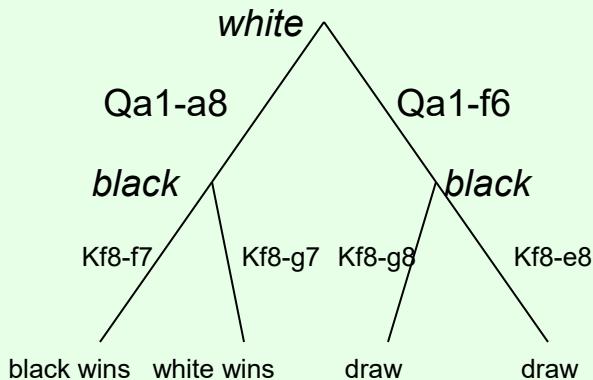
# Kidney exchange (in Part 1)



# Game playing & AI (in Part 2)

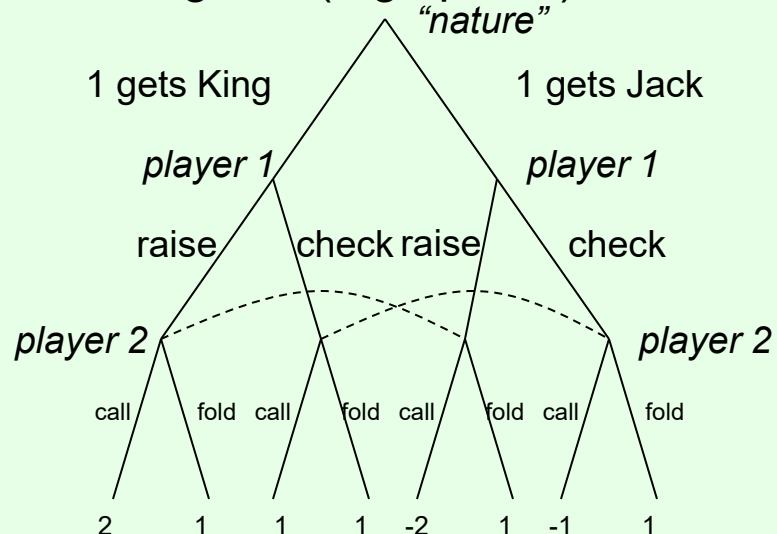
perfect information games:

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)



- 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~~

- 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~~

# 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?

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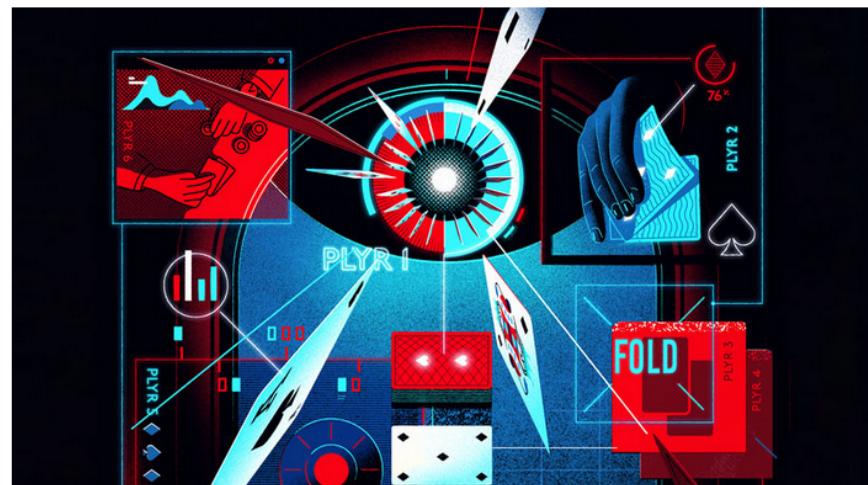
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# Artificial intelligence masters multiplayer poker



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?



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



## Federal Air Marshals

Which flights get a FAM?



## US Coast Guard

Which patrol routes should be followed?

## Wildlife Protection

Where to patrol to catch poachers or find  
their snares?



# Global Presence of Security Games Efforts



BEHIND THE SCENES, THE GAME'S ARMOR AND ITS MANY  
OPERATIONS ARE USED AROUND THE WORLD TO  
PROTECT AGAINST TERRORISM, POACHERS,  
ILLEGAL FISHING AND OTHER THREATS.



## SUCCESSFULLY TESTED

### Gulf of Mexico (River Drives CPMR, Texas)

APRIL 2012  
AEROS — After conducting extensive  
operations for AEROS, Client Mayor Ken Johnson  
of the City of Brownsville declared a successful  
"AEROS and real strategic partnership." [Read]

### Los Angeles Metro — TRUSTS

THE Los Angeles Sheriff's Department, which  
LA Metro is responsible for, recently  
selected to test drive version 1.0 of the  
Game's Department Metro area interface.  
Expectations are positive, as the software  
deploys natural police procedures to detect  
GTAKA and respond to LA Metro. [Read]

### Iganda — PAWS

APRIL 2012  
Iganda's major national parks of Queen  
Elizabeth National Park to investigate  
conservation efforts to promote the conservation  
of critically Endangered Tree Hyrax, warthogs  
and giant forest hogs. The park's efforts are  
locally and nationally as "bold and "green."

### Malaysia — RAINS

APRIL 2012  
RANTS, 0.01% of land is designated to  
protecting the survival of flora and other wild  
life, in accordance with the original plan.  
RANTS, began testing PAWS in Malaysia in  
September. Malaysia, to evaluate its ability to  
protects effective actions in the challenging  
Malaysian jungle.

## POSSIBLE FUTURE TEST SITES

Vietnam, Cambodia, Bangladesh, Indonesia  
— PAWS

## DEPLOYED

### Parks — PROTECT

PROTECT, intelligent conservation of U.S. Forest  
Service parks to optimize service and maintain  
natural resources points, smuggling and terror  
activities.

PROTECT is employed at:

- Part of New York and New Jersey
- Part of Florida
- Part of Los Angeles, Long Beach

St. Lucia Island (U.S. — FBI BOT)  
PROTECT provides protection to the U.S.  
Island (U.S. — FBI BOT) and U.S. Virgin Islands  
Department of Justice (DOJ).

Los Angeles International Airport — AEROS  
AEROS intelligent surveillance technologies across 100  
kilometers along the five roads that lead into  
the airport.

### U.S. Air Traffic — TRUSTS

As most states are transitioning air traffic to  
private airports, the Transportation Security  
Administration (TSA) has been held  
responsible. Held responsible, while  
existing flight schedules to make them  
easily accessible to would-be  
airline.



Indonesia — PAWS  
Indonesia, specifically Aceh, Sumatra, an  
associate member of the Association of  
Southeast Asian Nations (ASEAN), and a  
subsidiary of the Indonesian Ministry of  
Forests and Environment.

Papua New Guinea — PAWS  
Papua New Guinea, specifically  
engages PAWS to coordinate  
political activities for regions, justice and  
natural resources, especially those related to  
forest, especially illegal logging.

# Prediction markets

(Jan. 11, 2026)

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 **Will the Iranian regime fall before 2027?**

\$1,122,265 Vol. ⌚ Dec 31, 2026

[Past](#) [Jan 31](#) [Mar 31](#) [Jun 30](#) [Dec 31](#)

**48% chance** ▲ 33%

 50%  
40%  
30%  
20%  
10%  
0%

Dec Jan

[1H](#) [6H](#) [1D](#) [1W](#) [1M](#) [ALL](#)

✖ 📄 ↔ ⚙️

**Order Book**

 Buy Sell Market ▼

**Amount** \$0

+\$1 +\$20 +\$100 Max

**Trade**

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

All Iran Geopolitics Politics Middle

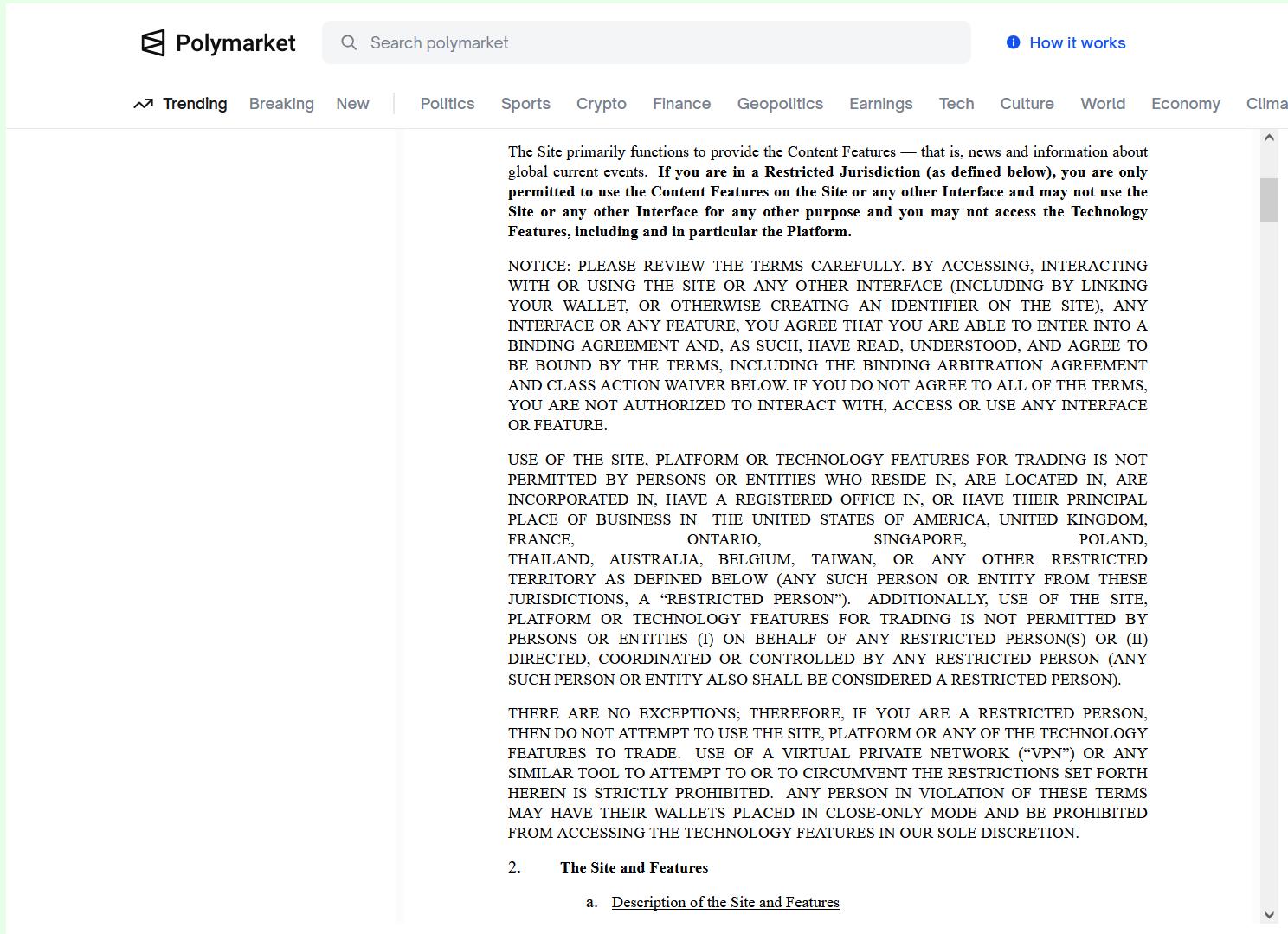
 **Nothing Ever Happens: Khamenei** 57%

 **Iran coup attempt by June 30?** 40%

 **US recognizes Reza Pahlavi as leader of Iran in 2026?** 30%

# Prediction markets

(Jan. 11, 2026)



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2. **The Site and Features**

a. [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)

$$\begin{aligned}P(\text{Sun}) &= .5 \\P(\text{Cloud with rain}) &= .3 \\P(\text{Cloud with lightning}) &= .2\end{aligned}$$

$$\begin{aligned}P(\text{Sun}) &= .8 \\P(\text{Cloud with rain}) &= .1 \\P(\text{Cloud with lightning}) &= .1\end{aligned}$$



- 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)

Google search results for "prediction markets proper scoring". The search bar shows the query. The results page includes a header with "All", "News", "Images", "Videos", "Shopping", "More", "Settings", and "Tools". Below the header, it says "About 714,000 results (0.43 seconds)".

**A Political Prediction Market - Join PredictIt Today - predictit.org**  
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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 providing liquidity, and ... a proper scoring rule can be a tedious process, and the relationship 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 paper, 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?
- ...