

CPS 296.1: Computational Microeconomics: Game Theory, Social Choice, and Mechanism Design

Instructor: Vincent Conitzer

(Sally Dalton Robinson Professor of Computer Science & Professor of Economics)

conitzer@cs.duke.edu

Course web page:

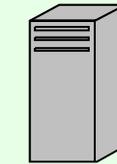
<http://www.cs.duke.edu/courses/fall11/cps296.1>

What is Economics?

- “Economics is the social science that analyzes the production, distribution, and consumption of goods and services.” [[Wikipedia, Aug. 2011](#)]
- Some key concepts:
 - Economic **agents** or **players** (individuals, households, firms, ...)
 - 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

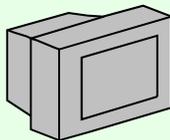
$$v(\text{server}) = 200$$



\$ 800

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

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



\$ 600

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

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



\$ 200



After trade (a more efficient outcome)

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

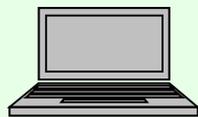


\$ 1100

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

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

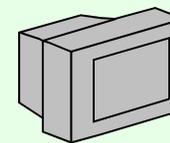
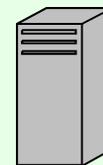
$$v(\text{laptop}) = 400$$



\$ 400

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

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



\$ 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?

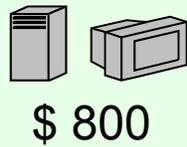
- “Computer science or computing science (abbreviated CS) is the study of the theoretical foundations of information and computation and of practical techniques for their implementation and application in computer systems.”
[Wikipedia, Aug. 2011]
- A **computational problem** is given by a function f mapping inputs to outputs
 - For integer x , let $f(x) = 0$ if x is prime, 1 otherwise
 - For an initial allocation of resources 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

input

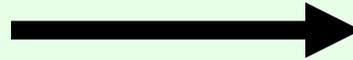
$$v(\text{server, monitor}) = \$400$$

$$v(\text{laptop}) = \$600$$

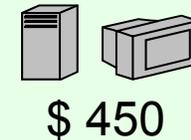


$$v(\text{server, monitor}) = \$500$$

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



output

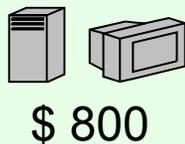


Here, gains from trade (\$300) are divided evenly (not essential)

Economic mechanisms

“true” input

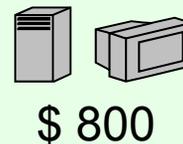
$$v(\text{server, printer}) = \$400$$
$$v(\text{laptop}) = \$600$$



agent 1's
bidding
algorithm

agents' bids

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



exchange
mechanism
(algorithm)

result



\$ 800

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



\$ 400

agent 2's
bidding
algorithm

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



\$ 400

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

*Agents will selfishly respond to
incentives*

What is **game theory**?

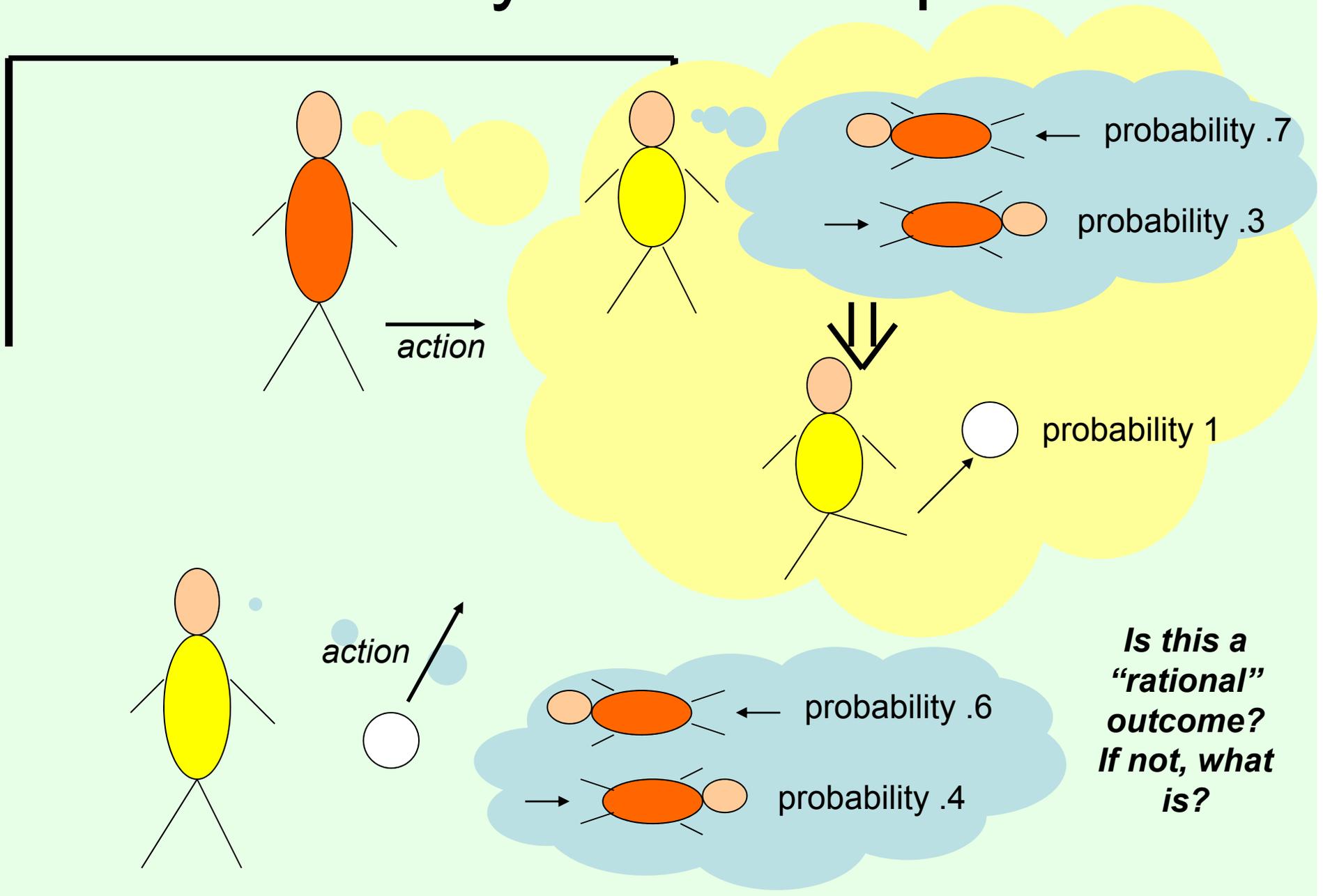
- “In mathematics, game theory models strategic situations, or games, in which an individual's success in making choices depends on the choices of others (Myerson, 1991). It is used in the social sciences (most notably in economics, management, operations research, political science, and social psychology) as well as in other formal sciences (logic, computer science, and statistics) and biology (particularly evolutionary biology and ecology).”

[Wikipedia, Aug. 2011]

What is **game theory**...

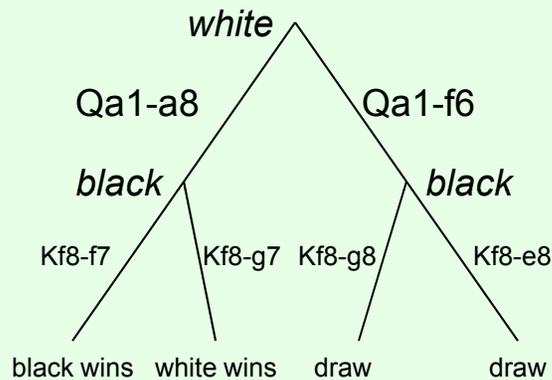
- Game theory studies settings where multiple parties (**agents**) each have
 - different preferences (utility functions),
 - different actions that they can take
- Each agent's utility (potentially) depends on all agents' actions
 - What is optimal for one agent depends on what other agents do
 - Very 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



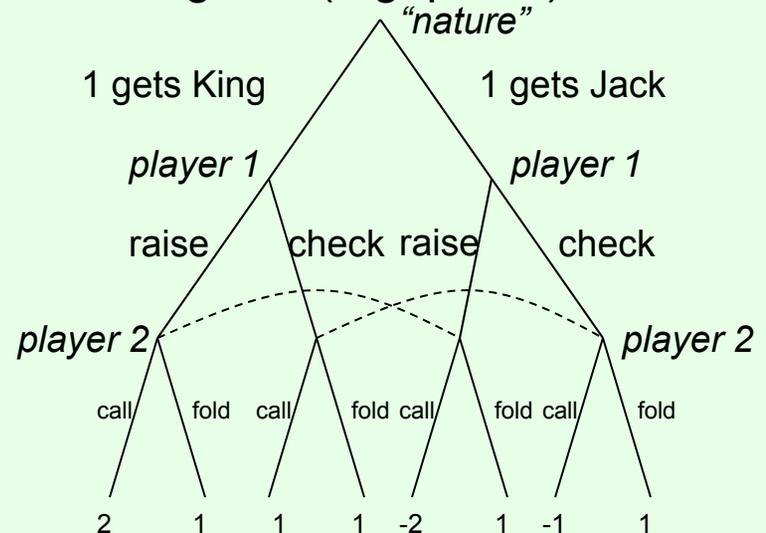
Game playing & AI

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



- 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, ...)
- Top computer programs (arguably) better than humans in chess, not yet in 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

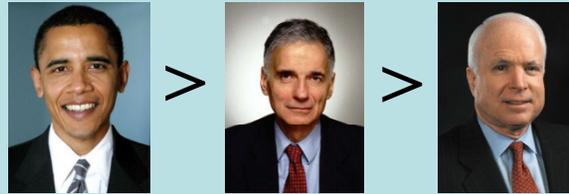
Questions and problems in (computational) game theory

- How should we **represent** games (=strategic settings)?
 - Standard game-theoretic representations not always concise enough
- What does it mean to **solve** a game?
 - **Solution concepts** from game theory, e.g., Nash equilibrium
- How **computationally hard** is it to solve games?
 - Can we solve them approximately?
- Is there a role for **(machine) learning** in games?
- What types of **modeling problems** do we face when addressing real-world games?
 - E.g., applications in security
- ...

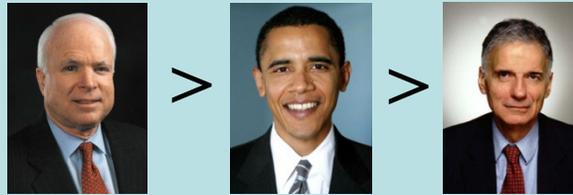
What is **social choice**?

- “Social choice theory is a theoretical framework for measuring individual interests, values, or welfares as an aggregate towards collective decision.” [[Wikipedia, Aug. 2011](#)]
- I.e., making decisions based on the preferences of multiple agents
- Largely, but not exclusively, focused on **voting**

Voting over outcomes

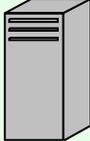
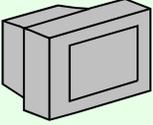


voting rule
(mechanism)
determines winner
based on votes



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

Combinatorial auctions

Simultaneously for sale:  ,  , 



bid 1

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



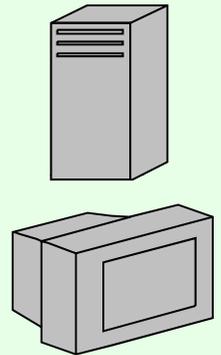
bid 2

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



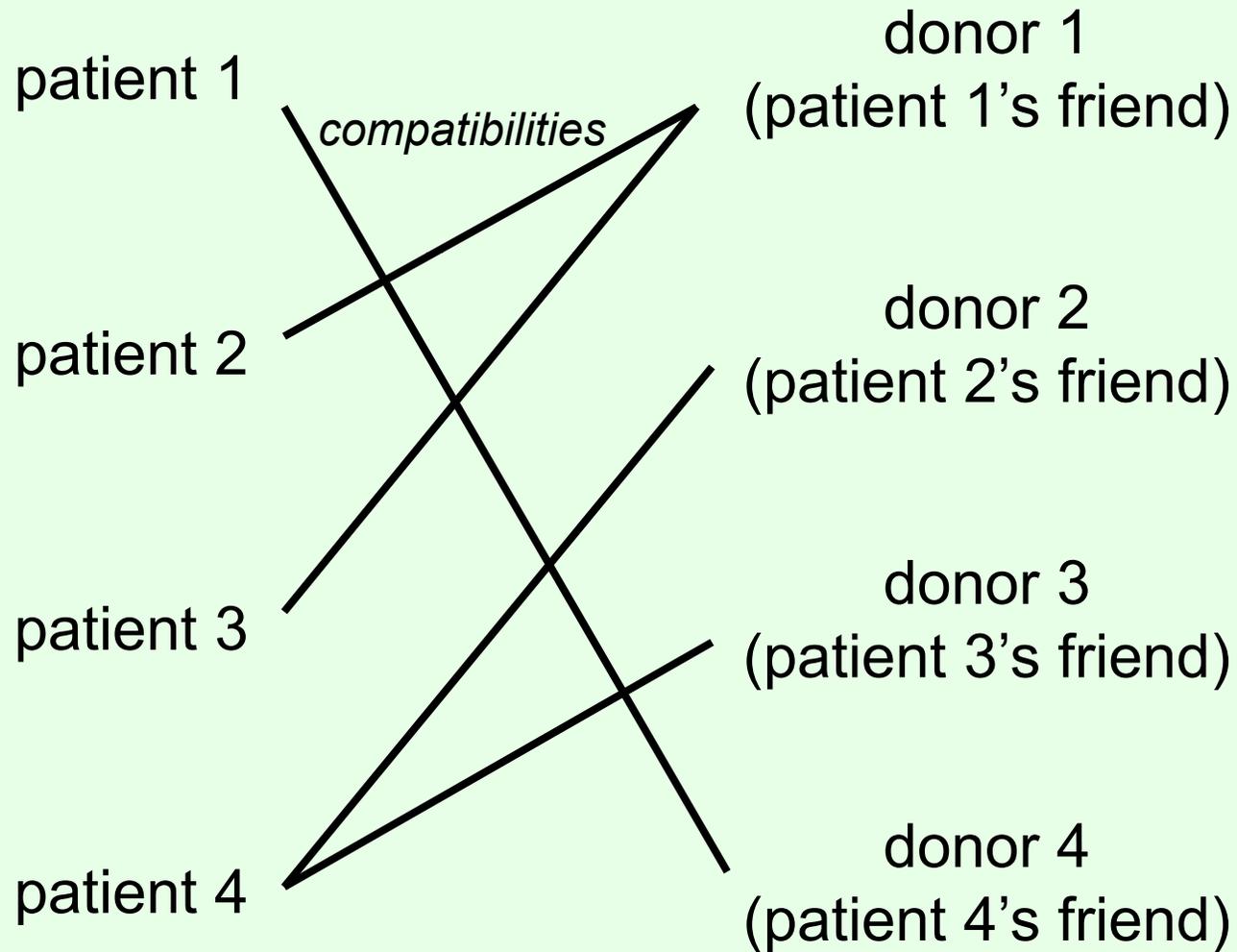
bid 3

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



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

Kidney exchange



Problems in computational social choice

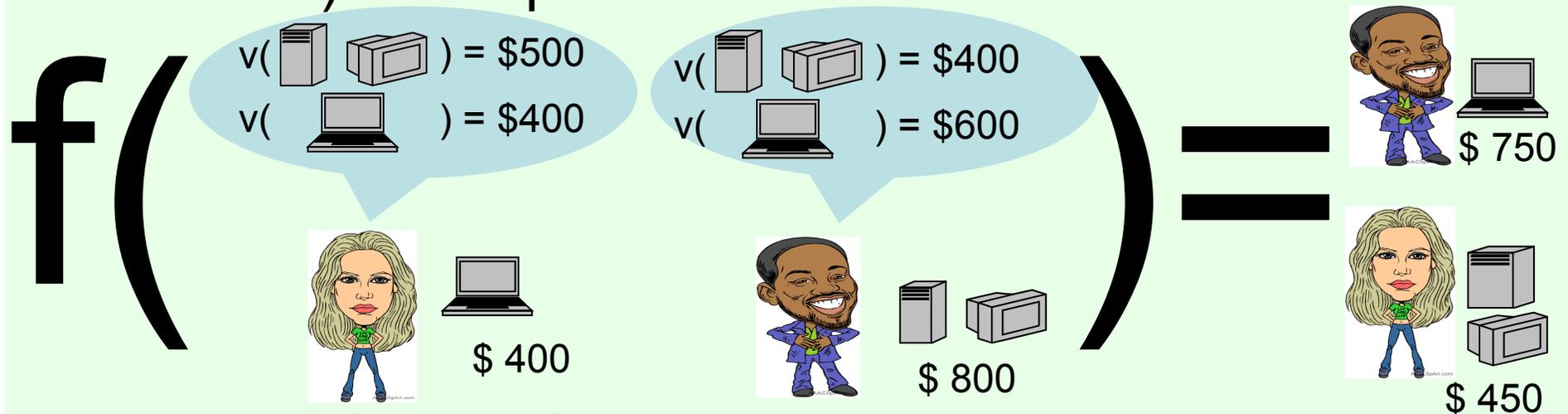
- **Winner determination** problem
 - For some voting rules, determining the winner is NP-hard
 - In a combinatorial auction, deciding which bids win is (in general) an NP-hard problem
- **Preference elicitation** (communication) problem
 - Can be impractical to communicate all of one's preferences (e.g., valuation for every bundle)
- **Mechanism design** problem
 - How do we get the bidders to behave so that we get good outcomes?
- These problems **interact** in nontrivial ways
 - E.g. limited computational or communication capacity can limit mechanism design options
 - ... but can perhaps also be used in a positive way

What is mechanism design?

- “[...] a field in game theory [...] The distinguishing features of [mechanism design] are:
 - that a game “designer” chooses the game structure rather than inheriting one
 - that the designer is interested in the game’s outcome
- “[...] usually solved by motivating agents to disclose their private information.” [[Wikipedia](#), Aug. 2011]

Mechanism design...

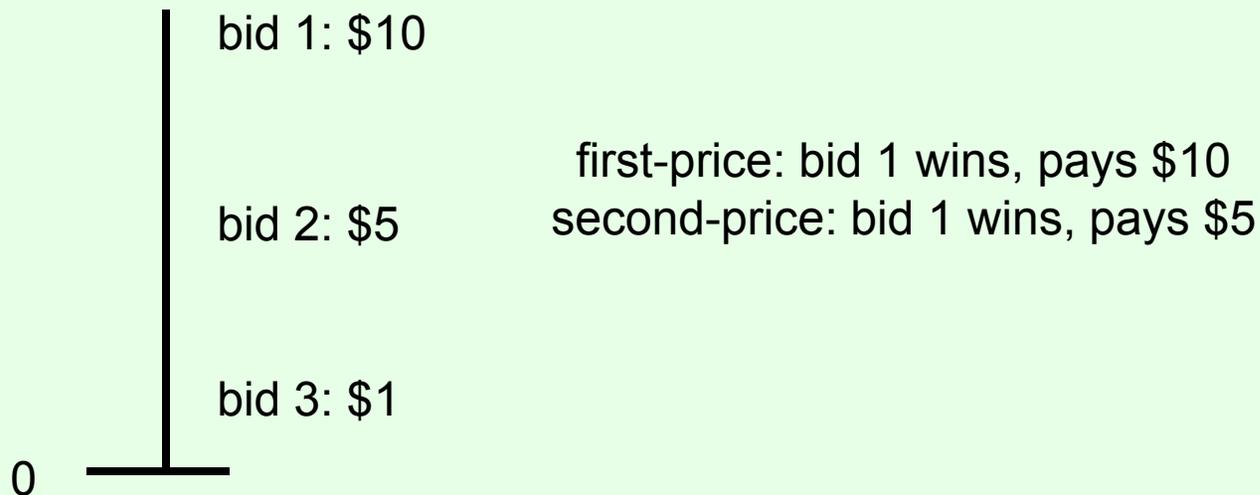
- **Mechanism** = rules of auction, exchange, ...
- A **function** that takes **reported preferences** (bids) as input, and produces **outcome** (allocation, payments to be made) as output



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

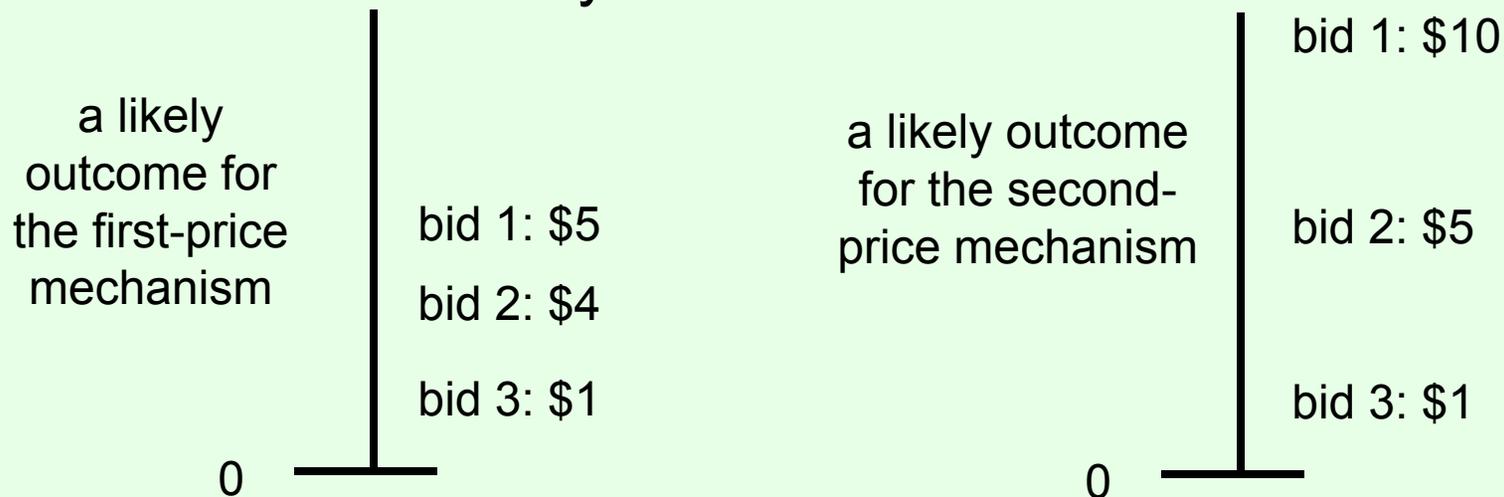
Example: (single-item) auctions

- **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?

Many uses of linear programming, mixed integer (linear) programming in this course

	Linear programming	Mixed integer linear programming
Game theory	<p>Dominated strategies</p> <p>Minimax strategies</p> <p>Correlated equilibrium</p> <p>Optimal mixed strategies to commit to</p>	<p>Nash equilibrium</p> <p>Optimal mixed strategies to commit to in more complex settings</p>
Social choice, expressive marketplaces	<p>Winner determination in auctions, exchanges, ... with partially acceptable bids</p>	<p>Winner determination in: auctions, exchanges, ... without partially acceptable bids; Kemeny, Slater, other voting rules; kidney exchange</p>
Mechanism design	<p>Automatically designing optimal mechanisms that use randomization</p>	<p>Automatically designing optimal mechanisms that do not use randomization</p>

Sponsored search

Web [Images](#) [Videos](#) [Maps](#) [News](#) [Shopping](#) [Gmail](#) [more](#) ▾



[Advanced Search](#)
[Preferences](#)

Web [+ Show options...](#)

[Scholarly articles for combinatorial auction](#)



[Algorithm for optimal winner determination in ...](#) - Sandholm - Cited by 755

[Combinatorial auctions](#) - Cramton - Cited by 364

[Taming the computational complexity of combinatorial ...](#) - Fujishima - Cited by 424

[Combinatorial auction](#) - Wikipedia, the free encyclopedia

Jun 26, 2009 ... A combinatorial auction is an auction in which bidders can place bids on combinations of items, or "packages," rather than just individual ...

en.wikipedia.org/wiki/Combinatorial_auction - [Cached](#) - [Similar](#)

[Introduction to Combinatorial Auctions](#)

File Format: PDF/Adobe Acrobat - [View](#)

combinatorial auctions can be studied in a wide range of auction In Chapter 18, Leyton-Brown and Shoham present the Combinatorial Auction Test Suite ...

www.cramton.umd.edu/.../cramton-shoham-steinberg-introduction-to-combinatorial-auctions.pdf - [Similar](#)

by P Cramton - [Cited by 17](#) - [Related articles](#) - [All 14 versions](#)

[Combinatorial Auctions](#)

A comprehensive book on combinatorial auctions—auctions in which bidders can bid on packages of items. The book consists of original material intended for ...

www.cramton.umd.edu/.../combinatorial-auctions-book-public.htm - [Similar](#)

[+ Show more results from www.cramton.umd.edu](#)

[Combinatorial Auctions: A Survey](#)

File Format: PDF/Adobe Acrobat - [View as HTML](#)

of combinatorial auctions. Second, it uses this subject as a vehicle to the auction. This feature of combinatorial auctions is called the threshold ...

www.cis.upenn.edu/~mkeams/.../combinatorial-auctions-survey.pdf - [Similar](#)

by S de Vries - [Cited by 496](#) - [Related articles](#) - [All 42 versions](#)

[Amazon.com: Combinatorial Auctions \(9780262033428\): Peter Cramton ...](#)

Amazon.com: Combinatorial Auctions (9780262033428): Peter Cramton, Yoav Shoham, Richard Steinberg: Books.

www.amazon.com/Combinatorial-Auctions.../0262033429 - [Cached](#) - [Similar](#)

[Combinatorial auctions enhance our ability to allocate mul-](#)

File Format: PDF/Adobe Acrobat - [View](#)

Jun 17, 2003 ... combinatorial auction that, during laboratory testing, eliminated ... currently used by the FCC in the field, a combinatorial auction ...

Sponsored Links

[Combinatorial Auctions](#)

for carbon, water, timber, grain, ore, licenses & rights
www.tradeslot.com

[Procurement solutions](#)

We deliver sustainable cost reduction via systems & upskilling
www.vendigital.com

[Combinatorial Auction](#)

Save on Combinatorial auction
Free Shipping Available. Buy Today!
www.Amazon.com/Books

Prediction markets

2012 Presidential Election Winner (Party) Democratic Party candidate to win 2012 Presidential Election

New: [Request A Quote](#)

PRESIDENT.DEM.2012



[Trade](#)

Last Trade : 64.0

[Suggest An Image](#)

Lifetime Last Week Last Day



Closing Price: 64

[Advanced graphing](#)

[Add this chart to your website/blog](#)

Links	Contract Info	BID		ASK	
Related Intrade Markets	Currency USD	Qty	Price	Price	Qty
Contract Specific Rules	Session lo/hi - - -	21	63.4	65.3	20
Search Yahoo News	Life lo/hi 55.0 - 79.9	15	63.2	66.0	10
Search Google	Previous Close 64.0	50	63.1	66.5	21
	Open Price -	180	63.0	67.6	20
	Last Price 64.0	20	62.0	67.8	1
	Last Trade Time -	1	60.2	68.0	100
	Today's Volume 0	200	60.0	68.5	1
	Total Volume 4728	10	59.0	68.9	50
	Market Lifetime: Sep 5 - Dec 31	3	55.2	70.0	200
		134	55.0	70.1	5
		5	50.2	71.2	4
		2	50.1	72.0	10
		1	0.1	72.8	1
				73.0	200
				73.9	10

Democratic Party candidate to win 2012 Presidential Election

Contract Specs	Examples	Margin Specs	Explanation
Tick Size	0.1	Contract Start Date	Sep 5, 2008
Tick Value	USD 0.01	Max Contract Price	100.0
USD per Point	USD 0.10	Contract Type	0-100
Min Contract Price	0.0	Contract ID	639648

Financial securities

- 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

$$P(\text{☀}) = .5$$

$$P(\text{☁}) = .3$$

$$P(\text{⚡}) = .2$$

$$P(\text{☀}) = .8$$

$$P(\text{☁}) = .1$$

$$P(\text{⚡}) = .1$$



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

Why should economists care about computer science?

- Finding efficient allocations of resources is a (typically hard) **computational problem**
 - Sometimes beyond current computational techniques
 - If so, unlikely that **any** market mechanism will produce the efficient allocation (even without incentives issues)
 - Market mechanisms must be designed **with computational limitations in mind**
 - New algorithms allow new market mechanisms

Why should economists care about computer science...

- **Agents** also face difficult computational problems in participating in the market
 - Especially acting in a game-theoretically optimal way is often **computationally hard**
 - Game-theoretic predictions **will not come true** if they cannot be computed
 - Sometimes bad (e.g., want agents to find right bundle to trade)
 - Sometimes good (e.g., do not want agents to manipulate system)

Why should computer scientists care about economics?

- Economics provides high-value computational problems
- Interesting technical twist: **no direct access to true input**, must incentivize agents to reveal true input
- Conversely: Computer systems are increasingly used by **multiple parties** with different preferences (e.g., Internet)
- Economic techniques must be used to
 - **predict** what will happen in such systems,
 - **design** the systems so that they will work well
- Game theory is relevant for **artificial intelligence**
 - E.g., computer poker