CPS 590.4: 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/spring14/compsci590.4/

Journal, conference, …

ACM Transactions on Economics and Computation (TEAC)

ec14

15th ACM CONFERENCE ON ECONOMICS AND COMPUTATION

JUNE 8-12 2014 | STANFORD UNIVERSITY, PALO ALTO

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*

CS-ECON@DUKE

Home   Schedule   Past talks   People

We are a group of people interested in the intersection of computer science and economics (and the social sciences more broadly) and the impact of this interplay on decisions in information technology and digital business. This includes applying techniques from computer science and optimization to economics -- for example, using computation to design market clearing mechanisms and to implement efficient allocation and pricing in them -- as well as applying techniques from economics to computer science -- for example, designing incentives for users of networked computer systems and social networks.

Contacts

For organizational questions about the seminar series, please contact Dima Korzhyk. For other matters, please approach the relevant faculty contact(s): Atila Abdulkadiroglu (Econ), Vincent Conitzer (CS), Rachel Kranton (Econ), Ben Lee (ECE), Kamesh Munagala (CS), Sasa Pekec (Fuqua). Pam Spencer helps with catering and arranging the speakers' travel.

Mailing List

Please subscribe to the cs-econ mailing list if you are at Duke (or in the vicinity) and interested in the seminar series. The list will be used for talk announcements.

http://econ.cs.duke.edu

- Atila Abdulkadiroglu
  Department of Economics.
- Owen Astrachan
  Department of Computer Science.
- Charles Becker
  Department of Economics.
- Alexandre Belloni
  The Fuqua School of Business.
- David B. Brown
  The Fuqua School of Business.
- Vincent Conitzer
  Department of Computer Science, and
- Landon Cox
  Department of Computer Science.
- Brendan Daley
  The Fuqua School of Business.
- Daniel A. Graham
  Department of Economics.
- Rachel E. Kranton
  Department of Economics.
- R. Vijay Krishna
  Department of Economics, UNC.
- Benjamin C. Lee
  Department of Electrical and Compute
- Giuseppe (Pino) Lopomo
  The Fuqua School of Business.
- David McAdams
  The Fuqua School of Business, and De
- Carl F. Mela
  The Fuqua School of Business.
- Kamesh Munagala
  Department of Computer Science.
- Andres Musalem
  The Fuqua School of Business.
- Aleksandar Sasa Pekec
  The Fuqua School of Business.
- Philipp Sadowski
  Department of Economics.
- Peng Sun
  The Fuqua School of Business.
- Curtis R. Taylor
  Department of Economics.
- Kenneth C Wilbur
  The Fuqua School of Business.

Master's of Science in Economics and Computation (MSEC)

The MSEC degree is a joint master's program of the Departments of Economics and Computer Science. The joint field of economics and computation has recently emerged from two converging intellectual needs, which has created the opportunity for a truly interdisciplinary program.

The MSEC program is the outcome of exciting developments across the two fields:

- Computer science is becoming increasingly important for economists addressing complex questions on large repositories of data;
- The explosion of computer uses in all areas of life has made it necessary for computer scientists to understand the economics of computing systems; and,
- Computer scientists may now also analyze informational and financial transactions between people, businesses, governments, and electronic agents in economic terms.

Duke UNIVERSITY Economics

About | Undergraduate | Master's Program | Ph.D. Program | Research | Centers & Initia

Home / Master's Program / Master's of Science in Economics and Computation

"Macroeconomic problems are almost always analytically intractable and therefore require a computer to solve ... Having a background in computer science made it much easier to learn (computational) methods, as well as apply cutting-edge advances in technology to economic problems."

David Klemish
MSEM

"Tech giants such as Google, Microsoft, Yahoo, and Facebook are in many ways ahead of academia in getting computer scientists and economists to work together, and interest in these topics extends well beyond this group of companies. With this Master's program, Duke is at the forefront of catching up with industry in breaking down boundaries."

Vince Conitzer
Department of Computer Science

Application Deadline

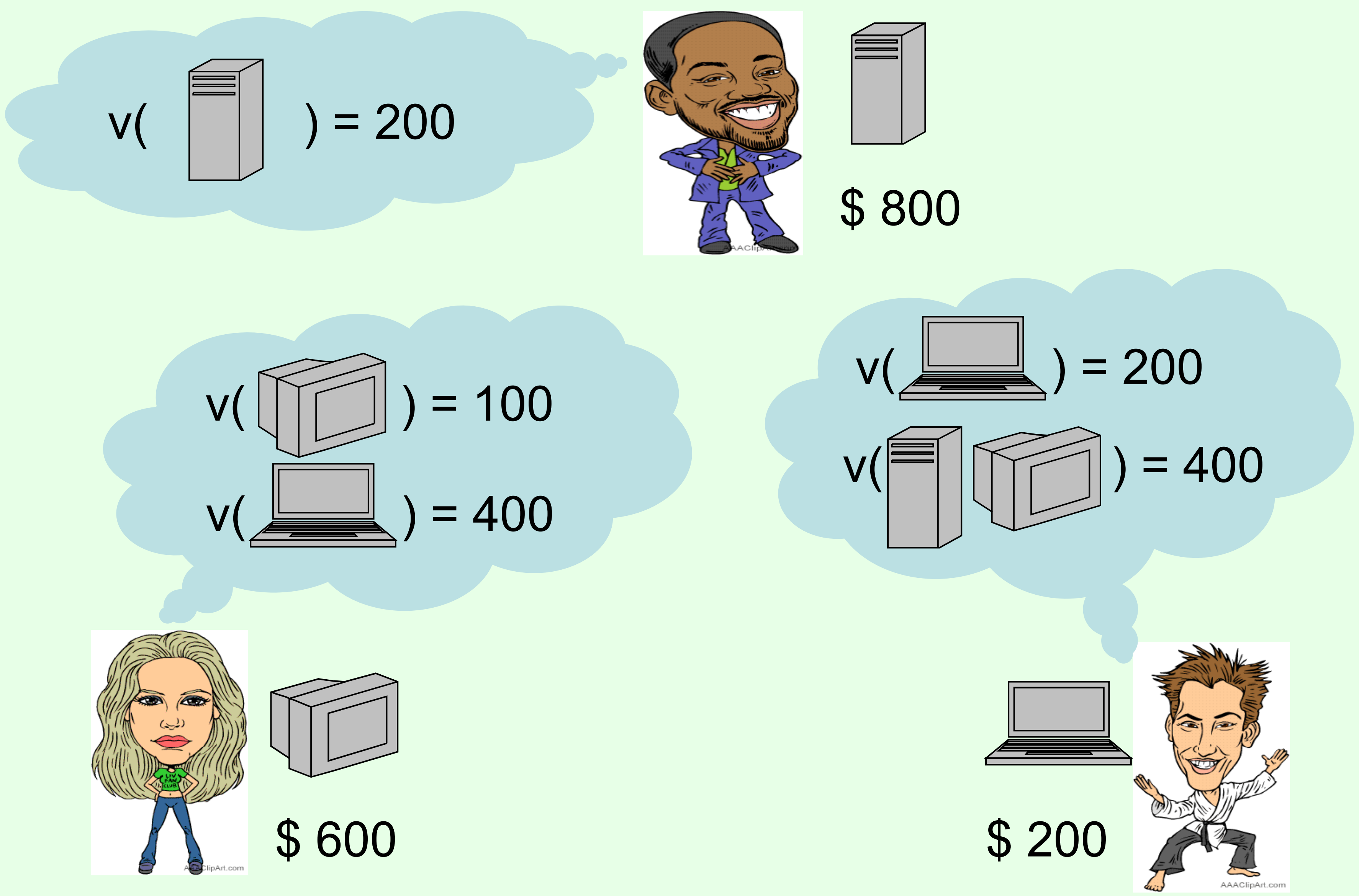
For Fall 2014: February 15, 2014

Charles Becker, MSEC Program Director

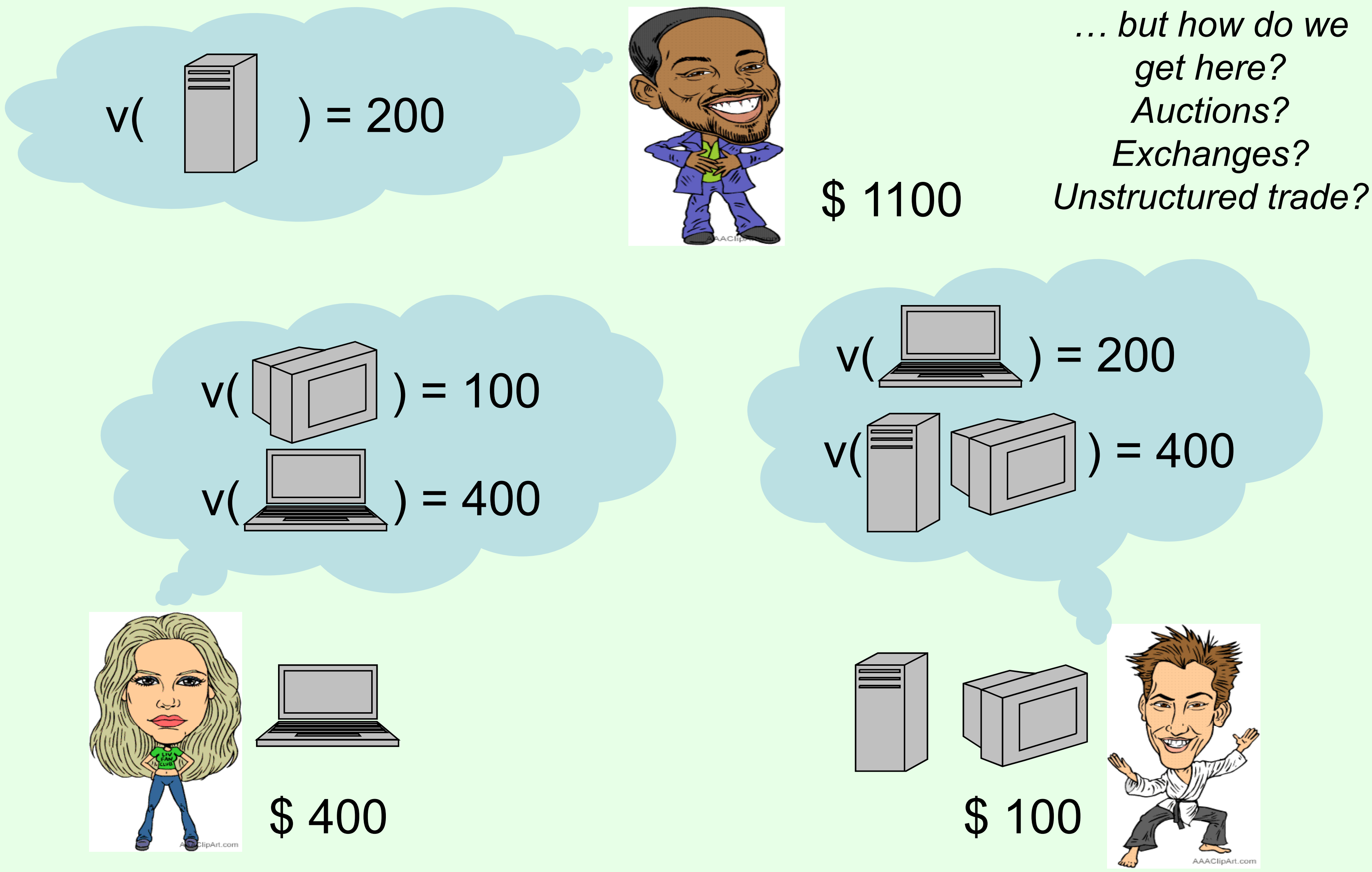
What is Economics?

- “Economics is the social science that analyzes the production, distribution, and consumption of goods and services.” [Wikipedia, Jan. 2014]
- 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



After trade (a more efficient outcome)



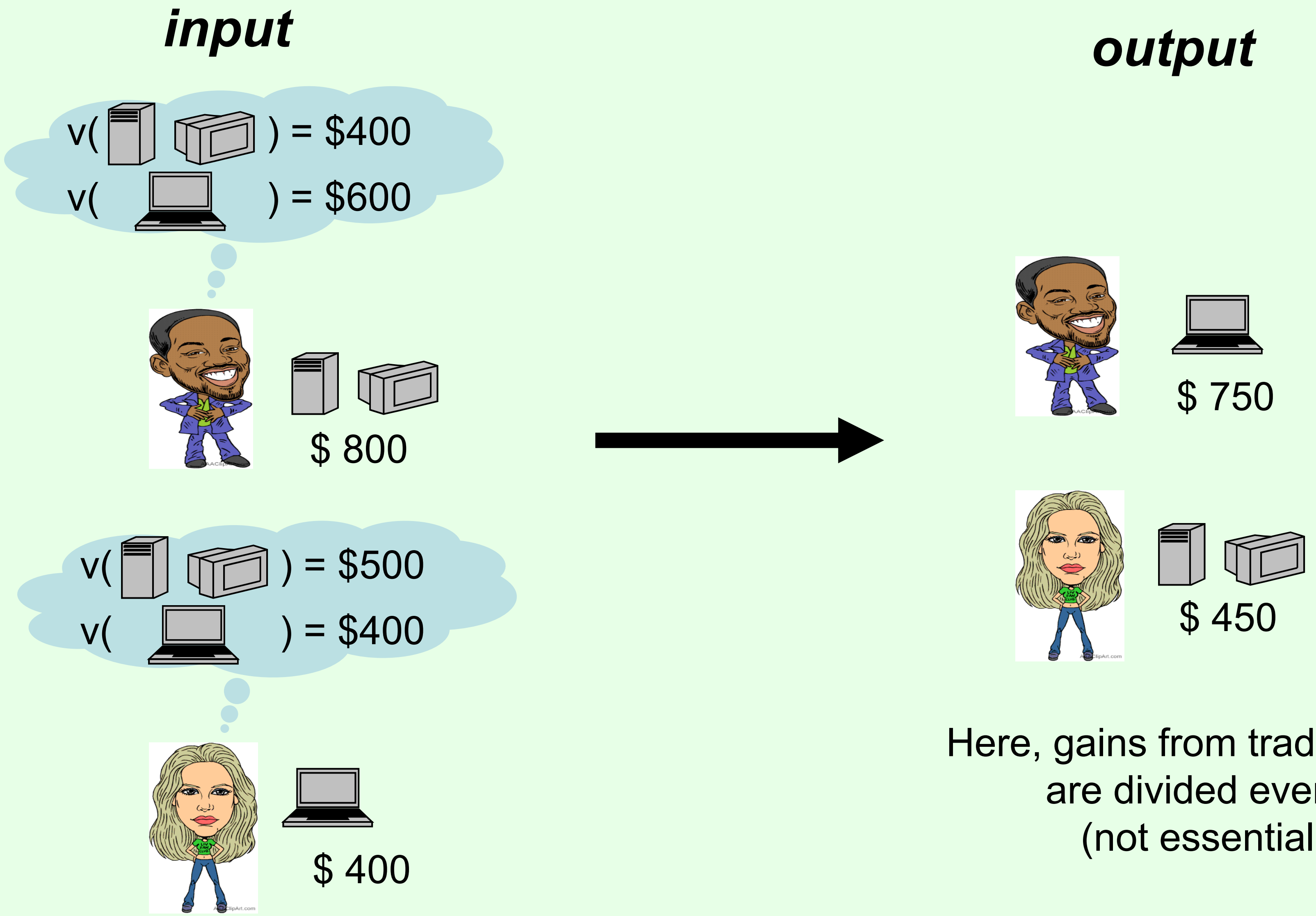
Some distinctions in economics

- 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?

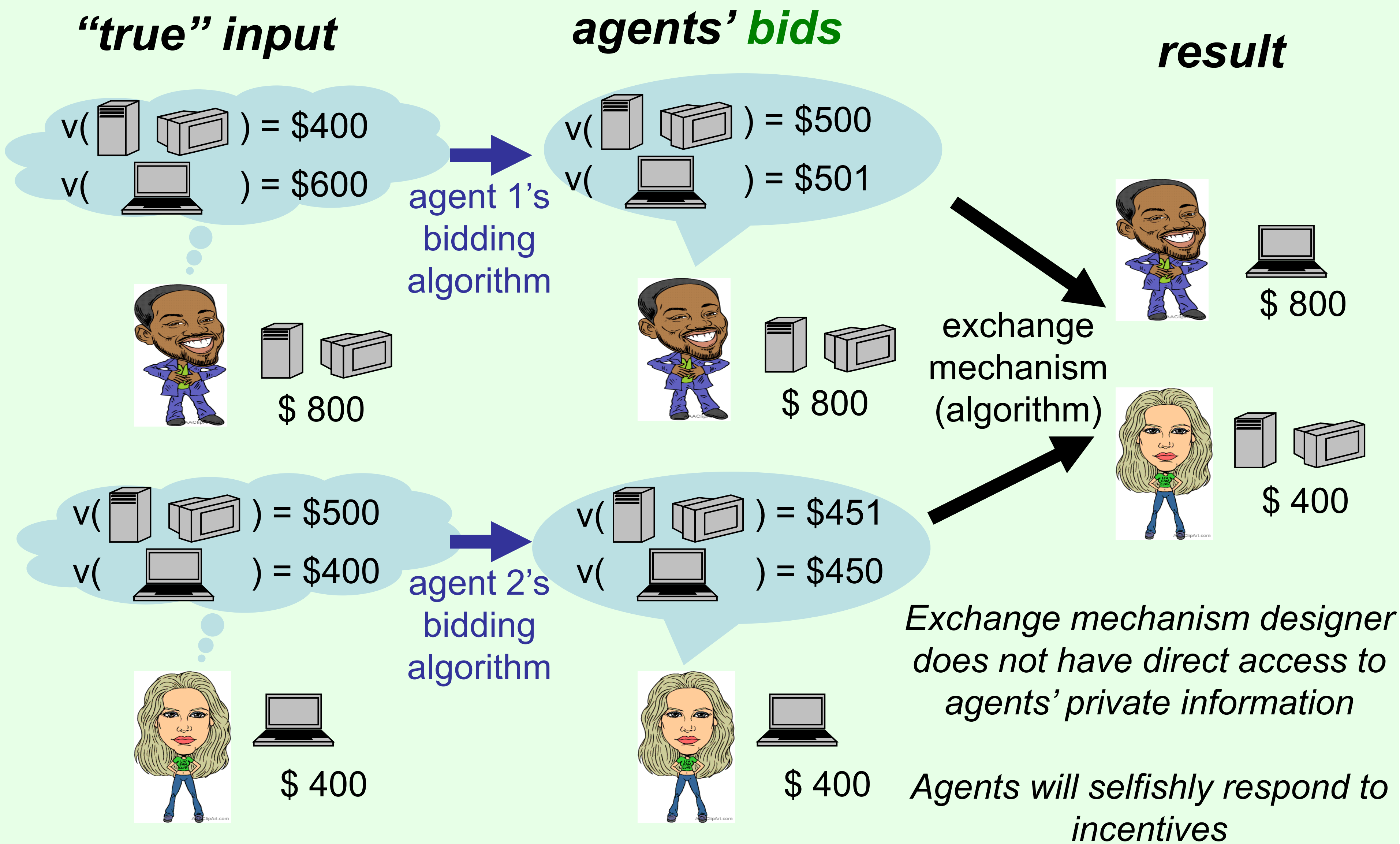
- "Computer science (abbreviated CS or CompSci) is the scientific and practical approach to computation and its applications. […] A computer scientist specializes in the theory of computation and the design of computational systems." [Wikipedia, Jan. 2014]
- A computational problem is given by a function 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



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

Economic mechanisms



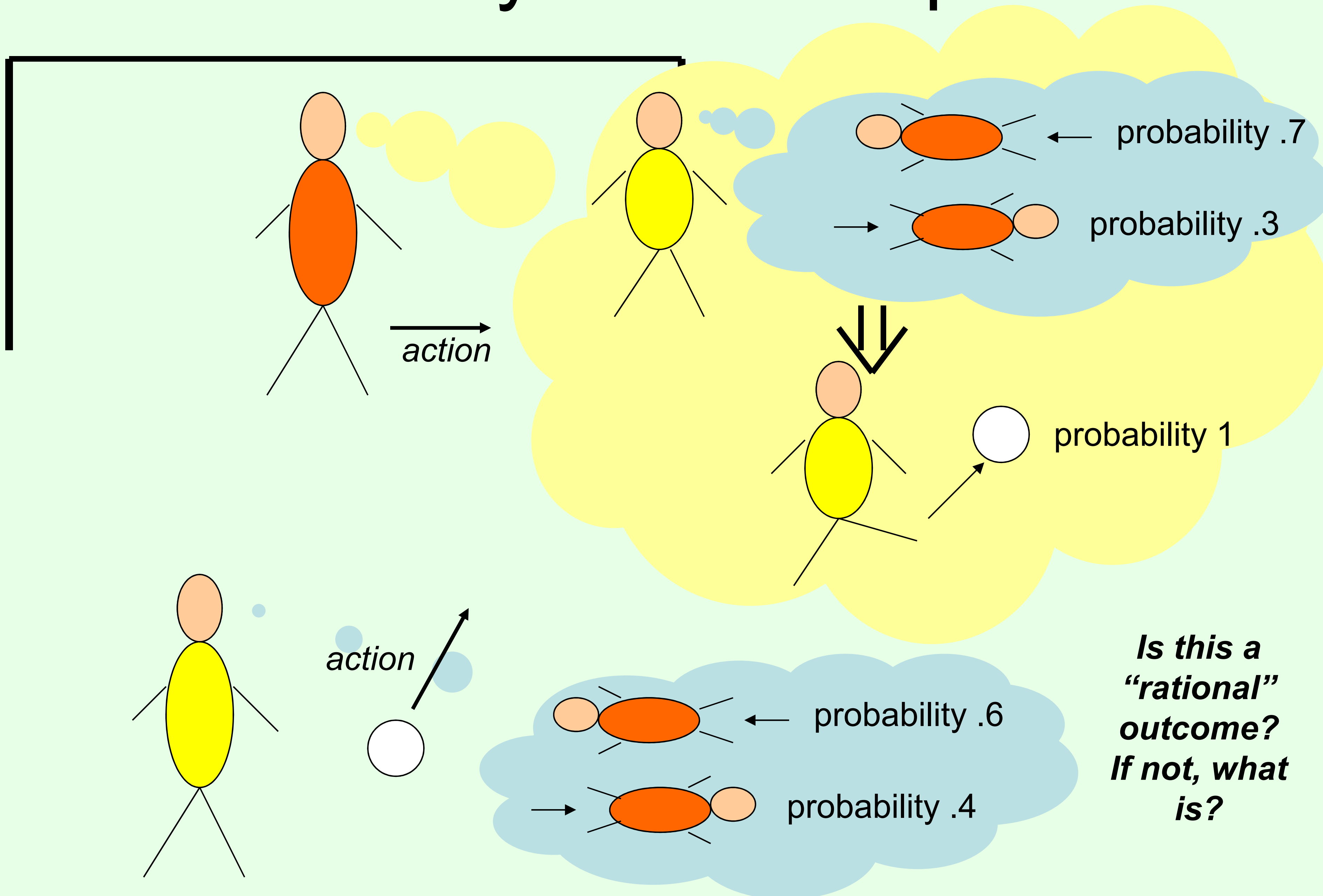
What is game theory?

- “Game theory is a study of strategic decision making. More formally, it is ‘the study of mathematical models of conflict and cooperation between intelligent rational decision-makers’ […] Game theory is mainly used in economics, political science, and psychology, as well as logic and biology.” [Wikipedia, Jan. 2014]

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

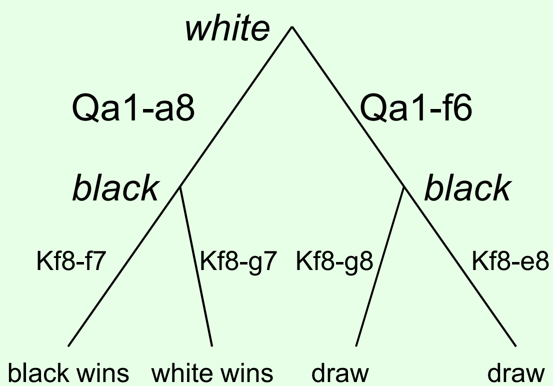
Penalty kick example



Is this a "rational" outcome? If not, what is?

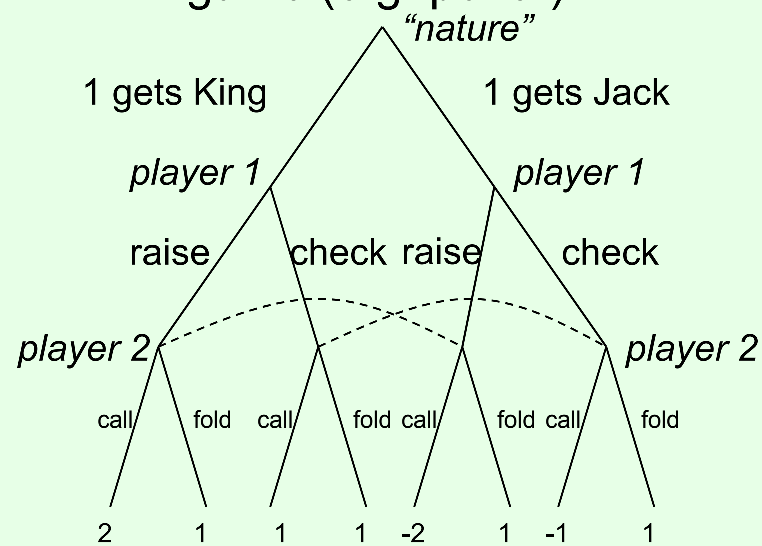
Game playing & AI

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



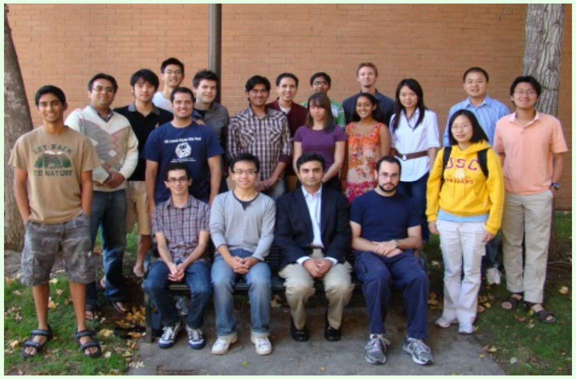
- Optimal play: value of each node = value of optimal child for current player (backward induction, minimax)
- For chess and Go, tree is too large
  - Use other techniques (heuristics, limited-depth search, alpha-beta, …)
- Top computer programs (arguably) better than humans in chess, not yet in Go

imperfect information games: uncertainty about the state of the game (e.g. poker)

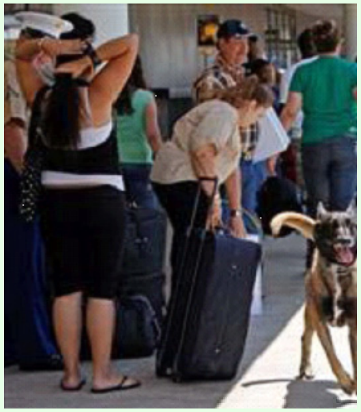


- Player 2 cannot distinguish nodes connected by dotted lines
  - Backward induction fails; need more sophisticated game-theoretic techniques for optimal play
- Small poker variants can be solved optimally
- Humans still better than top computer programs at full-scale poker (at least most versions)
-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

Real-world security applications



Milind Tambe's TEAMCORE group (USC)



Airport security

- Where should checkpoints, canine units, etc. be deployed?
- Deployed at LAX and another US airport, being evaluated for deployment at all US airports

Federal Air Marshals

- Which flights get a FAM?

US Coast Guard

- Which patrol routes should be followed?
- Deployed in Boston Harbor

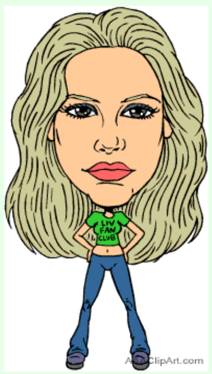
Questions and problems in (computational) game theory

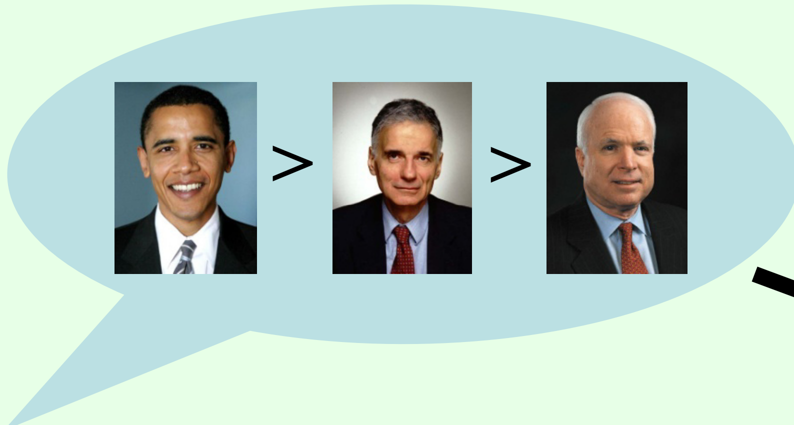
- How should we represent games (=strategic settings)?
  - Standard game-theoretic representations not always concise enough
- What does it mean to solve a game?
  - Solution concepts from game theory, e.g., Nash equilibrium
- How computationally hard is it to solve games?
  - Can we solve them approximately?
- 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?

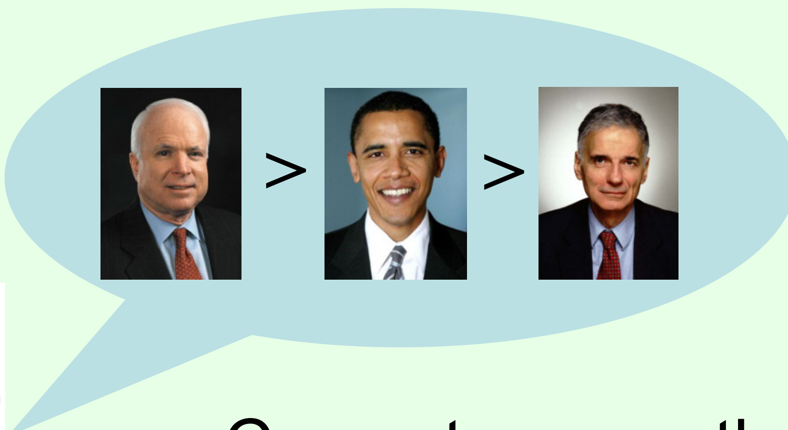
- “Social choice theory or social choice is a theoretical framework for analysis of combining individual opinions, preferences, interests, or welfares to reach a collective decision or social welfare in some sense.” [Wikipedia, Jan. 2014]
- I.e., making decisions based on the preferences of multiple agents
- Largely, but not exclusively, focused on voting

Voting over outcomes



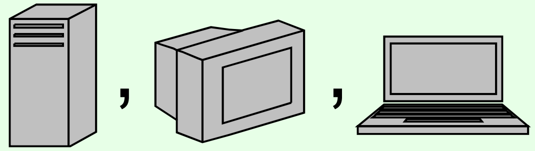


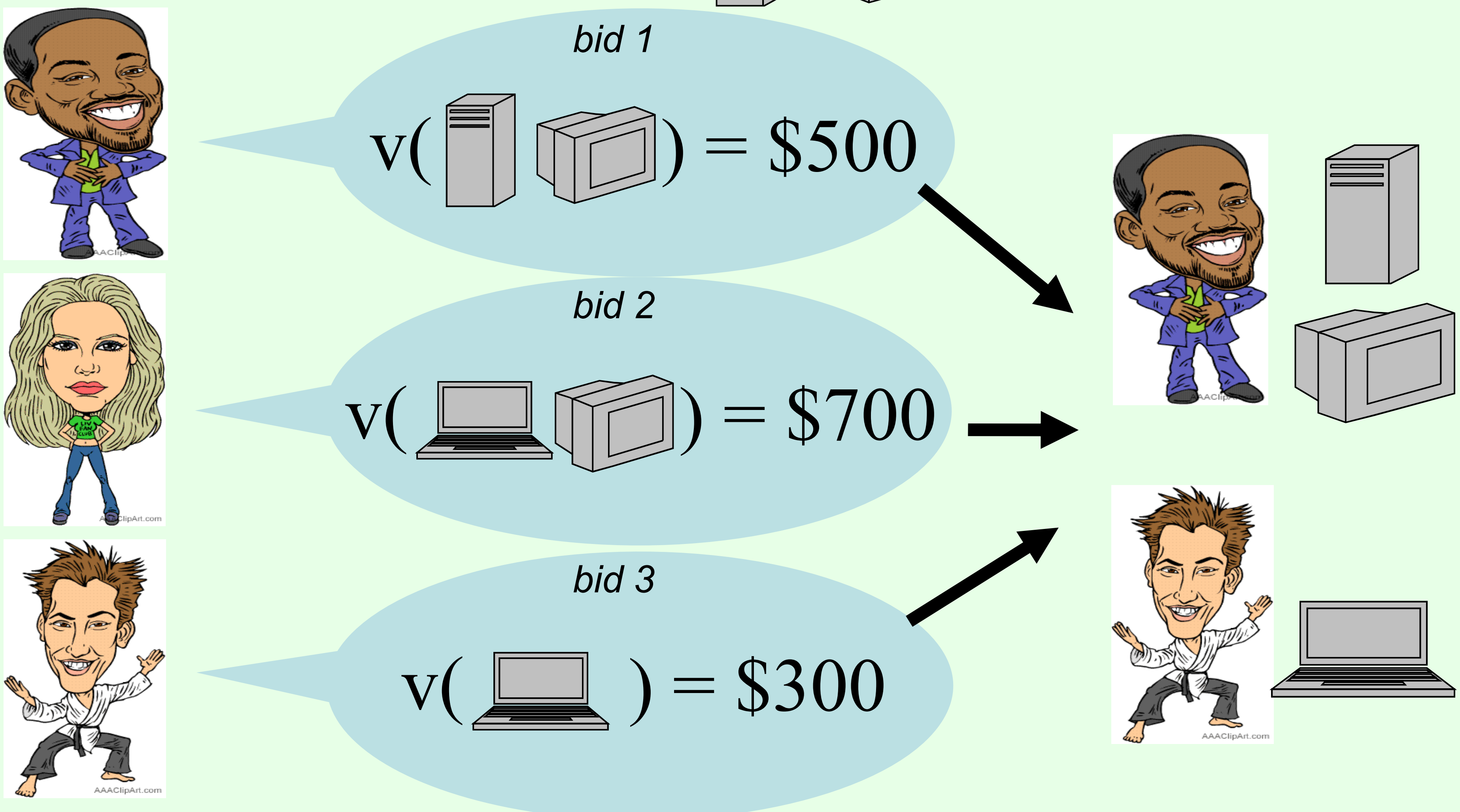
voting rule
(mechanism)
determines winner
based on votes



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

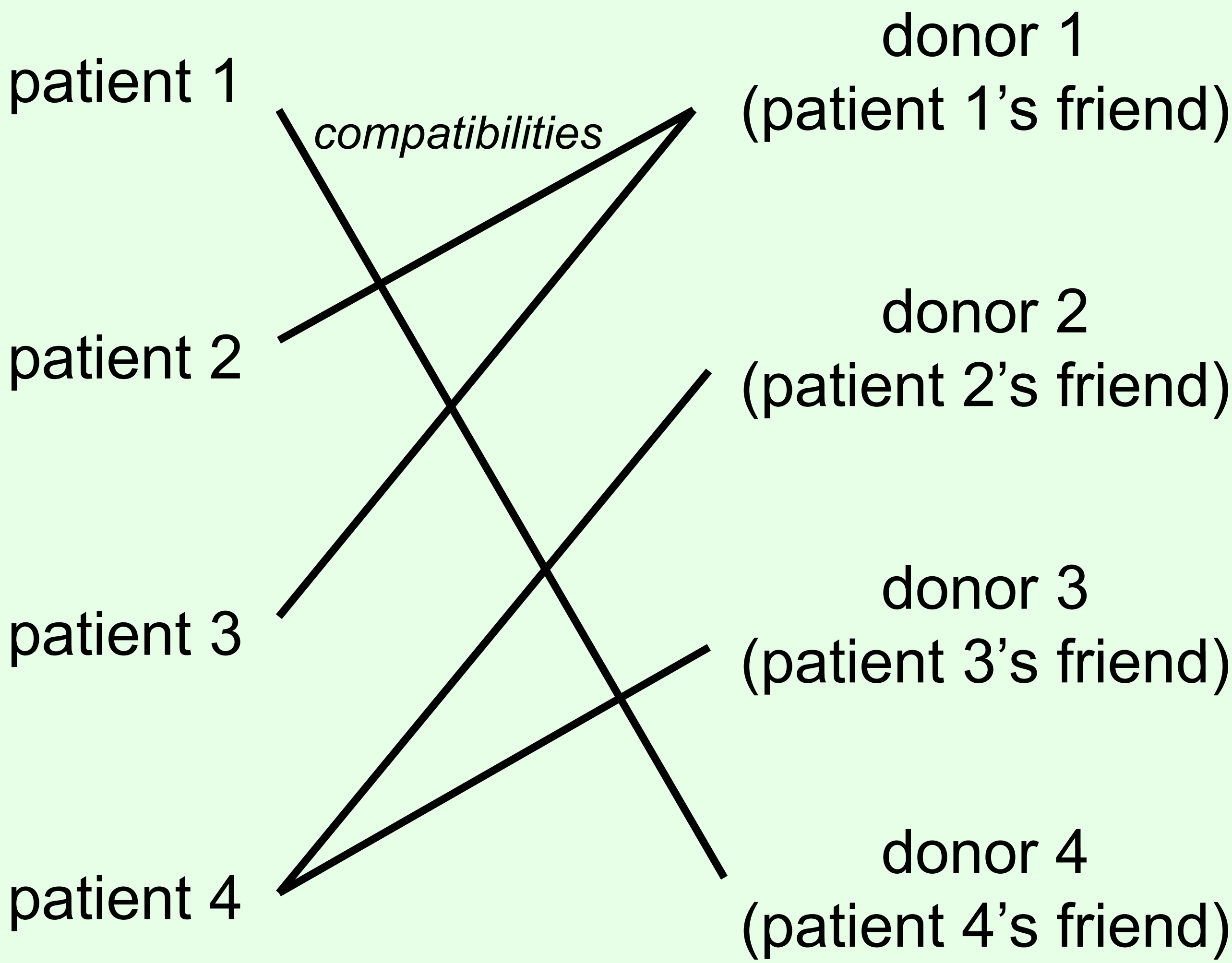
Combinatorial auctions

Simultaneously for sale: 



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

Kidney exchange



Problems in computational social choice

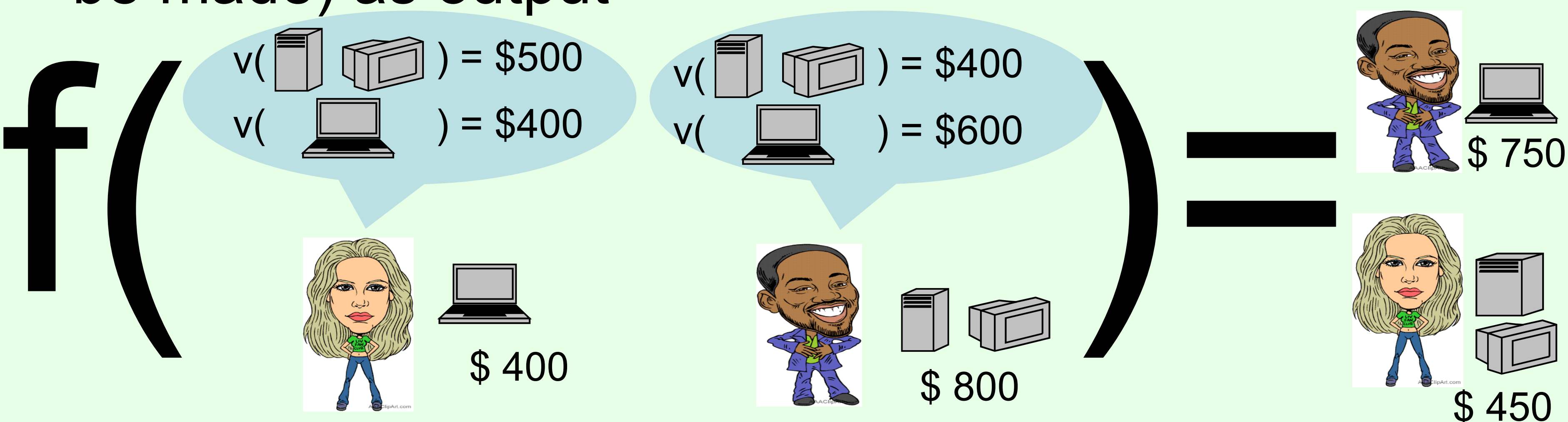
- Winner determination problem
  - For some voting rules, determining the winner is NP-hard
  - In a combinatorial auction, deciding which bids win is (in general) an NP-hard problem
- Preference elicitation (communication) problem
  - Can be impractical to communicate all of one's preferences (e.g., 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, Jan. 2014]

Mechanism design…

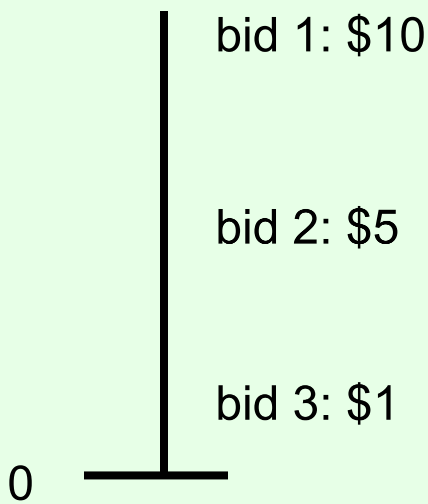
- Mechanism = rules of auction, exchange, …
- A function that takes reported preferences (bids) as input, and produces outcome (allocation, payments to be made) as output



- 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



first-price: bid 1 wins, pays $10
second-price: bid 1 wins, pays $5

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 (→ 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

a likely outcome for the first-price mechanism

bid 1: \$5

bid 2: \$4

bid 3: \$1

0

a likely outcome for the second-price mechanism

bid 1: \$10

bid 2: \$5

bid 3: \$1

0

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	Dominated strategies Minimax strategies Correlated equilibrium Optimal mixed strategies to commit to	Nash equilibrium Optimal mixed strategies to commit to in more complex settings
Social choice, expressive marketplaces	Winner determination in auctions, exchanges, … with partially acceptable bids	Winner determination in: auctions, exchanges, … without partially acceptable bids; Kemeny, Slater, other voting rules; kidney exchange
Mechanism design	Automatically designing optimal mechanisms that use randomization	Automatically designing optimal mechanisms that do not use randomization

Sponsored search

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

Google | combinatorial auction | Search | 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

[PDF] 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

[PDF] **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/~mkearns/.../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

[PDF] **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

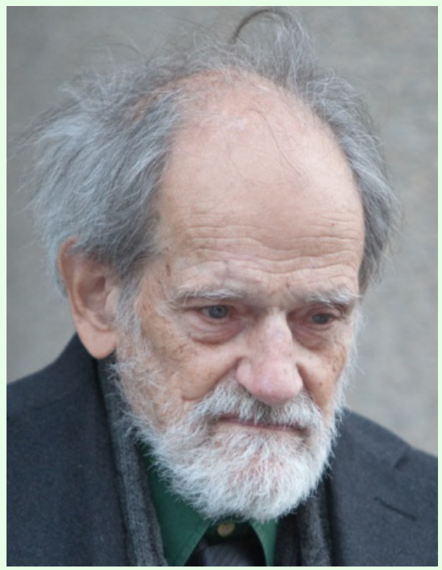
Procurement solutions
We deliver sustainable cost reduction via systems & upskilling
www.vendigital.com

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

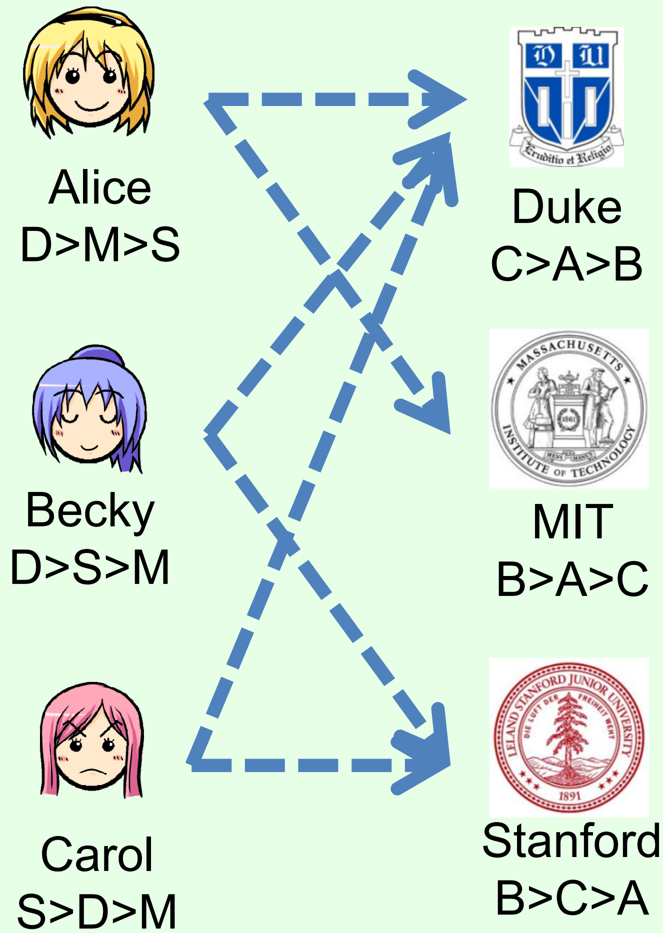
Deferred Acceptance algorithm

[Gale & Shapley 1962]

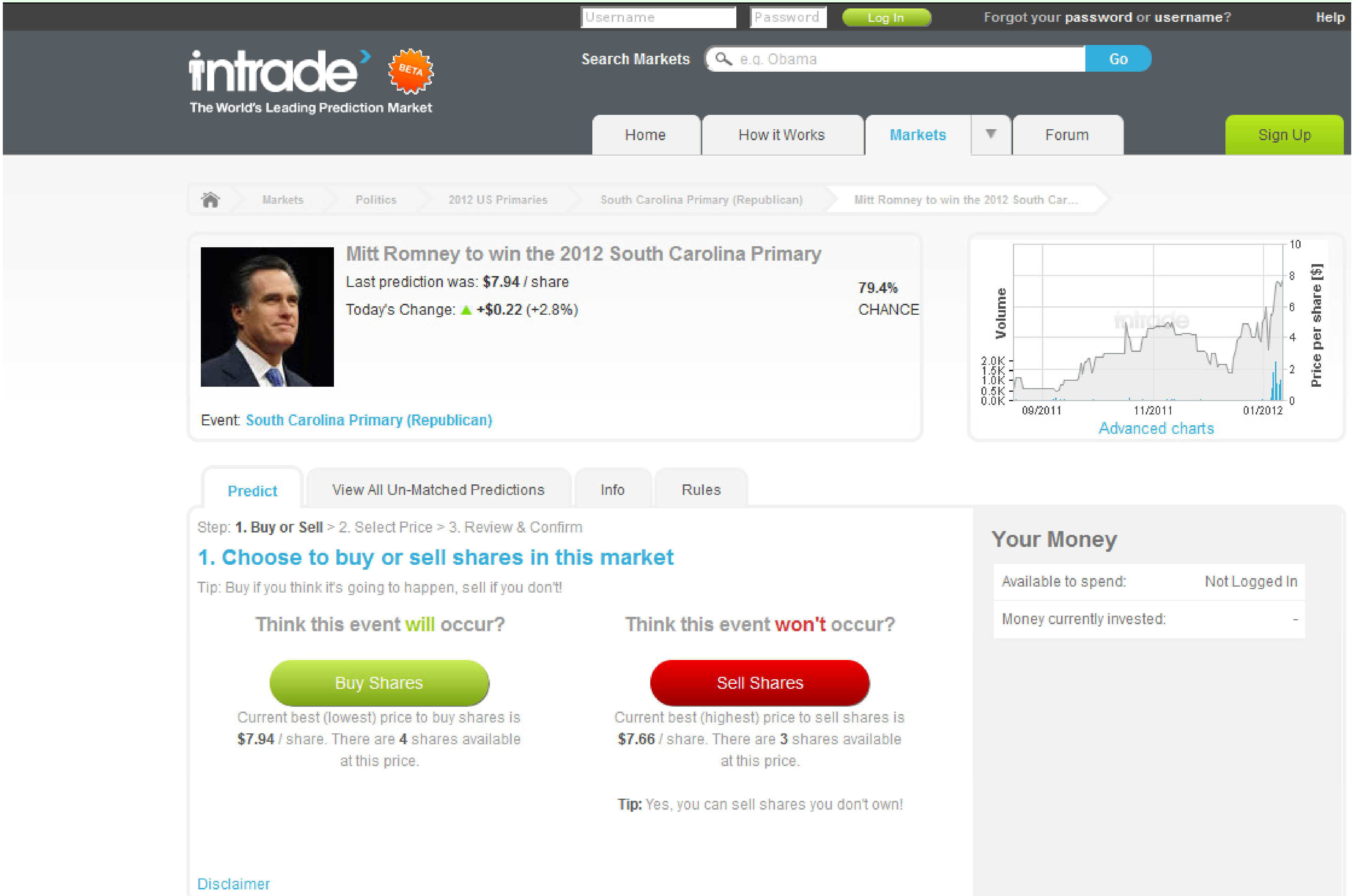
David Gale



Lloyd Shapley



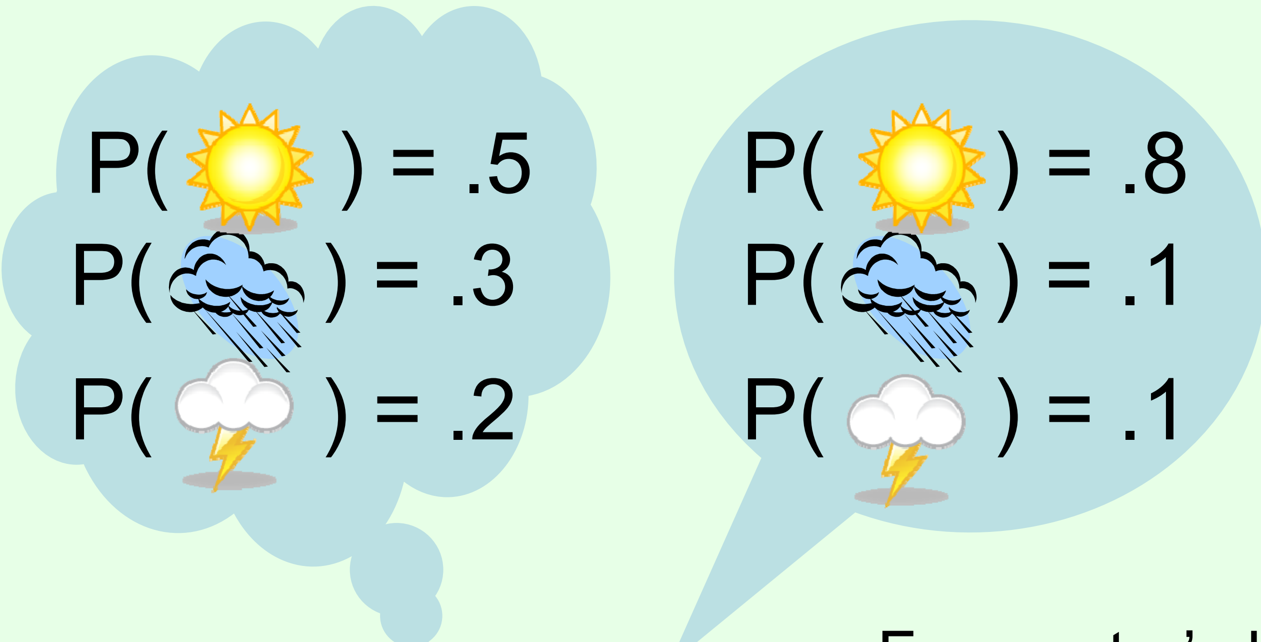
Prediction markets



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



- 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