Attracting Students to Computer Science Using Artificial Intelligence, Economics, and Linear Programming

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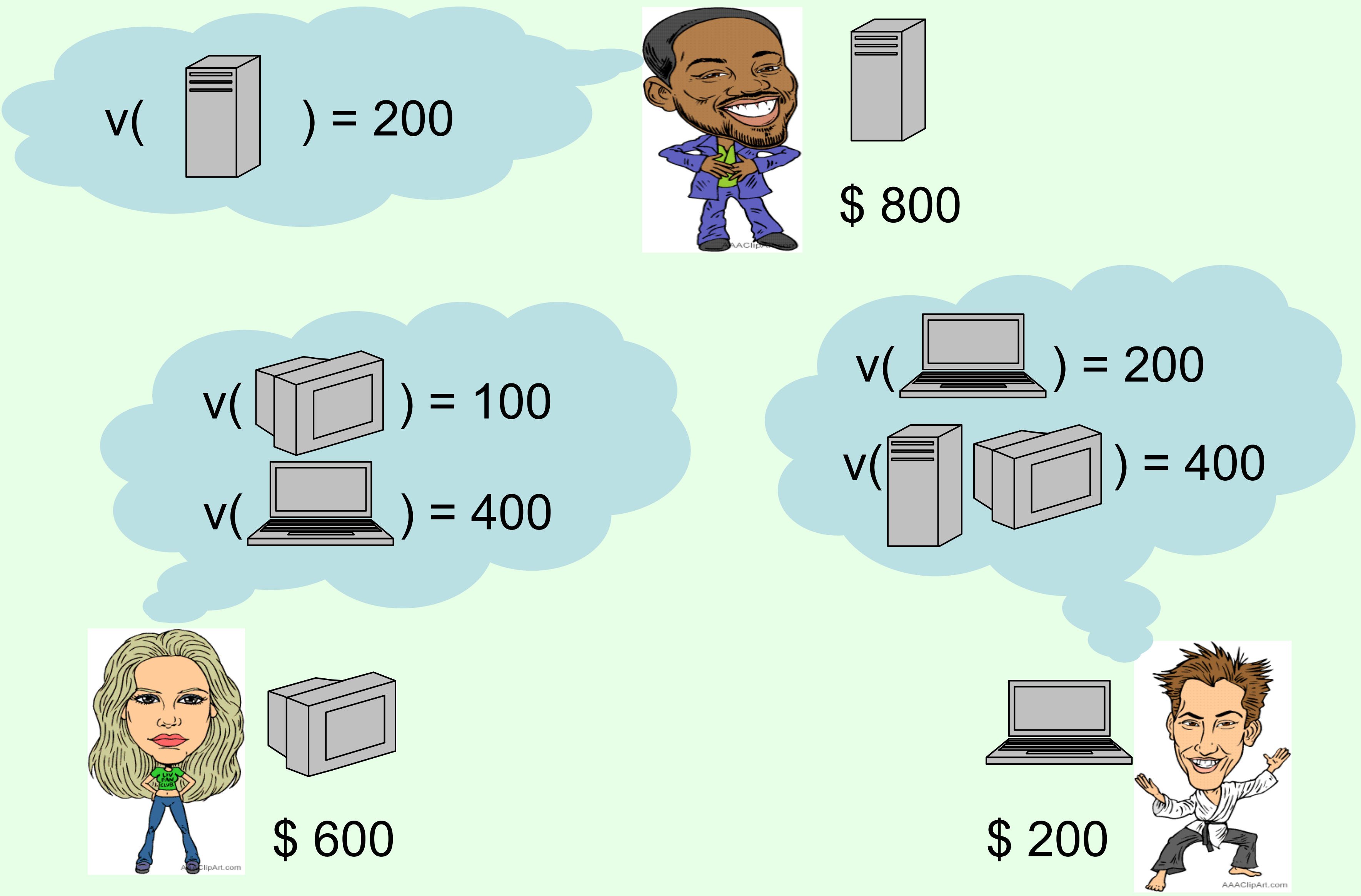
AI & Economics

- AI has always used techniques from economics
  - Herbert Simon
  - Probabilities, beliefs, utility, discounting, …
- Last ~decade: AI research increasingly focused on multiagent systems, economics
  - Auctions, voting
  - Game theory
  - Mechanism design
- Conferences
  - Conference on Autonomous Agents and Multiagent Systems (AAMAS)
  - ACM Conference on Electronic Commerce (EC)
  - Also lots of work at IJCAI, AAAI, …
  - Some at UAI, ICML, …

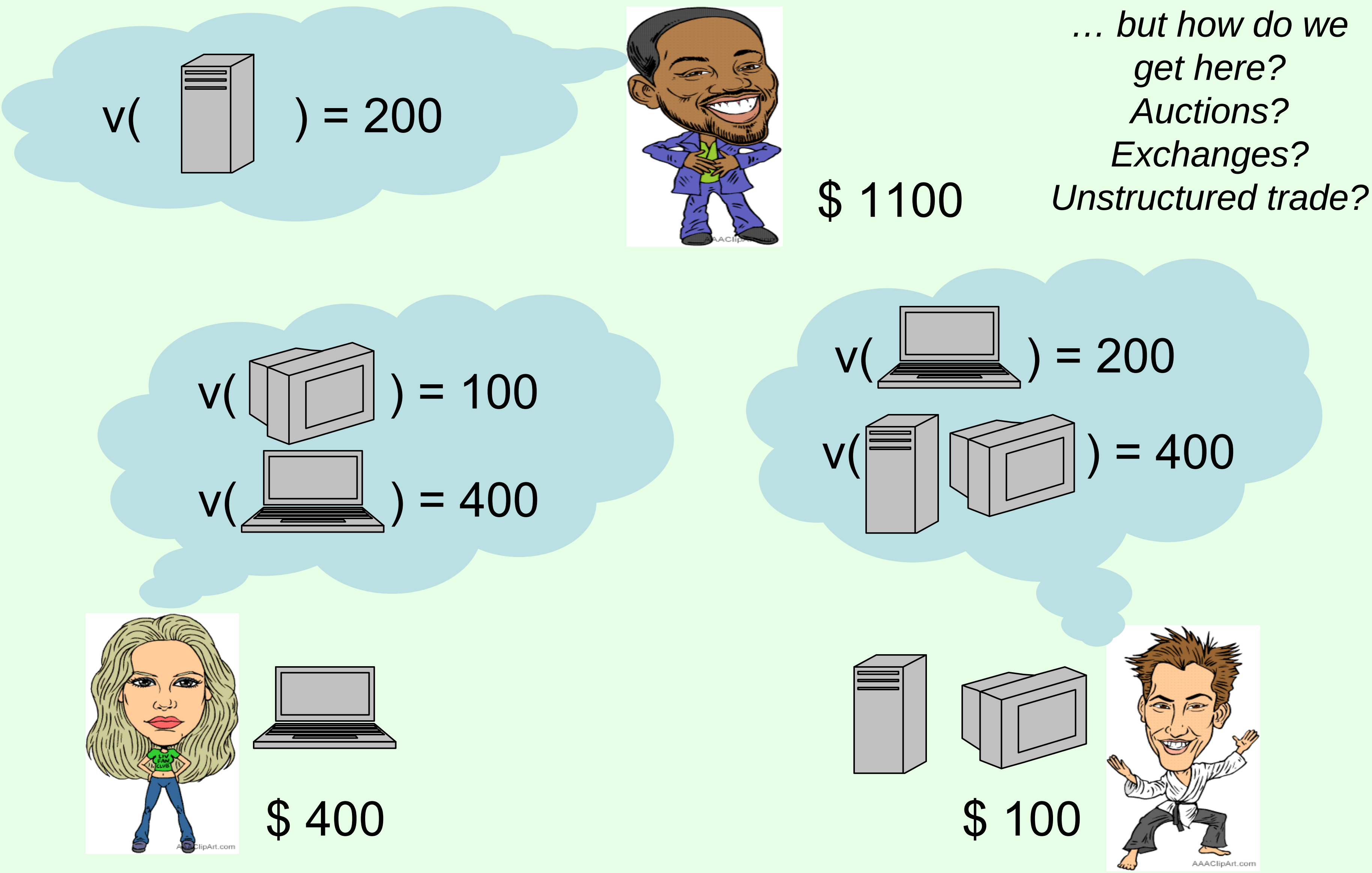
What is Economics?

- "the social science that studies the production, distribution, and consumption of valuable goods and services" [Wikipedia, Jan. 07]
- 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

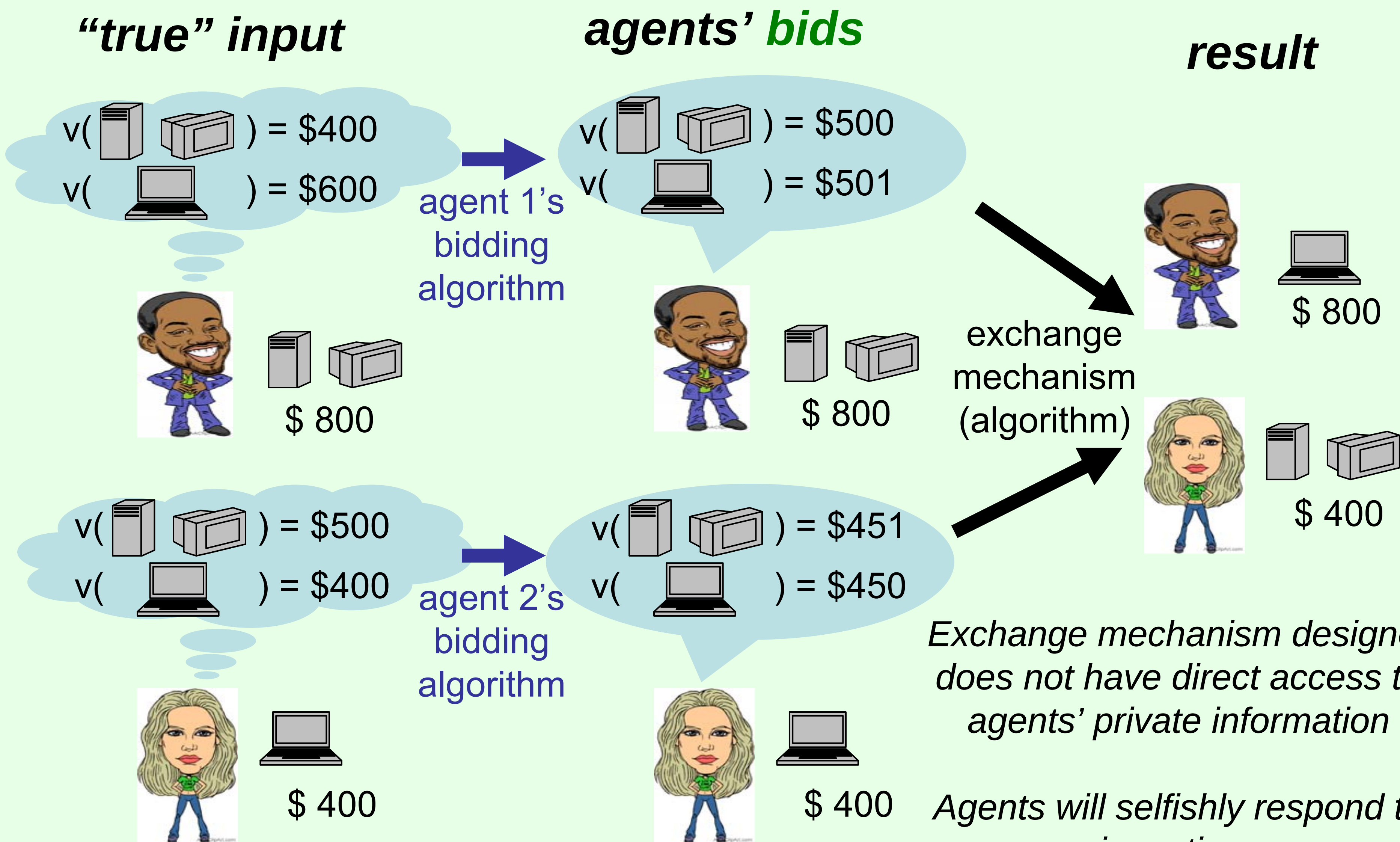
An economic picture



After trade (a more efficient outcome)



Economic mechanisms



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

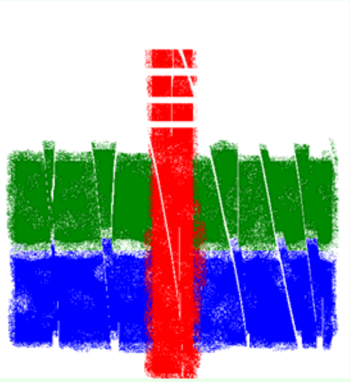
Agents will selfishly respond to incentives

Teaching an introductory course

- Goals:
  - Expose computer science students to basic concepts from microeconomics, game theory
  - Expose economics students to basic concepts in programming, algorithms
  - Show how to increase economic efficiency using computation
- Cannot include whole intro programming course
- Solution: focus strictly on linear/integer programming
  - Can address many economics problems
  - Nice modeling languages that give flavor of programming
  - Computer science students have generally not been exposed to this either

Example linear program

- We make reproductions of two paintings



maximize $3x + 2y$

subject to

$4x + 2y \leq 16$

$x + 2y \leq 8$

$x + y \leq 5$

$x \geq 0$

$y \geq 0$

- Painting 1 sells for \$30, painting 2 sells for \$20
- Painting 1 requires 4 units of blue, 1 green, 1 red
- Painting 2 requires 2 blue, 2 green, 1 red
- We have 16 units blue, 8 green, 5 red

Solving the linear program graphically

maximize $3x + 2y$

subject to

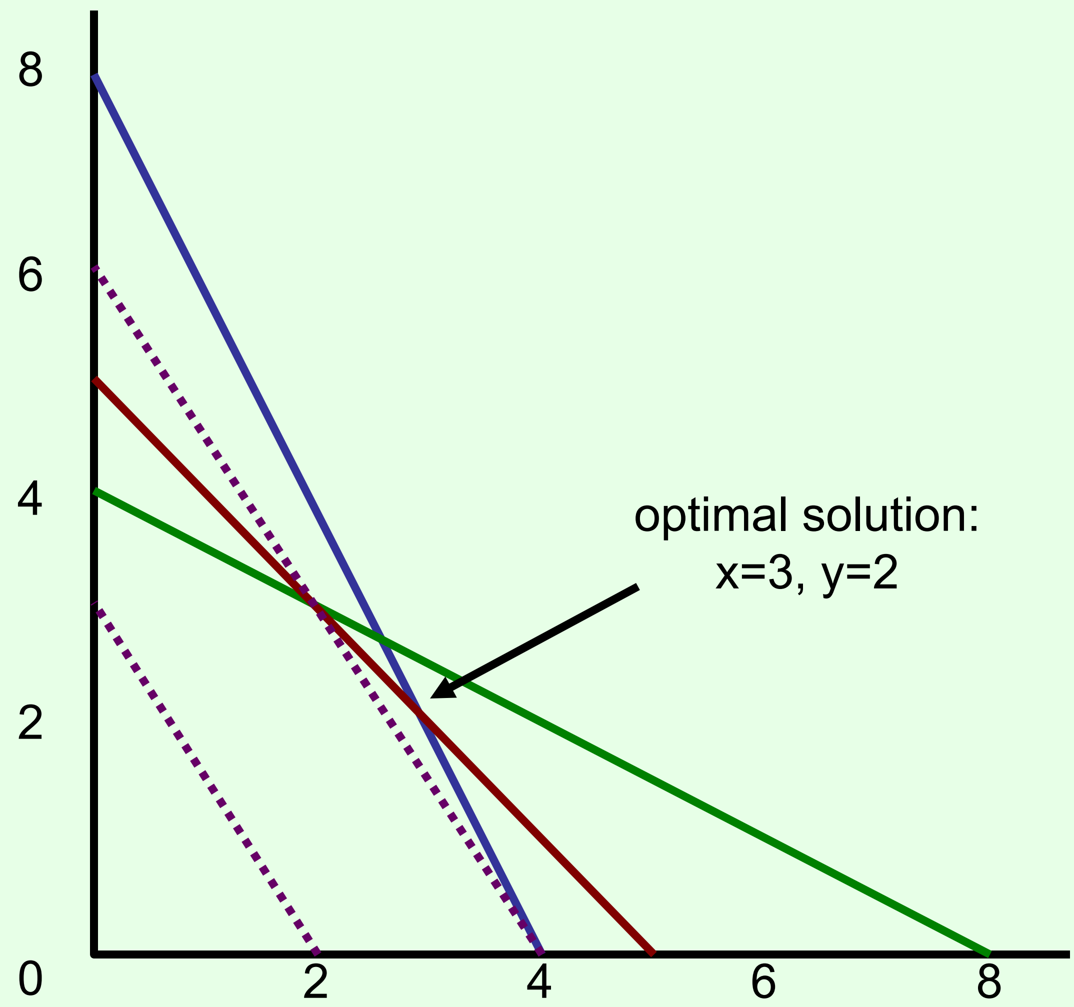
$4x + 2y \leq 16$

$x + 2y \leq 8$

$x + y \leq 5$

$x \geq 0$

$y \geq 0$



Modified LP

maximize $3x + 2y$

subject to

$4x + 2y \leq 15$

$x + 2y \leq 8$

$x + y \leq 5$

$x \geq 0$

$y \geq 0$

Optimal solution: $x = 2.5$, $y = 2.5$

Solution value = $7.5 + 5 = 12.5$

Half paintings?

Integer (linear) program

maximize $3x + 2y$

subject to

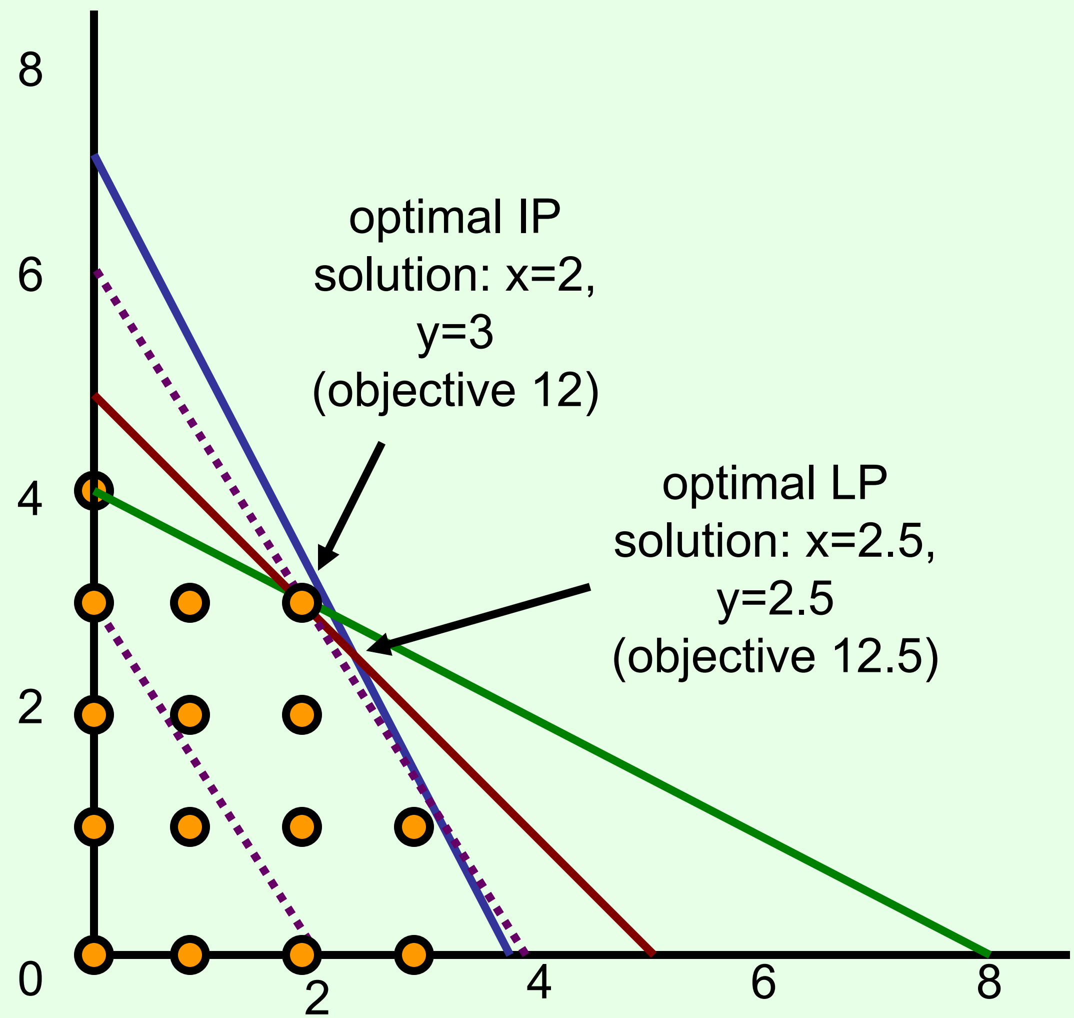
$4x + 2y \leq 15$

$x + 2y \leq 8$

$x + y \leq 5$

$x \geq 0$, integer

$y \geq 0$, integer



Mixed integer (linear) program

maximize 3x + 2y

subject to

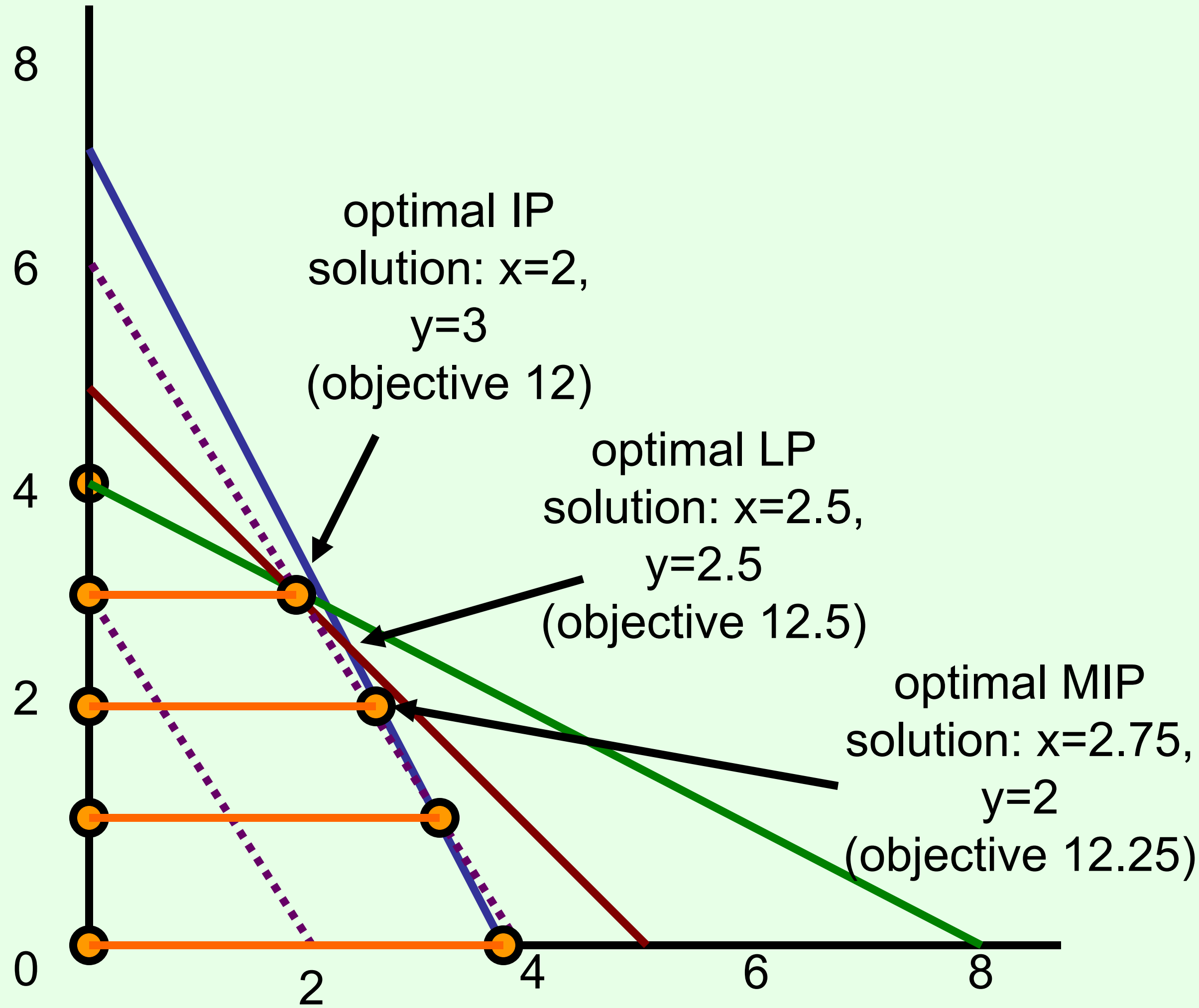
4x + 2y ≤ 15

x + 2y ≤ 8

x + y ≤ 5

x ≥ 0

y ≥ 0, integer



The MathProg modeling language

```
set PAINTINGS;
set COLORS;
var quantity_produced{j in PAINTINGS}, >=0, integer;
param selling_price{j in PAINTINGS};
param paint_available{i in COLORS};
param paint_needed{i in COLORS, j in PAINTINGS};
maximize revenue: sum{j in PAINTINGS}
   selling_price[j]*quantity_produced[j];
s.t. enough_paint{i in COLORS}: sum{j in PAINTINGS}
paint_needed[i,j]*quantity_produced[j] <=
   paint_available[i];
…
```

The MathProg modeling language

```
…
data;
set PAINTINGS := p1 p2;
set COLORS := blue green red;
param selling_price := p1 3 p2 2;
param paint_available := blue 15 green 8 red 5;
param paint_needed :
                p1  p2 :=
blue            4   2
green           1   2
red             1   1;
end;
```

A knapsack-type problem

- We arrive in a room full of precious objects
- Can carry only 30kg out of the room
- Can carry only 20 liters out of the room
- Want to maximize our total value
- Unit of object A: 16kg, 3 liters, sells for $11
  - There are 3 units available
- Unit of object B: 4kg, 4 liters, sells for $4
  - There are 4 units available
- Unit of object C: 6kg, 3 liters, sells for $9
  - Only 1 unit available
- What should we take?

Knapsack-type problem instance…

maximize $11x + 4y + 9z$

subject to

$16x + 4y + 6z <= 30$

$3x + 4y + 3z <= 20$

$x <= 3$

$y <= 4$

$z <= 1$

$x, y, z >=0$, integer

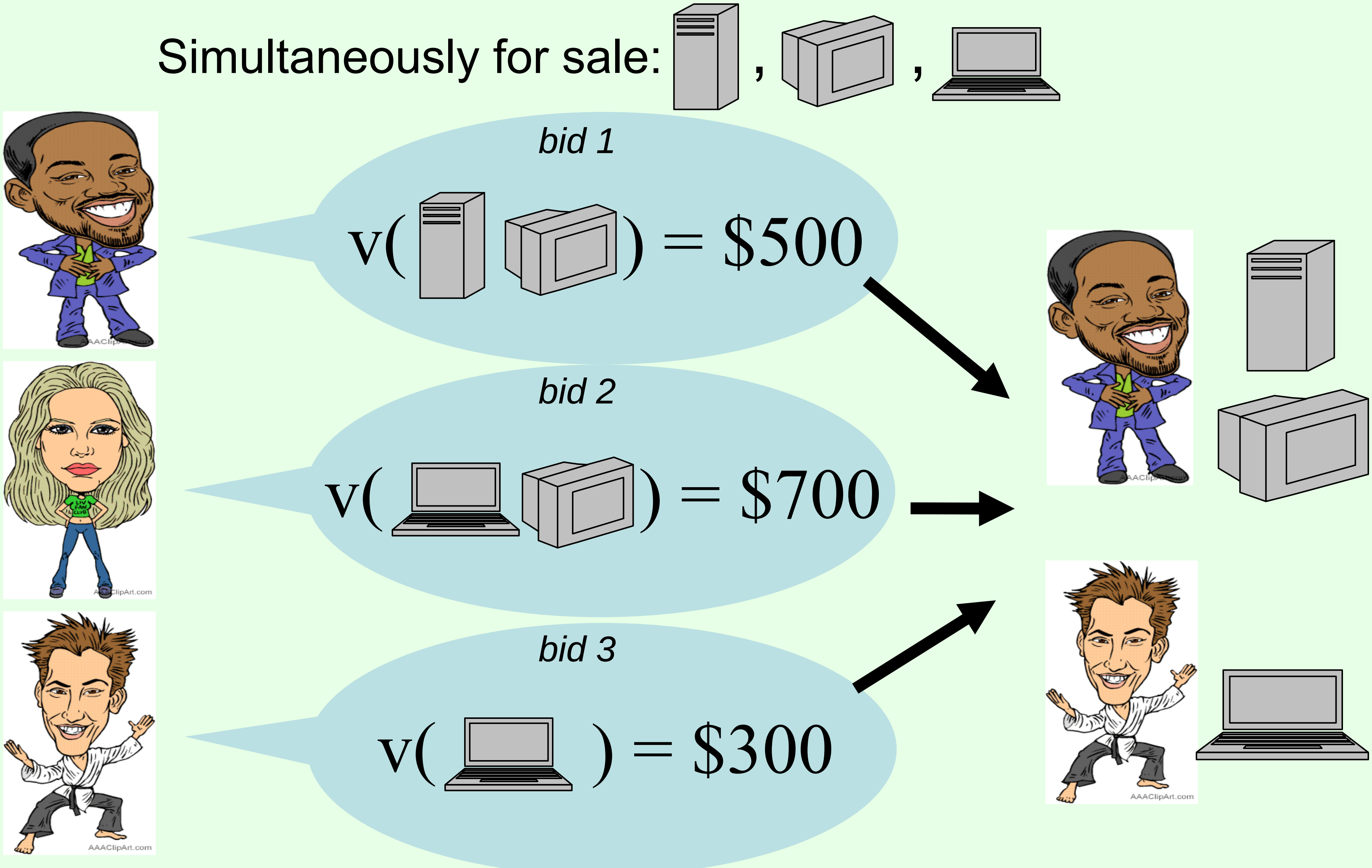
Knapsack-type problem instance in MathProg modeling language

```
set OBJECT;
set CAPACITY_CONSTRAINT;
param cost{i in OBJECT, j in CAPACITY_CONSTRAINT};
param limit{j in CAPACITY_CONSTRAINT};
param availability{i in OBJECT};
param value{i in OBJECT};
var quantity{i in OBJECT}, integer, >= 0;
maximize total_value: sum{i in OBJECT} quantity[i]*value[i];
s.t. capacity_constraints {j in CAPACITY_CONSTRAINT}: sum{i
   in OBJECT} cost[i,j]*quantity[i] <= limit[j];
s.t. availability_constraints {i in OBJECT}: quantity[i] <=
   availability[i];
…
```

Knapsack-type problem instance in MathProg modeling language…

```
…
data;
set OBJECT := a b c;
set CAPACITY_CONSTRAINT := weight volume;
param cost: weight volume :=
   a           16      3
   b           4       4
   c           6       3;
param limit:= weight 30 volume 20;
param availability:= a 3 b 4 c 1;
param value:= a 11 b 4 c 9;
end;
```

Combinatorial auctions



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

The winner determination problem (WDP)

- Choose a subset A (the accepted bids) of the bids B,
- to maximize $\Sigma_{b \text{ in } A} v_b$,
- under the constraint that every item occurs at most once in A
  - This is assuming free disposal, i.e. not everything needs to be allocated

An integer program formulation

x_b equals 1 if bid b is accepted, 0 if it is not

maximize $\Sigma_b \, v_b \mathbf{x_b}$

subject to

for each item j, $\Sigma_{b:\, j \text{ in } b} \, \mathbf{x_b} \leq 1$

for each bid b, $\mathbf{x_b}$ in $\{0,1\}$

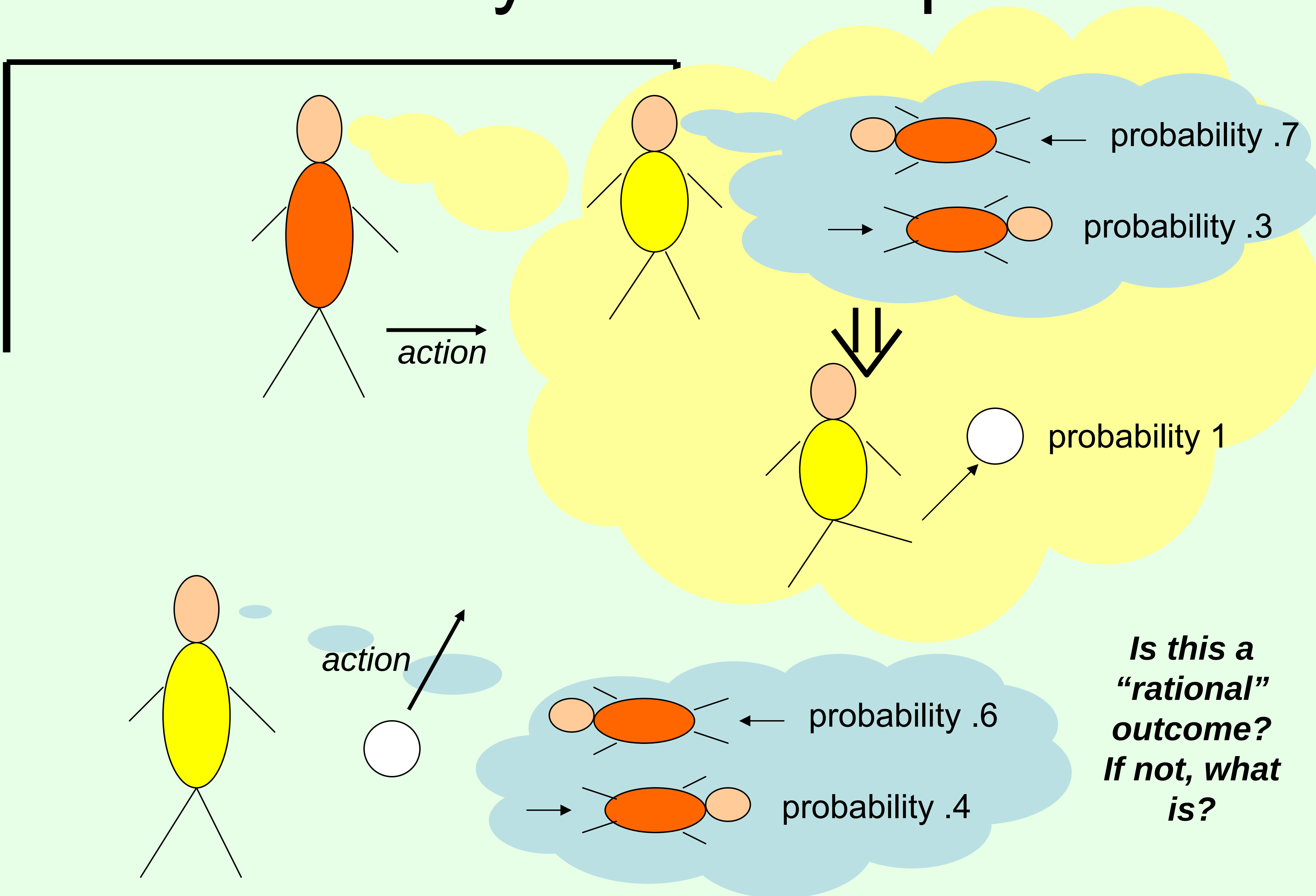
WDP in the modeling language

```
set ITEMS;
set BIDS;
var accepted{j in BIDS}, binary;
param bid_amount{j in BIDS};
param bid_on_object{i in ITEMS, j in BIDS},
  binary;
maximize revenue: sum{j in BIDS}
  accepted[j]*bid_amount[j];
s.t. at_most_once{i in ITEMS}: sum{j in BIDS}
  accepted[j]*bid_on_object[i,j] <= 1;
```

Game theory

- 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

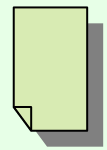
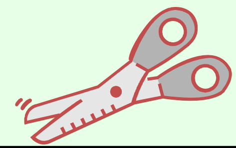
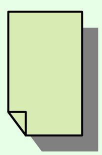
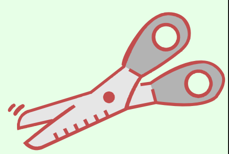
Penalty kick example



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

Rock-paper-scissors

Column player aka.
player 2
(simultaneously)
chooses a column

			
	0, 0	-1, 1	1, -1
	1, -1	0, 0	-1, 1
	-1, 1	1, -1	0, 0

Row player
aka. player 1
chooses a row

A row or column is
called an action or
(pure) strategy

Row player's utility is always listed first, column player's second

Zero-sum game: the utilities in each entry sum to 0 (or a constant)
Three-player game would be a 3D table with 3 utilities per entry, etc.

Minimax strategies

- A conservative approach:
- We (Row) choose a distribution over rows
  - p_r is probability on row r
- To evaluate quality of a distribution, pessimistically assume that Column will choose worst column for us:

  $\arg\min_c \Sigma_r p_r u_R(r, c)$
- Try to optimize for this worst case:

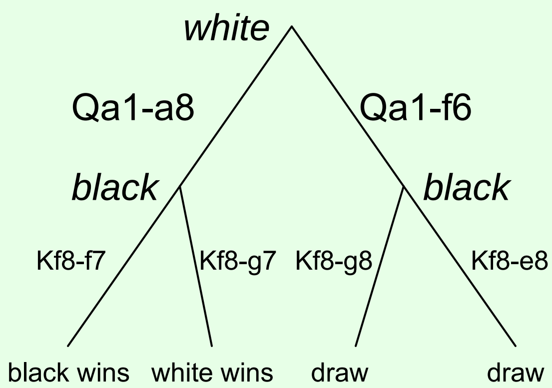
  $\arg\max_{p_r} \min_c \Sigma_r p_r u_R(r, c)$
- Theoretically very well-motivated in zero-sum

Solving for minimax strategies using linear programming

- maximize $\mathbf{u_R}$
- subject to
  - for any column c, $\Sigma_r \mathbf{p_r} u_R(r, c) \geq \mathbf{u_R}$
  - $\Sigma_r \mathbf{p_r} = 1$

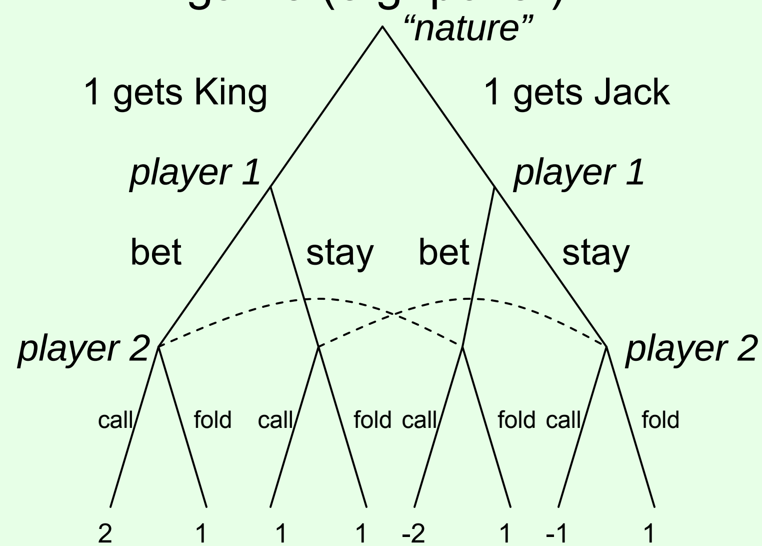
Game playing & AI

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



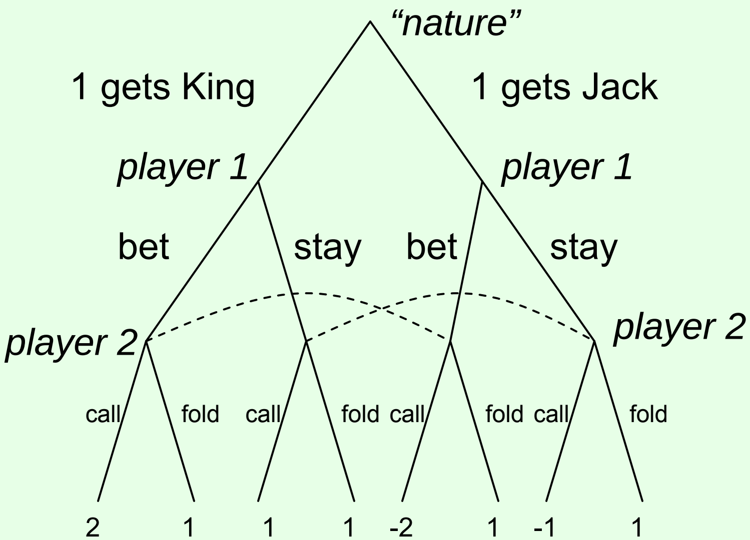
- Optimal play: value of each node = value of optimal child for current player (backward induction, minimax)
- For chess and Go, tree is too large
  - Use other techniques (heuristics, limited-depth search, alpha-beta, …)
- Top computer programs (arguably) better than humans in chess, not yet in Go

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
- Top computer (heads-up) poker players are based on techniques for game theory

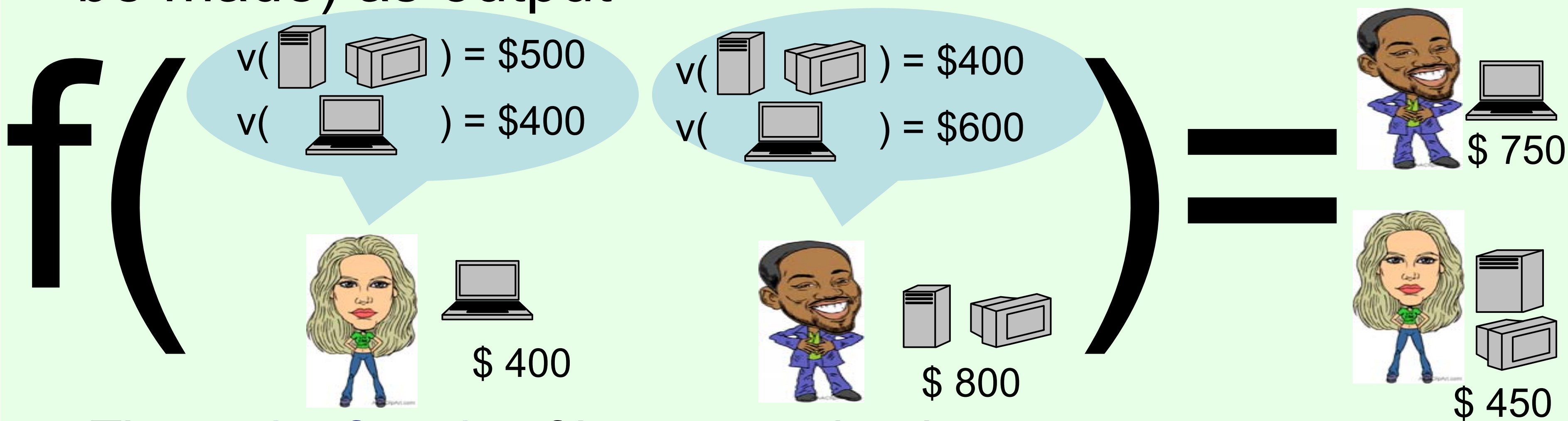
Solving the tiny poker game



		cc (2/3)	cf (0)	fc (1/3)	ff (0)
1/3	bb	0, 0	0, 0	1, -1	1, -1
2/3	bs	.5, -.5	1.5, -1.5	0, 0	1, -1
0	sb	-.5, .5	-.5, .5	1, -1	1, -1
0	ss	0, 0	1, -1	0, 0	1, -1

Mechanism design

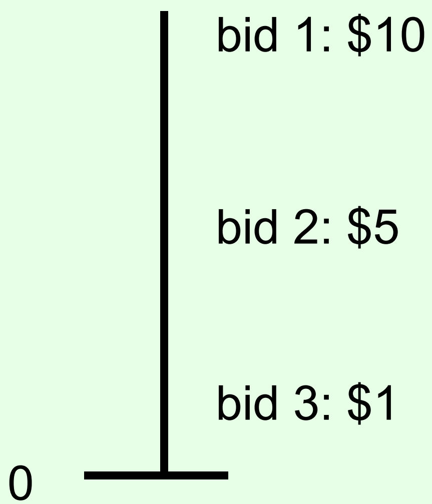
- Mechanism = rules of auction, exchange, …
- A function that takes reported preferences (bids) as input, and produces outcome (allocation, payments to be made) as output



- The entire function f is one mechanism
- E.g.: 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, it turns out 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

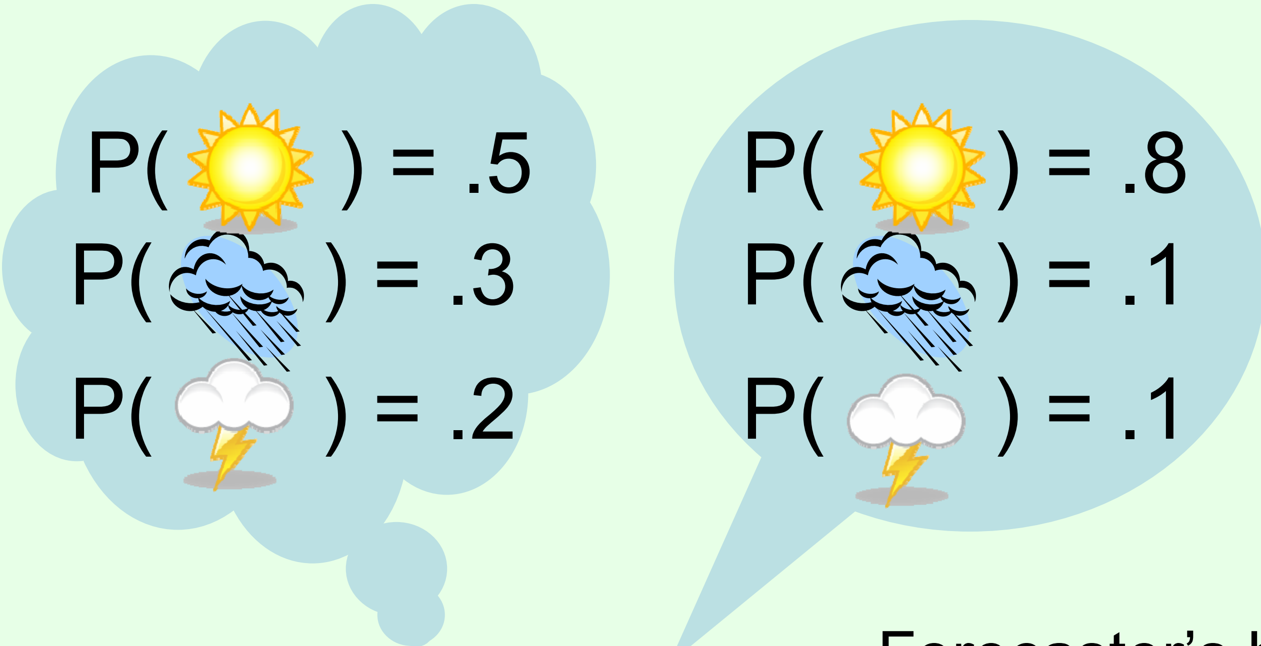
Are there other auctions that perform better? How do we know when we have found the best one?

Other settings/applications

Financial securities

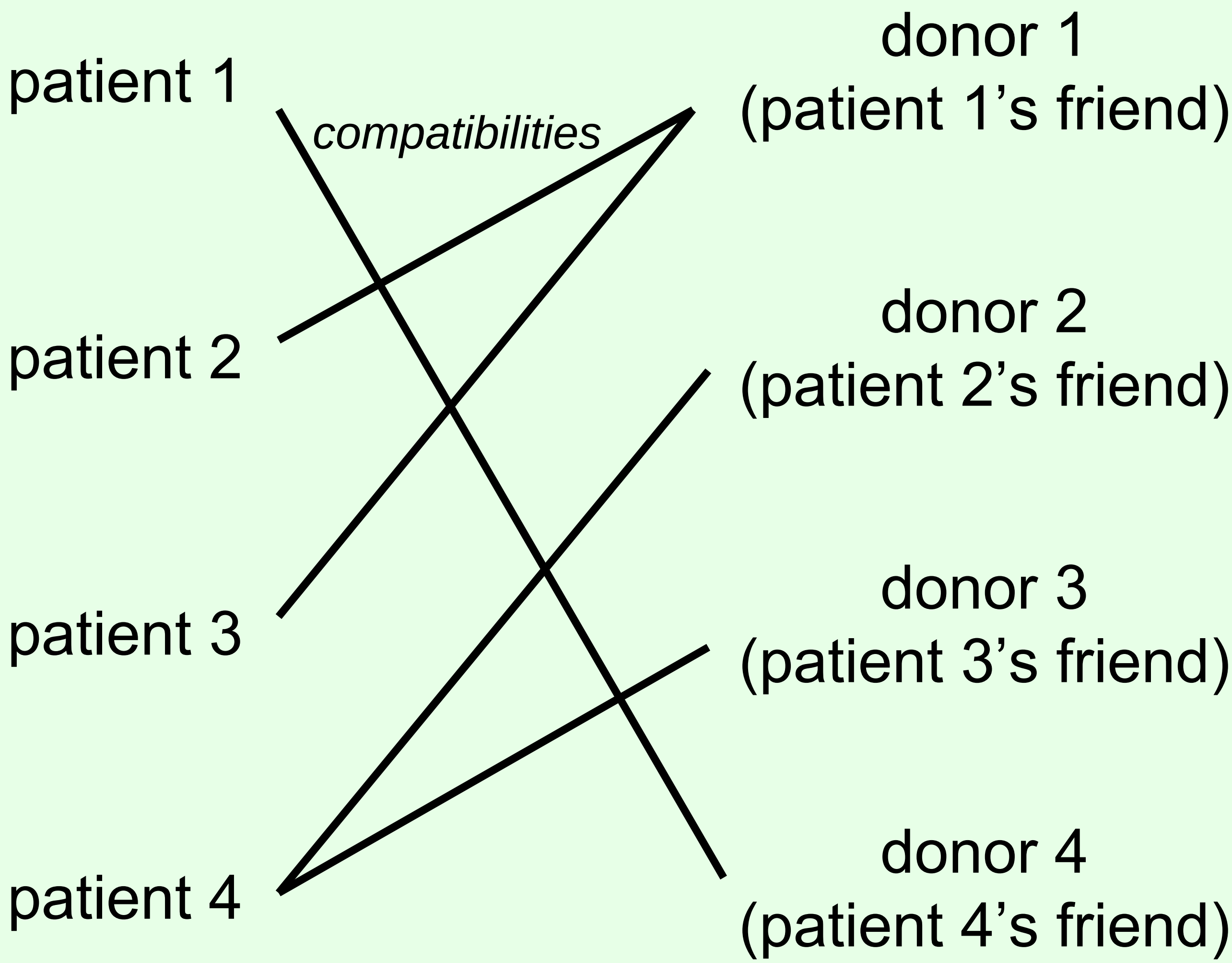
- Tomorrow there must be one of   
- Agent 1 offers \$5 for a security that pays off \$10 if  or 
- Agent 2 offers \$8 for a security that pays off \$10 if  or 
- Agent 3 offers \$6 for a security that pays off \$10 if 
- Can we accept some of these at offers at no risk?

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

Kidney exchange



Conclusion

- Students enjoyed course
  - Overall quality rating of 4.78 out of 5
  - No complaints about missing prerequisites
  - One economics student took intro programming the next semester
- Downsides w.r.t. attracting new students:
  - Tends to attract economics students who already have some cs background anyway
  - Tends to attract juniors, seniors

Thank you for your attention!