Using Expressiveness to Improve the Economic Efficiency of Social Mechanisms

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Joint work with:

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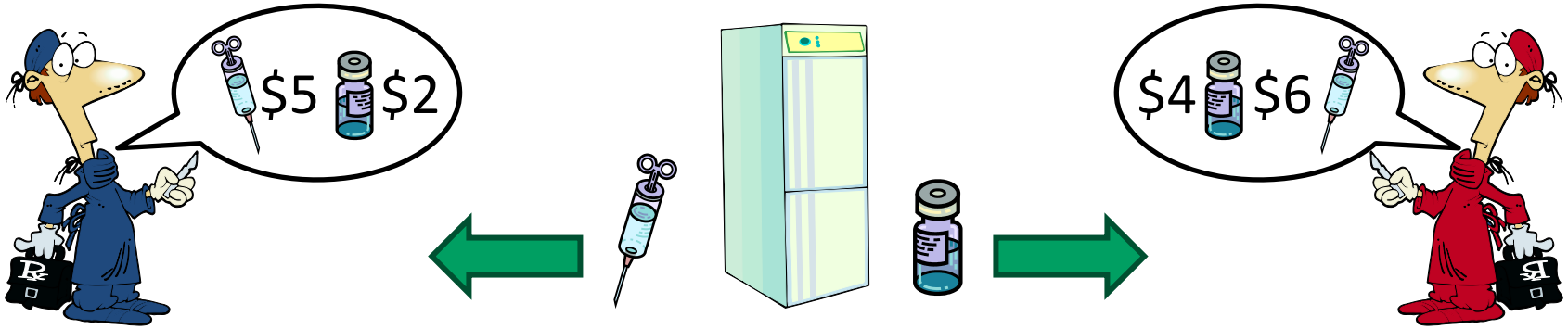
Talk outline

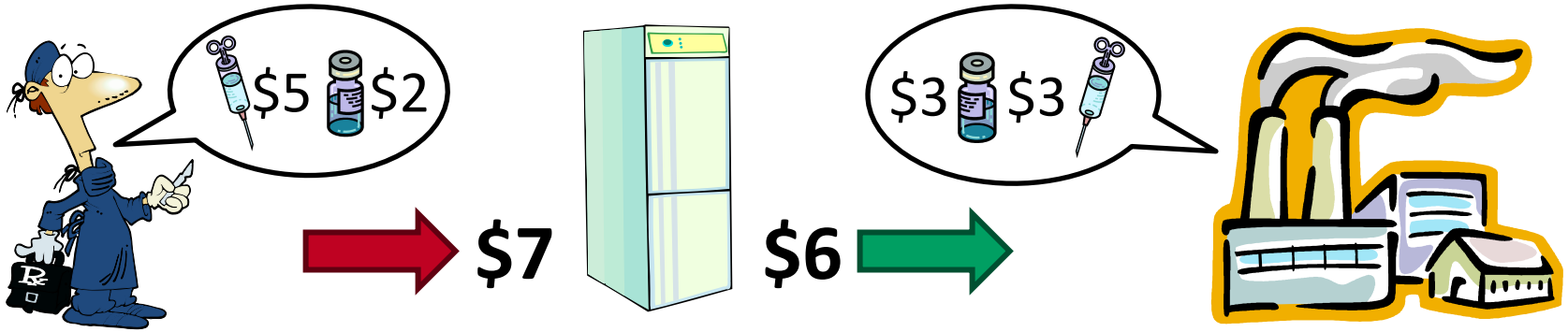
- Examples of expressive mechanisms
- Computational theory of expressiveness in mechanisms
- Relationship between expressiveness & efficiency
- Relationship between expressiveness & communication
- Example instantiation: channel-based mechanisms
- Related work & conclusions

What is a mechanism?

- An **outcome function** that computes an (optimal) outcome (e.g., allocation of items) based on the expressions of the agents



- A **payment function** that computes a payment from or to each agent (optional)



Mechanism design desiderata

- **Clear incentives for participants** (e.g., dominant or pure strategy Nash equilibrium)
- **High efficiency / social welfare** (or potentially revenue)
- **Usability** (e.g., eliminate time struggling w/ interface)
- **No subsidies necessary** (i.e., budget balanced)
- **Incentivize participation** (i.e., individual rationality)

Broad trend toward expressiveness

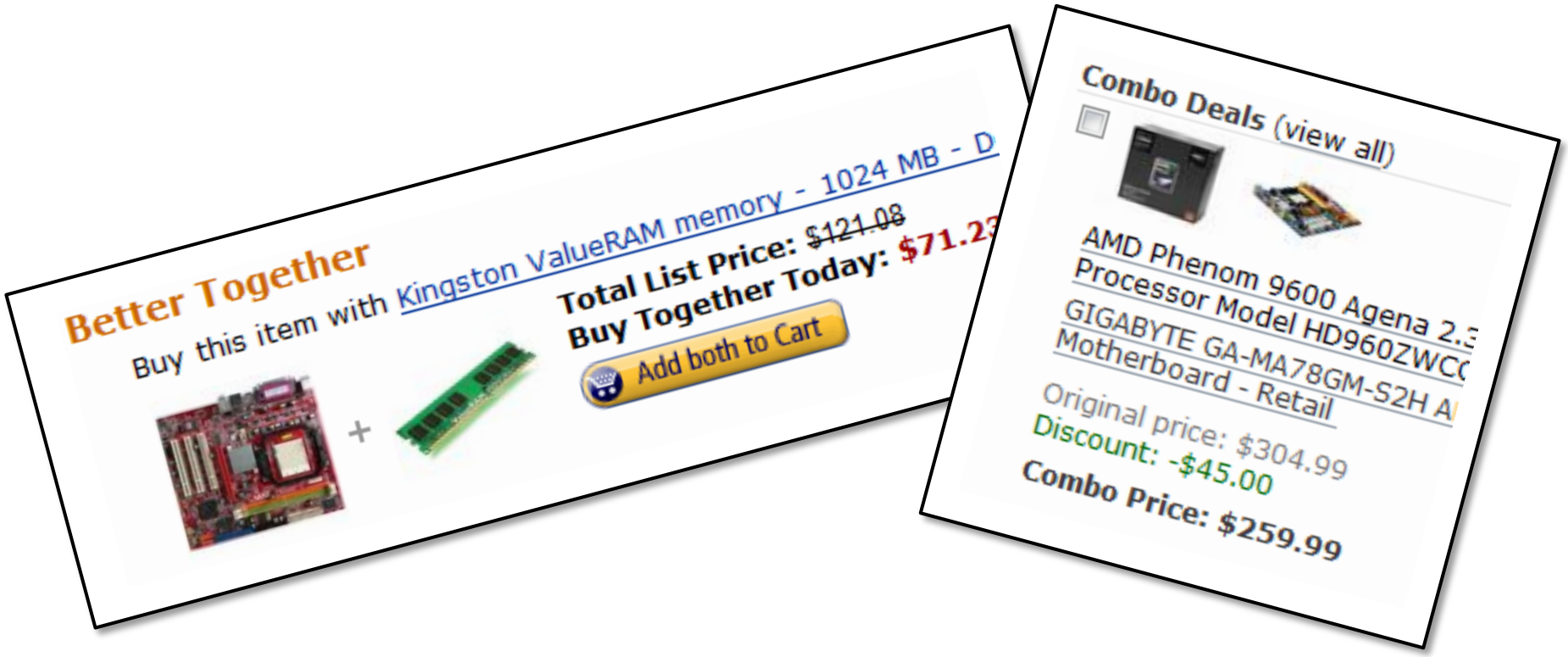
Electronic mechanisms are becoming more expressive

- **Generalized combinatorial auctions (aka., "Expressive Commerce") applied to sourcing (2001-)** [Sandholm 07]

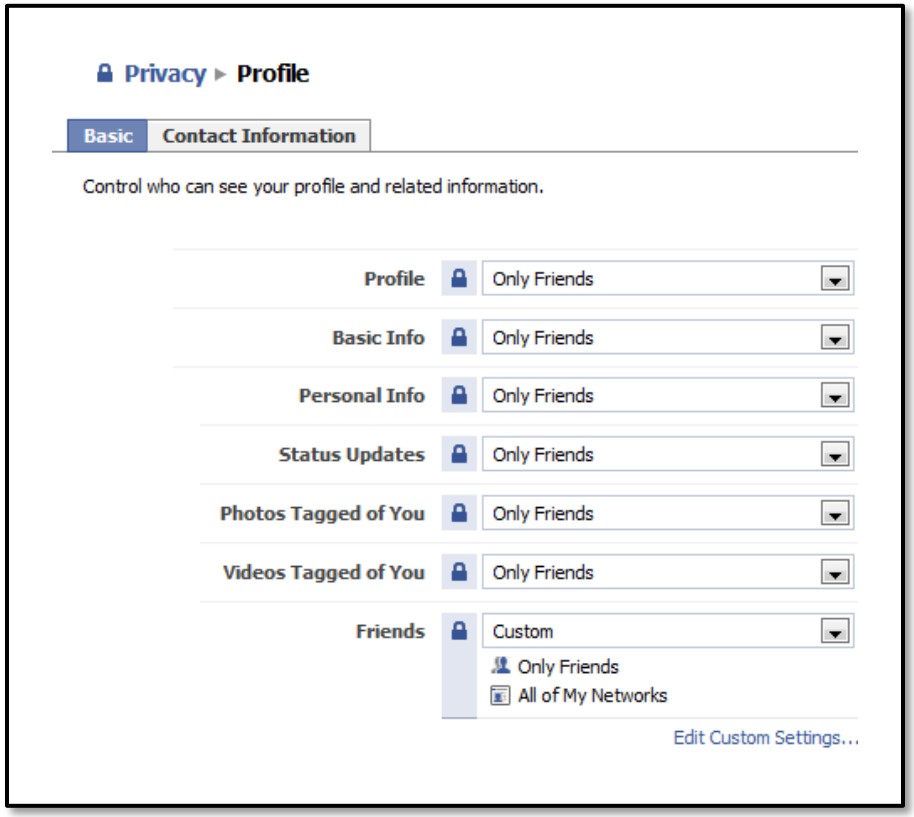
  - **Expressiveness forms for bidders:**
    - Flexible forms of package bids
    - Side constraints, e.g., capacity constraints
    - Rich forms of conditional discounts
    - Discount schedules
    - Multi-attribute bids
    - Free-form expression of alternates
  - **Expressiveness forms for bid taker(s):**
    - Side constraints
    - Multi-attribute preferences

priceline.com introduces “Name Your Own Price” (1998)

amazon.com & newegg.com offer bundles of items (ca. 2000)



facebook increases expressiveness of privacy control (2006)



iTunes adds option for users to *rent* movies (2007)

Airlines charge extra for baggage, food & choice seats (2008)

Checked baggage

Checked bags	Under 50 lbs/23 kg	51-70 lbs/23-32 kg (includes $50 weight fee)	71-100 lbs/32-45 kg (includes $100 weight fee)	Over 100 lbs/45 kg
First bag	$15*	$65*	$115*	Not accepted
Second bag	$25*	$75*	$125*	Not accepted
Third - ninth bag	$100*	$150*	$200*	Not accepted

Lunch/Dinner

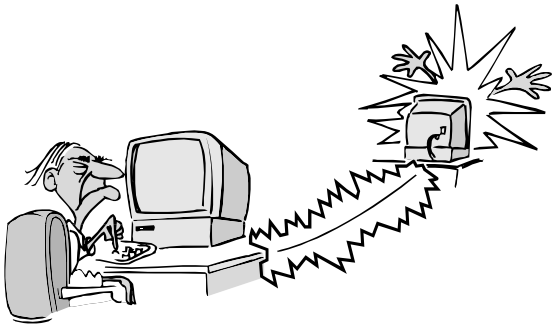
Chef Salad $7

Crisp Romaine lettuce served with smoked turkey and turkey-ham, cubed cheddar and swiss cheeses, chopped hardboiled egg and ripe cherry tomatoes, served with a side of Ranch dressing and a chocolate chip cookie.

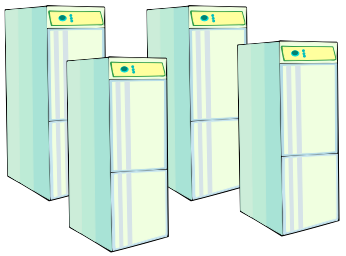
U·S AIRWAYS
CHOICESEATS

But expressiveness is not free…

- More expressiveness requires **more communication** [Nisan & Segal 06]



- More expressive mechanisms are **more complex** to run [Rothkopf et. al. 98] [Sandholm 02] [Martin et. al. 08]

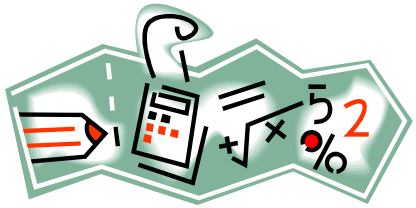


- More expressiveness can make mechanisms **harder to use*** [Schwartz 04] [Sadeh et. al. 08]

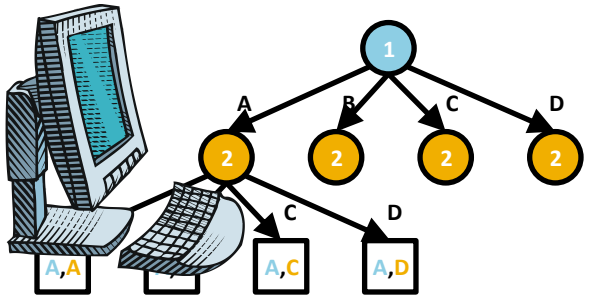
* It can also remove "shoe-horning" burden

Overall research approach

1. Develop a **new theory** of expressiveness in mechanisms



2. Develop **models and algorithms** to estimate the impact of different expressiveness alternatives



3. Study efficiency and **usability tradeoffs**

What makes a mechanism expressive? A straw man notion

Item bid auction

Dimension $\Re^2$ expression space

Combinatorial auction

Dimension $\Re^3$ expression space

What makes a mechanism expressive?

Prop: Dimensionality of expression space does not suffice

Proof intuition [based on work of Georg Cantor, 1890] **:**

Dimension $\Re^3$ expression space

Mapping

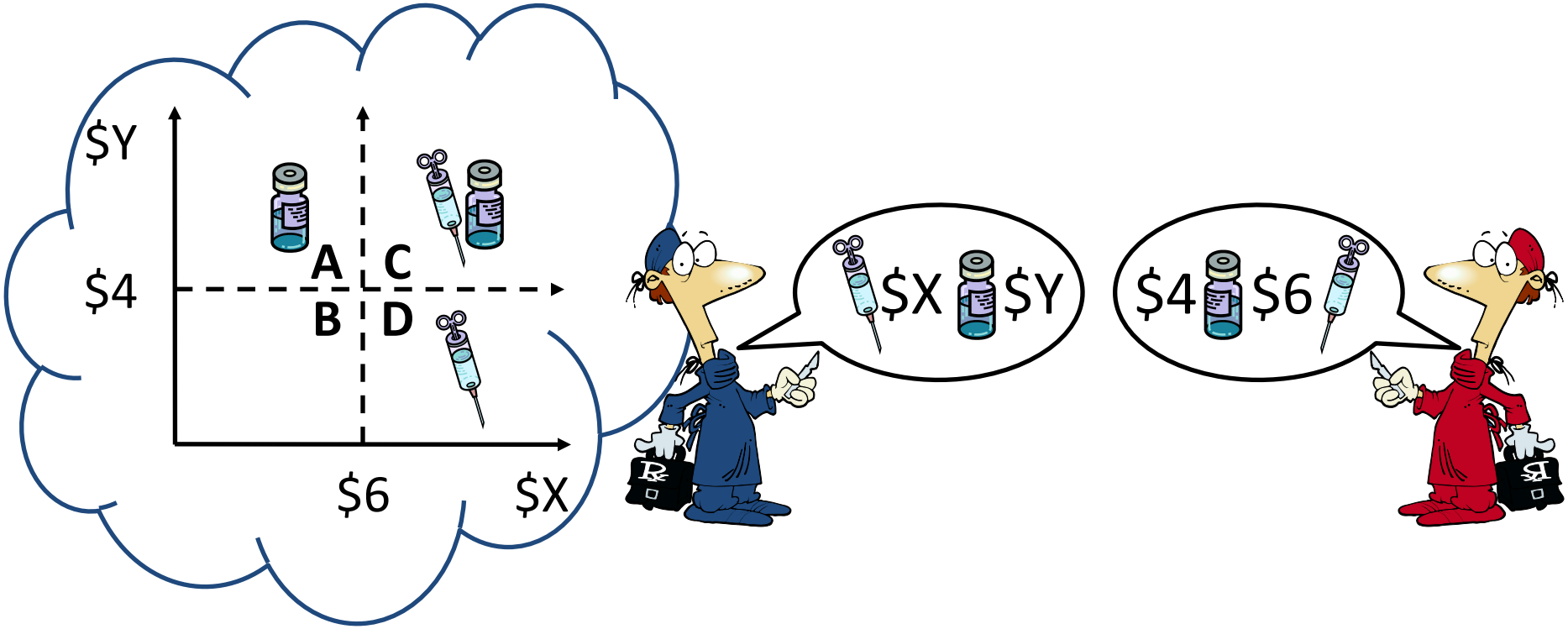
Dimension $\Re^1$ expression space

A computational theory of expressiveness

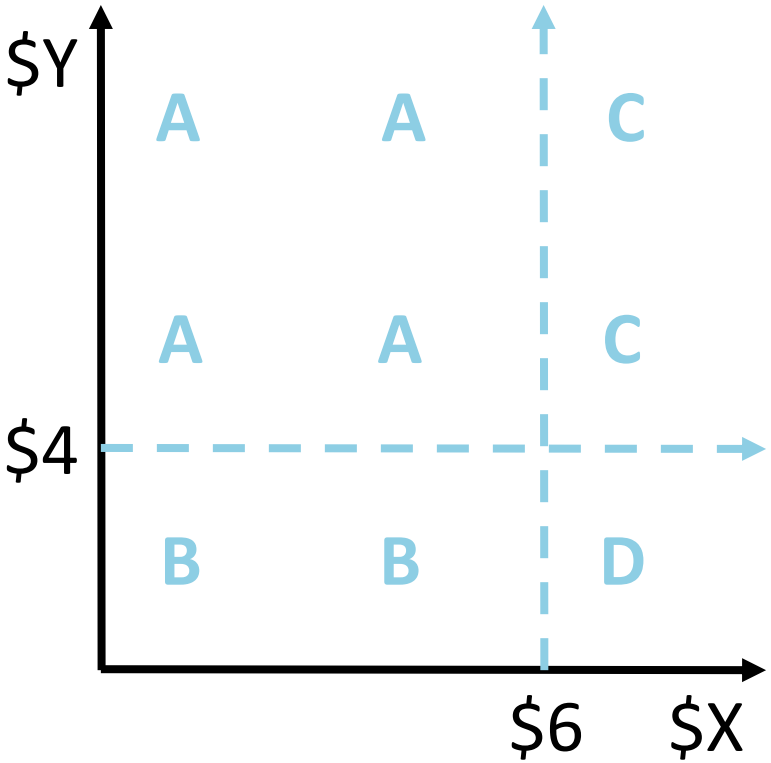
[Benisch, Sadeh, & Sandholm, AAAI 2008]

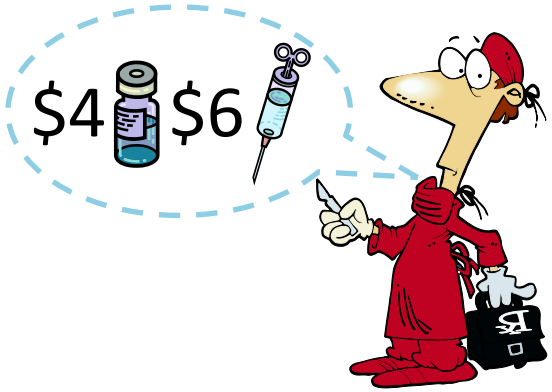
Our notion: Expressive mechanisms allow agents more *impact* on outcome

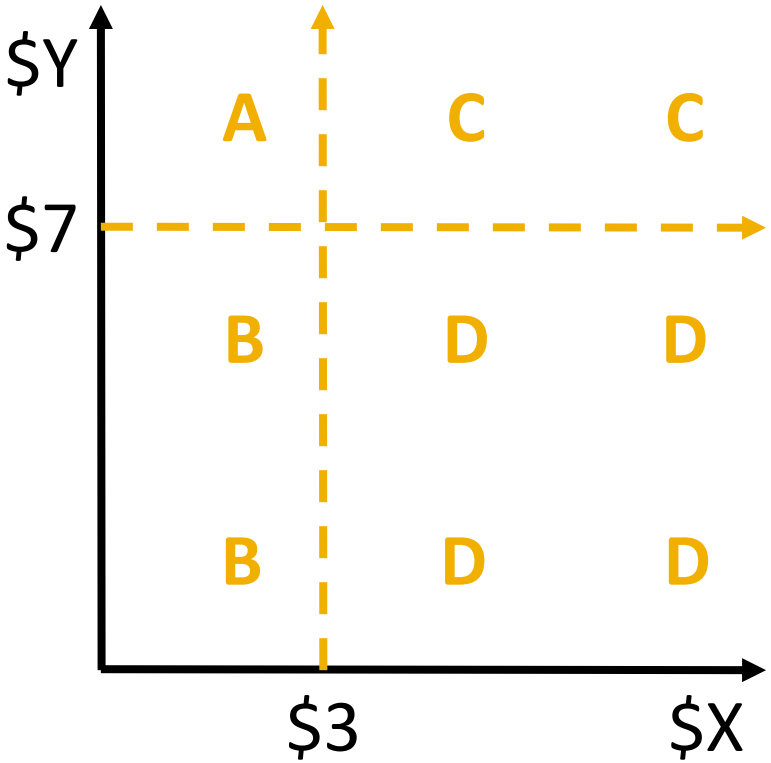
An agent's *impact* is a measure of the outcomes it can choose between by altering only its own expression



Uncertainty introduces the need for greater impact



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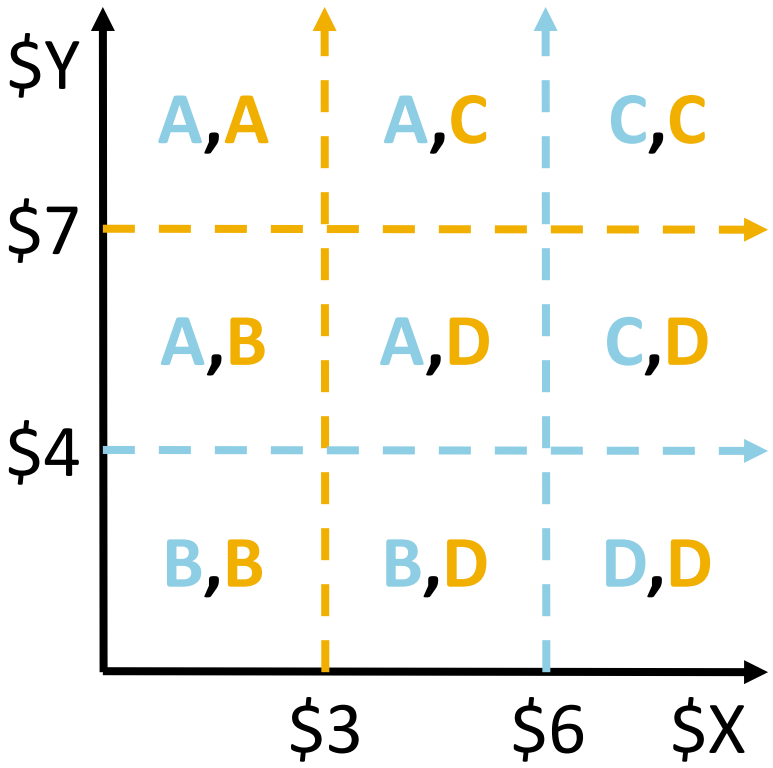
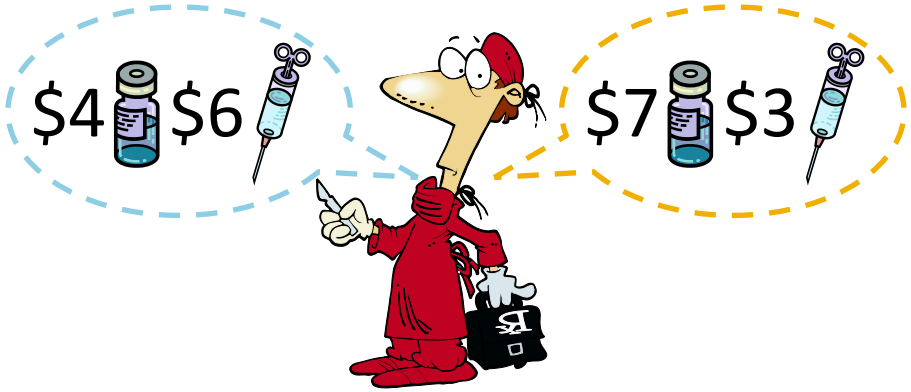
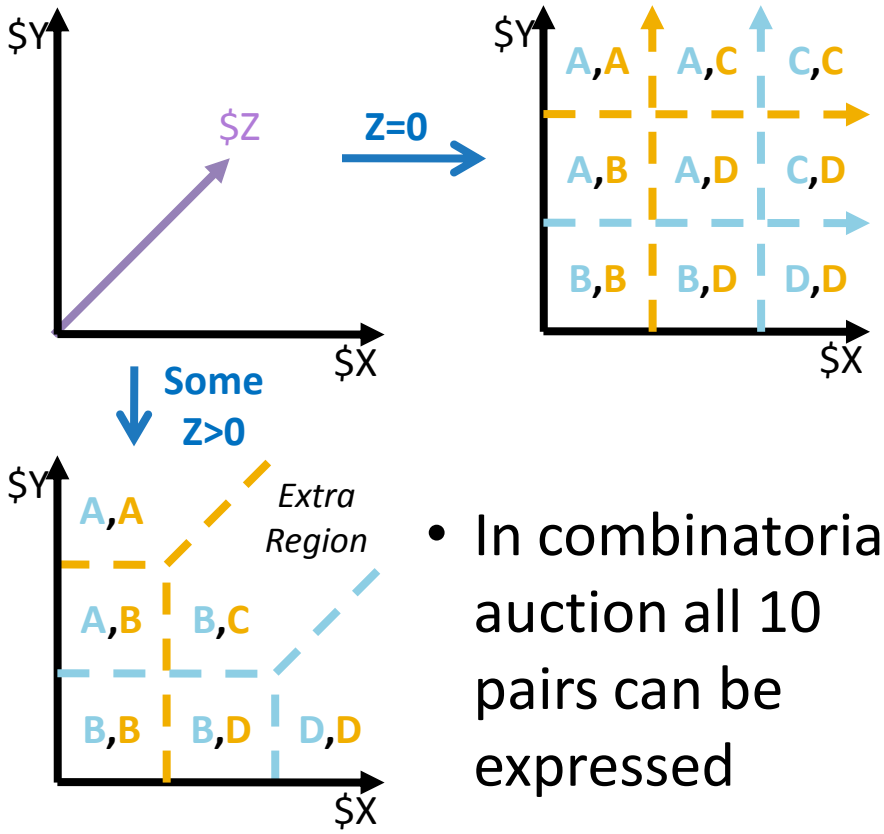
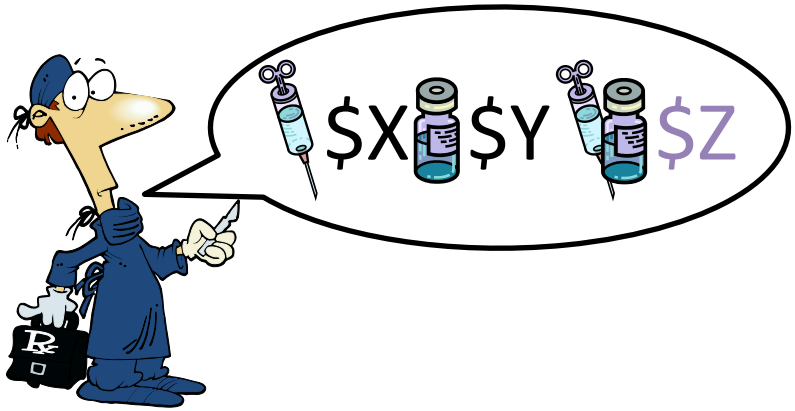




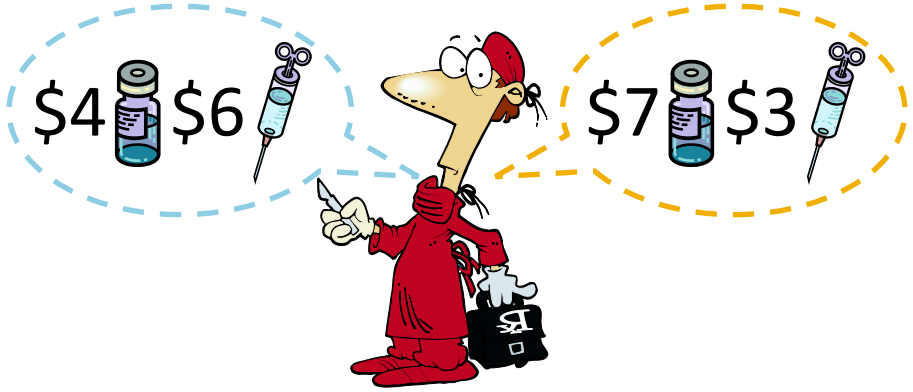
- 10 outcome pairs but only 9 regions
- In this example the *impact vector* **B**,**C** can't be expressed

Expressive mechanisms





- In combinatorial auction all 10 pairs can be expressed

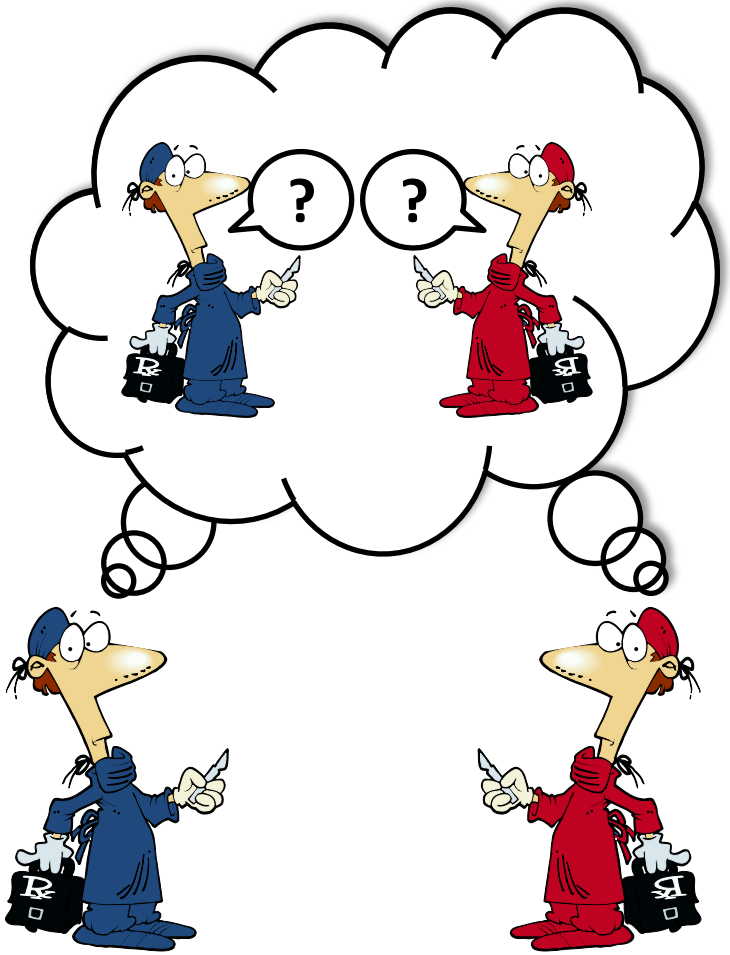


- Our measure of expressiveness for one agent (*semi-shattering*): how many combinations of outcomes can he choose among
  - Not just for combinatorial allocation problems because outcomes can be anything
  - Captures multi-attribute considerations as well

Expressiveness and efficiency

An upper bound on best-case efficiency based on expressiveness

- We study a mechanism's efficiency when agents **cooperate**
- It bounds the efficiency of **any equilibrium**
- It can be **implemented** in Bayes-Nash Equilibrium (but not necessarily dominant strategies)



A mechanism's best-case efficiency increases strictly with expressiveness

Theorem: the upper bound on efficiency for an optimal mechanism increases *strictly monotonically* as more expressiveness (# of expressible impact vectors) is allowed

Proof intuition: induction on the number of expressible impact vectors; each time this is increased at least one more efficient outcome is allowed

Any increase in expressiveness can lead to a large increase in the bound

Theorem: the upper bound on efficiency for an optimal mechanism can increase *arbitrarily* when any increase in expressiveness (# of expressible impact vectors) is allowed

Proof intuition: construct preference distributions that ensure at least one type makes each combination of outcomes arbitrarily more efficient than any others

The bound can always be achieved

Theorem: for any outcome function there exists at least one payment function that yields a expected budget-balanced mechanism that achieves the bound's efficiency in Bayes-Nash equilibrium strategies

Proof intuition: if agents are charged their *imposed externality* (i.e., the inconvenience that they cause to other agents), then making expressions that maximize social welfare is a weekly preferable for every agent if every other agent does the same

Expressiveness and communication complexity

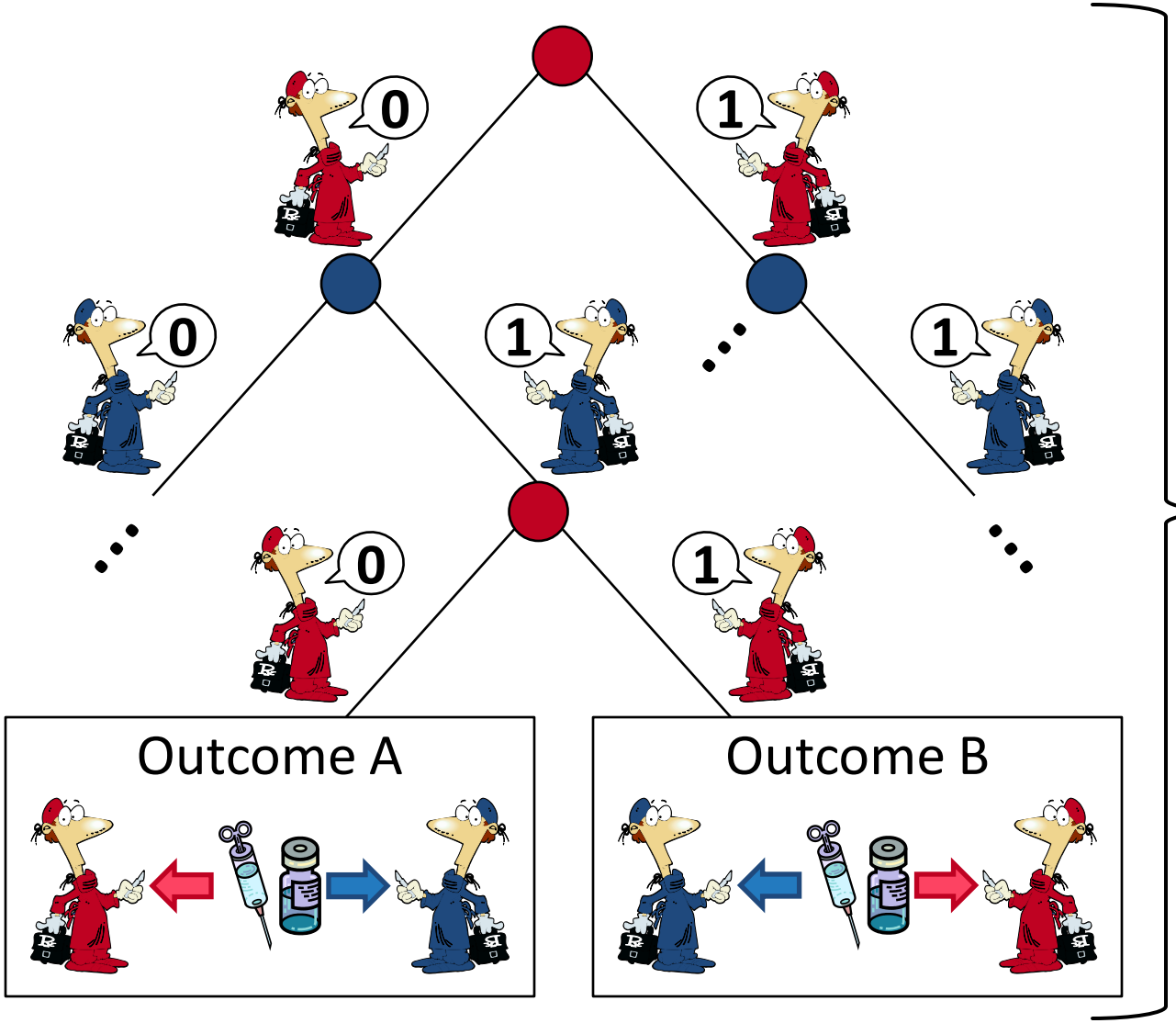
What is communication complexity?

- Measures the **amount of communication** (e.g., # of bits) needed to compute discrete functions w/ distributed inputs [Yao 79]

- Communication bounds apply even to "clever" protocols (e.g., **partial and/or sequential revelation**)

- Can be **applied** to mechanism design [Nisan & Segal 06]

An example communication protocol



Depth of tree is worst-case number of bits needed

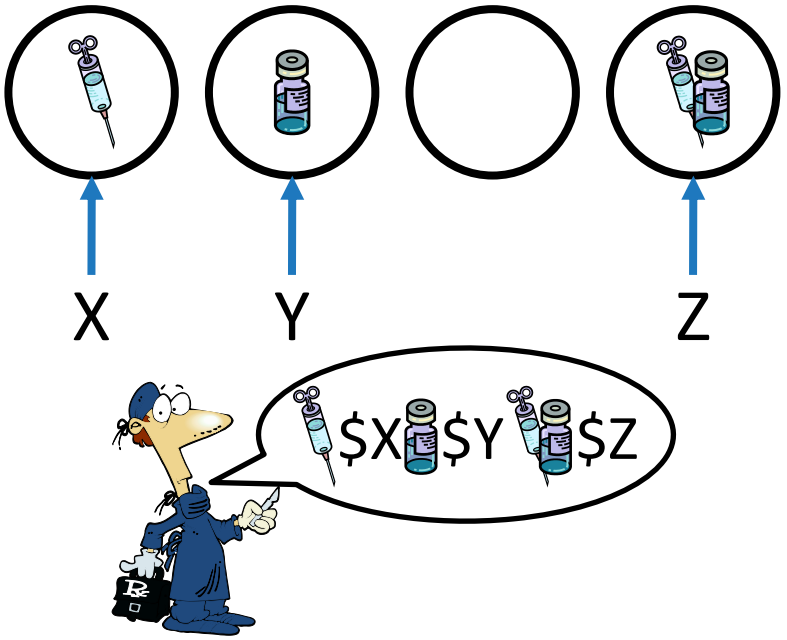
An increase in expressiveness increases communication complexity

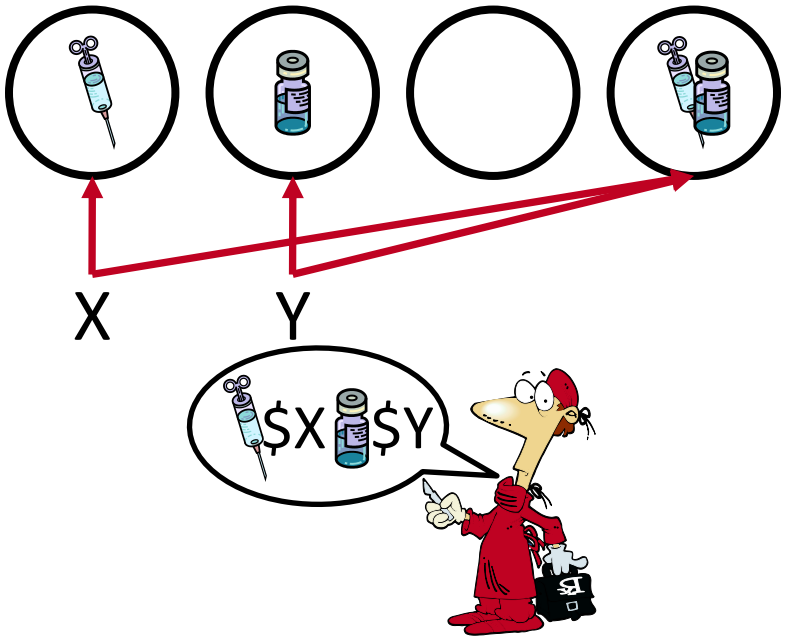
Theorem: there exist upper and lower bounds on communication complexity that increase with our notions of expressiveness

Proof intuition (lower bound): if an agent can semi-shatter a set of outcomes, the joint type space of the other agents constitutes a “fooling set”

Channel-based mechanisms

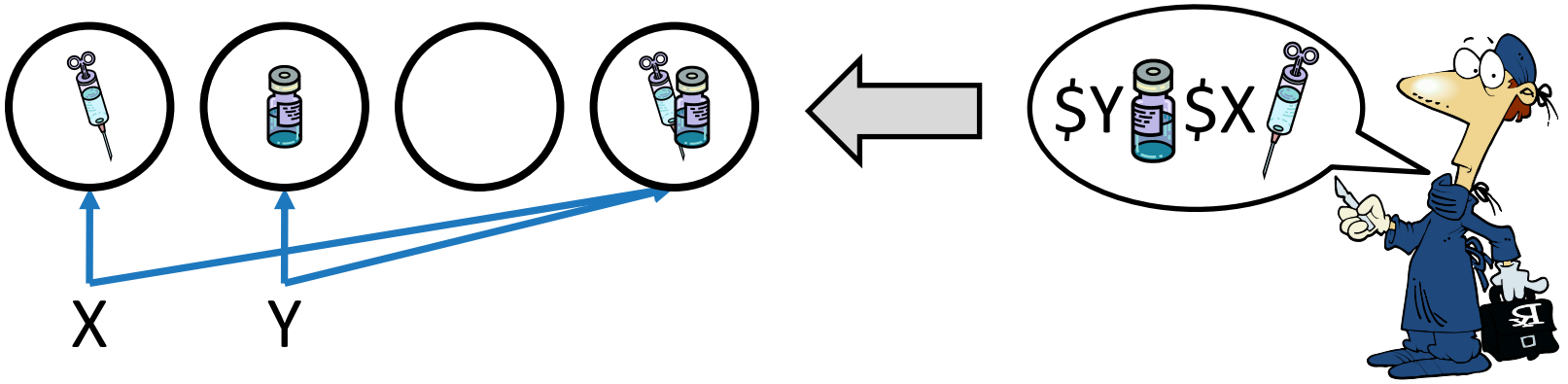
Channel-based mechanisms consist of a mapping from *channels* to outcomes





- Each agent reports a real value on each of its channels
- The outcome with channels that have the greatest sum is chosen
- Subsumes prior models: combinatorial auctions, multi-item auctions w/per-item bids, *k-wise* dependence **[Conitzer et. al., 05]**

Overlapping channels prevent agents from semi-shattering outcomes



Theorem: any mechanism where channels overlap as above (e.g., a multi-item auction without full expressiveness), can be arbitrarily inefficient for some preference distributions

Related work

- **Informational complexity**: technical assumptions precluded "cantorization" [Hayek 45] [Hurwicz 72][Mount & Reiter 74]
- **Communication complexity**: does not address what happens to efficiency in moderately expressive mechanisms [Nisan & Segal 06]
- **Finding equilibria of inexpressive mechanisms**: fast search algorithms [Wilenius & Andersson 07] and analytical characterizations are elusive [Rosenthal & Wang 96] [Szentes & Rosenthal 03]
- **Expressiveness and dominant strategy implementation**: primarily negative results with limited expressiveness [Blumrosen & Feldman 06] [Parkes 02]

Summary

- Expressiveness can be used to design **more efficient mechanisms** in a wide range of domains
- Expressiveness can also have negative consequences, if not used properly:
  - It can cost users time and money
  - It can lead to less competition and revenue
  - It can occasionally lead to less efficient equilibria
- We have **new theory** to help guide the design and implementation of expressive mechanisms