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
introduces “Name Your Own Price” (1998)
Better Together
Buy this item with Kingston ValueRAM memory - 1024 MB - D
Total List Price: $121.98
Buy Together Today: $71.23
Add both to Cart

Combo Deals (view all)
AMD Phenom 9600 Agena 2.3
Processor Model HD960ZWCC
GIGABYTE GA-MA78GM-S2H AI
Motherboard - Retail
Original price: $304.99
Discount: -$45.00
Combo Price: $259.99

Amazon.com & Newegg.com® offer bundles of items (ca. 2000)
"...we did a bad job of explaining what the new features were and an even worse job of giving you control of them.... This is the same reason we have built extensive privacy settings — to give you even more control over who you share your information with."
CD+Tunes adds option for users to *rent* movies (2007)
Airlines charge extra for baggage, food & choice seats (2008)

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

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.
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

Combinatorial auction

Dimension $\mathbb{R}^2$ expression space

Dimension $\mathbb{R}^3$ expression space
What makes a mechanism expressive?

**Prop:** Dimensionality of expression space does not suffice

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

![Diagram](https://via.placeholder.com/150)

Dimension $\mathbb{R}^3$ expression space $\rightarrow$ Mapping $\rightarrow$ Dimension $\mathbb{R}^1$ 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
• 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 with 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

Outcome A

Outcome B
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