Using Expressiveness to Improve the Efficiency of Social and Economic Mechanisms

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Thesis outline

• Identifying a broad trend toward expressiveness and usability/efficiency tradeoffs

• A general theory of expressiveness in mechanisms

• Operationalizing the theory in:
  1. Advertisement markets
  2. Privacy mechanisms
  3. Catalogs with bundle discounts
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
Some 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
What is position preference?
Position preference lets you tell Google where you'd like your ad to appear among all the AdWords ads on a given page. (It's a preference, not a promise -- we can't guarantee you'll always get the position you ask for.)

You can request that your ad be shown only when it is:
- Higher than a given position (such as above 7)
- Lower than a given position (such as below 4)
- Within a range of positions (such as from 2-8)
- In a single exact position (such as position 2)
“...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.”
Amazon.com & NewEgg.com offer bundles of items (ca. 2000)

Better Together
Buy this item with Kingston ValueRAM memory - 1024 MB - D
Total List Price: $124.08
Buy Together Today: $71.23
Add both to Cart

Combo Deals (view all)
AMD Phenom 9600 Agena 2.2 GHz Processor Model HD960ZWCC
GIGABYTE GA-MA78GM-S2H A11 Motherboard - Retail
Original price: $304.99
Discount: -$45.00
Combo Price: $259.99
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**
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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** [from Georg Cantor, 1890] :

Dimension $\mathbb{R}^3$ expression space $\xrightarrow{\text{Mapping}}$ Dimension $\mathbb{R}^1$ expression space
A computational theory of expressiveness

[M.B., Sadeh, Sandholm, *AAAI* 08]
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.
An inexpressive mechanism
An inexpressive mechanism

\[
\begin{array}{ccc}
X & Y & 3 \\
A & C & C \\
B & D & D \\
\end{array}
\]
An inexpressive mechanism

- 10 outcome pairs but only 9 regions
- In this example the *impact vector* \( \text{B,C} \) can’t be expressed
An expressive mechanism

In a combinatorial auction all 10 pairs can be expressed!

• Our measure of expressiveness for one agent (semi-shattering): how many combinations of outcomes he can choose among
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* with more allowed expressiveness (# of expressible impact vectors)

*For illustration purposes only*
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* with any increase in allowed expressiveness (# of expressible impact vectors).

![Graph showing the relationship between allowed expressiveness and efficiency bound.](image)

- **Efficiency bound of opt. mechanism**
- Small increases can lead to large jumps
Implementation is always possible in Bayes-Nash equilibrium

**Theorem:** at least one **budget-balanced** mechanism can achieve the bound’s efficiency in **Bayes-Nash equilibrium** (when agents have private values)
Related work on expressiveness theory

• **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]

• **Equilibria of inexpressive mechanisms**: fast search algorithms [Wilenius & Andersson 07] and analytical characterizations are elusive [Rosenthal & Wang 96] [Szentes & Rosenthal 03]

• **Expressiveness and dominant strategies**: negative results w/ limited expressiveness [Blumrosen & Feldman 06] [Parkes 02]
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How to operationalize our theory

1. Adapt the **theoretical framework**

2. Collect / estimate **user preferences**

3. Use **search algorithms** to find best-case / equilibrium strategies

4. Compare **efficiency** of the mechanisms
Online advertisement markets (aka. sponsored search)

[M.B., Sadeh, Sandholm, *IJCAI 09*]

[M.B., Sadeh, Sandholm, *Ad Auctions Workshop 08*]
What is sponsored search?

- Advertisers bid for sponsored links on different keywords

Sponsored links

“Organic” links
We compare different ad auctions

**GSP**: used by Google, Yahoo!, Bing, Baidu, ...

Inexpressive mechanism

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<th>Rank</th>
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<td>2</td>
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<td>$4</td>
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<tr>
<td>3</td>
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<tr>
<td>4</td>
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**Our proposal**: extra bid for premium slots

Premium mechanism

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<th>Rank</th>
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<td>$5</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>$4</td>
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**Fully expressive mechanism**

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<td>3</td>
<td></td>
<td>$3</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>$2</td>
</tr>
</tbody>
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We simulate the utility functions of a heterogeneous bidder population.
Computing the bound w/ tree search

We search for the most efficient assignment of outcomes to joint types.

Joint type k+1
Agent 1: Value, Agent 2: Value, ...

Joint type k
Agent 1: Brand, Agent 2: Brand, ...

infeasible
Inexpressive mechanism can be inefficient, premium is much better.
Expressiveness is more important when bidders are moderately different.
Related work on ad markets

• **Improvements from other expressive ad market designs** [Lahaie et al. 08] [Parkes & Sandholm 05] [Boutilier et al. 08]

• **Preference models and methods similar to ours** [Baye & Morgan 05] [Even-Dar et al. 07] [Thompson & Leyton-Brown 09]

• **Counter-point work**: some question the need for added expressiveness in this domain [Abrams et al. 07] [Milgrom 10]
Privacy mechanisms

[M.B., Kelley, Sadeh, Cranor, Personal Ubi. Comp. 10]
[Kelley, M.B., Cranor, Sadeh, CHI (note) 11]
[M.B., Kelley, Sadeh, Sandholm, Cranor, Hankes-Drielsma, SOUPS (poster) 08]
[Ravichandran, M.B., Kelley, Sadeh, PETS 09]
What is a privacy mechanism?
Experimental methodology

• Subjects given Nokia N95s with our tracking software

• Each day, they visited our web app & audited locations

• For each location, we asked: “While at this location, would you have shared with...”

  Friends & Family?  Facebook Friends?

  Anyone at CMU?  Advertisers?

• Entrance and exit surveys were also administered
You were observed to be at Location A between Sunday September 21, 8:48pm and Monday September 22, 9:02am.

Please indicate whether or not you would have been comfortable sharing your location during this time with each of the groups below.

Would you have been comfortable sharing your location between Sunday September 21, 8:48pm and Monday September 22, 9:02am with:

Click here if you believe that this observation is completely inaccurate.
Demographics

- 73% male
- 27% female
- 35% grad
- 58% u-grad
- 7% staff

- Avg. age ~22 years old
- 27 subjects, 3 weeks each
- ~7,500 hrs. collected in total during Nov. 2009
Privacy mechanisms we compare

1. **Wht List**: block/allow entire groups only
2. **Time**: groups & time of day (15-min intervals)
3. **Time+**: adds day of week (weekdays vs. weekends)
4. **Location**: groups & lat-lon rectangle
5. **Loc/Time**: Loc and Time rules
6. **Loc/Time+**: Loc and Time+ rules
Calculating accuracy & time shared

Accuracy = \frac{\text{correct\_hrs} - c \times \text{incorrect\_hrs}}{\text{correct\_hrs}}

Time shared = \frac{\text{correct\_hrs} + \text{incorrect\_hrs}}{\text{total\_hrs}}

• We vary $c$ from 1 to 100 and find the most accurate rules for each subject & mechanism

• We report average accuracy and time shared (w/ 95% confidence intervals)
Average accuracy w/ $c = 20$
Average time shared w/ $c = 20$

![Bar chart showing average time shared with different groups.](chart.png)
Average **accuracy** varying cost (for Facebook friends)

Average **time shared** varying cost (for Facebook friends)
Finding policies with a limited number of rules

- Preprocessors group “similar” blocks of time & locations

- Admissible heuristic with unlimited number of rules guides search
Average accuracy varying # of rules (for Facebook friends w/ $c = 20$)
Related work on privacy mechanisms

• **Complex location-sharing preferences**: others also show this [Barkhus & Dey 03] [Consolovo et al. 05] [Burghardt et al. 08]

• **Complex sharing preferences**: also shown in other domains [Sadeh et al. 08] [Tsai et al. 09] [Mazurek et al. 10]

• **Users may be unwilling to use increased expressiveness**: has been shown for privacy [Sadeh et al. 08] [Kelley et al. 08]
Expressive catalogs with bundle discounts

[M.B. & Sandholm, *Under review 11*]
Catalog pricing example

Traditional catalog
Profit: $6
Surplus: $2

Catalog w/ bundle discounts
Profit: $8
Surplus: $4
A framework for bundling and pricing

1) Collect preference data
   - Focus groups or experiments
     - Low quantity, high quality

2) Build valuation models
   - Domain specific knowledge
     - E.g., prior distributions

3) Optimize bundle prices
   - Catalog w/ bundle discounts
   - Offer bundles to customers

Customers make purchases

Customer purchase data

High quantity, low quality

Low quantity, high quality
A general customer valuation model

- We model customer valuations with a hyper-graph
- Nodes and hyper-edges represent probability distributions over valuations
- We also model pair-wise covariance
Profitable pairs are negatively related

Offering discounts on optimal item-only prices for symmetric two-item instances
Fitting our model to purchase data

Tree search over variances

- $\sigma_a = 1$
- $\sigma_a = 2$
- $\sigma_a = 3$

Local search over means

- $\Sigma_{ab} = -1$
- $\Sigma_{ab} = 0$
- $\Sigma_{ab} = 1$

Covariance $= \Sigma_{ab}$

PDF of $x_{(a)}$

PDF of $x_{(b)}$

PDF of $x_{(a,b)}$

Item draw, $x_{(i)}$

Bundle draw, $x_{(a,b)}$
Profitable pairs not bought together?

Offering discounts on optimal item-only prices for symmetric two-item instances
Results on realistic shopping cart data

We conservatively estimate $E[\text{profit}] \text{ inc.}$ w/ different settings for a classic generator used by [Agrawal & Srikant 94] and [Brin et al. 97]

<table>
<thead>
<tr>
<th># of items</th>
<th>Items/cust</th>
<th>Pop. bundles</th>
<th>$E[\text{profit}] \text{ inc.}$</th>
<th>$E[\text{surp.}] \text{ inc.}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>20</td>
<td>2000</td>
<td>2.80%</td>
<td>8.34%</td>
</tr>
<tr>
<td>1000</td>
<td>20</td>
<td>1000</td>
<td>1.10%</td>
<td>3.01%</td>
</tr>
<tr>
<td>100</td>
<td>2</td>
<td>200</td>
<td>0.89%</td>
<td>2.65%</td>
</tr>
<tr>
<td>100</td>
<td>2</td>
<td>100</td>
<td>0.15%</td>
<td>0.86%</td>
</tr>
</tbody>
</table>

*Offering discounts only on two-item bundles that are unrelated to any other items*
Related work on bundling in catalogs

- **Bundling in a two product monopoly**: early economics work focused on simple settings [Adams & Yellen 76] [Dansby & Conrad 84] [McAfee et al. 89]

- **Optimizing with survey data**: integer programs [Hanson & Martin 90], a car configuration advisor [Rusmevichientong et al. 06], consumer electronics [Jedidi et al. 03]

- **Setting bundle discounts for information goods**: online approaches [Brooks & Durfee 00] [Kephart et al. 01] and an analytical treatment [Bakos & Brynjolfsson 99]
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Concluding remarks

• Expressiveness can be used to design more efficient mechanisms in a wide range of domains

• Expressiveness can also have negative consequences:
  • It can cost users
  • It can increase communication/computation

• We have provided a methodology to help guide the design and implementation of expressive mechanisms
Thank you! Any questions?