CS 286r: Computational Mechanism Design

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Spring, 2007
Motivation

- Ubiquitous **computing** and **Internet** connectivity:
  - lower transaction (⇒ dynamic protocols)
  - greater reach
  - new markets (new goods)

- Specific **comp sci** contributions:
  - algorithms for winner determination
  - algorithms for automated bidding
  - machine learning (“filters”)
  - ontologies + XML, “wiki” power, tags etc.

- Chance to *construct* new markets. Not for the few!

- Heaps of compelling **applications**
Two Communities

- **Economics**
  - traditional emphasis on game-theoretic rationality, *describing*, and systems (“economies”) with *multiple* self-interested agents.

- **Computer Science**
  - traditional emphasis on computational & informational constraints, *building*, and systems with one user (or a user with adversarial opponents)

**Vision:** Unification, resolve conflicts between game-theoretic and computational constraints, develop rigorous theories, methodologies and algorithms.
Lots of Excitement!

- **Eighth ACM Electronic Commerce Conference**, June 2007
  - combinatorial auctions, mechanism design, Web 2.0, economics of security, sponsored search, viral marketing, etc.

- **Dagstuhl Workshop on Comput. Social Systems and the Internet**, July 2007
  - computer scientists, economists, game theorists

- **DIMACS Workshop on Auctions with Transaction Costs**, March 2007
  - computer scientists, economists, game theorists

- **WINE, AMEC, INFORMS** clusters, SS workshops, etc.

- Yahoo! research, Google, YouTube, Facebook, MS research, ...
What is this Course?

Rotating topics course.

• Spring, 2007. Computational Mechanism Design. [w/ focus on sponsored search]

Previous:

• Spring, 2006. Multi-agent learning and Implementation.

Tentative:

• Spring, 2008. Challenge Problem (we did ‘Iterative Combinatorial Exchanges’ in 2004). Virtual economies (e.g. second life)??
Computational Mechanism Design

**Fundamental Concept:** design systems s.t. the equilibrium are “good“, from econ & CS perspective.
Sponsored Search

- Buzz word: MONETIZATION
- Google AdSense. Yahoo “Panama.” MSN.
- Google: $6B revenue 2005, $10B revenue 2006
- Online:Offline split, roughly $16B to $300B. Online projected to grow 30%/year.
- Google has 100’000s of web sites in network, 100’000s advertisers. Big and small. More and more not just driving business on web.
- Ecosystem of “marketmakers.” 1000’s of players.
Course Structure

- **Introductory lectures**: [until 2/14]
  - (4 in total) GT, MD, auction theory.

- **Current Research papers**: [bulk of course]
  - **Part I** (theory and practice)
    - optimal auction design (3 views)
    - new soln. concepts
    - method for “automated” MD
  - **Part II** (spons. search, bidding agents)
    - auction design (theory)
    - bidding dynamics
    - AI for GT analysis (incl. TAC)
  - **Part III** (dynamic mechs.)
    - theory, online algorithms
    - new soln concepts
    - online optim., using for auction design
Prerequisites, Enrollment

Enrollment limited to around 20 students. Complete Survey at end of class!

- Level of math. sophist., at least a basic course in linear algebra (such as M 21b, AM 21b, or equivalent)
- Theoretical CS, at least CS 121 (complexity theory) and CS 124 (algorithms).
- Familiarity with “agent rationality” concepts, e.g. an AI course, CS 181 or CS 182, or an appropriate econ/GT course.

Advanced algorithms, game theory, microeconomics, linear programming, etc. all helpful but not required.
# Grading

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight</th>
<th>Description</th>
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<tbody>
<tr>
<td>Problem sets</td>
<td>25%</td>
<td>2–3 short problem sets on introductory material*</td>
</tr>
<tr>
<td>Participation</td>
<td>20%</td>
<td>Reading papers, submitting short summary &amp; Qs ahead of class, participation in discussion.</td>
</tr>
<tr>
<td>Presentation of research paper</td>
<td>15%</td>
<td>A short survey and critique. (with a partner)</td>
</tr>
<tr>
<td><strong>Project</strong></td>
<td>40%</td>
<td>Proposal, class presentation &amp; final report</td>
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* chat with me to place out
Logistics

TF’s:

- Jacomo Corbo
- Florin Constantin

Office hours:

- Parkes. TR 2-3pm MD 229
- Corbo. T 9.30-11.30am MD 219
- Constantin. TBD

Notes distributed in class and online. Missed course materials from the TFs
Projects

- **Goal:** Develop a deep understanding of an important open research area, and, to the extent possible, to work on an open research problem.

- Projects may be theoretical or experimental.

- Suggested topics provided, although can submit own subject to approval.

- Proposals due after Spring Break; Presentations in reading week; Project reports before Finals.
Projects’05

- Avg. case analysis of dynamic auctions
- Impl. & analys. of false-name proof mechs
- Privacy preserving auctions
- A continuous combinatorial exchange
- Beyond AdWords
- Activity rule for budget-constrained bidders
What is a Mechanism?
Solution Concepts

- **Nash equilibrium.** Every agent plays a utility-maximizing strategy, given the utility-maximizing strategies of other agents.
  – assumes *rational* and *well-informed* agents

- **Dominant strategy.** Every agent has a utility-maximizing strategy *whatever* the strategies of other agents.
  – stronger implementation concept, does not require well-informed or rational agents
What’s Driving all the Interest?
Lots of Application!

- Resource allocation on federated distributed systems
  - ATLAS project, PlanetLab, Netbed, etc.

- Sponsored search; marketing (e.g. viral)

- Consumer-to-consumer markets (e.g. eBay)
  - sequential problem, complements

- Digital Goods (e.g. YouTube, Revver, etc.)

- Optimal sourcing and logistics
  - e.g., Proctor & Gamble’s North American truck requirements, UPMC pharm/surg

- Airport take-off and landing slot auctions
  - LaGuardia airport legislation
A Large Problem: London Bus Routes

- 3.5 million passengers each day
- 5000 buses
- 700 routes
- Competitive tendering since 1997
The Generalized Vickrey Auction

(Vickrey 61, Groves 71, Clarke 73)

1. Agents \( i \in N \) submit bids \( \hat{v}_i(S_i) \) for all bundles \( S_i \subseteq G \) of routes.

2. Compute allocation \( \hat{S} \) to maximize reported value:

\[
\max_{(S_1, \ldots, S_n)} \sum_{i} \hat{v}_i(S_i)
\]

3. Compute best allocation \( \hat{S}_{-i} \) without each agent \( i \):

\[
\max_{(S_1, \ldots, S_n)} \sum_{j \neq i} \hat{v}_j(S_j)
\]

4. Pick alloc. \( \hat{S} \), and collect payments

\[
p_{\text{gva},i}(\hat{v}) = \sum_{j \neq i} \hat{v}_j(\hat{S}) - \sum_{j \neq i} \hat{v}_j(\hat{S}_{-i})
\]

This is efficient and strategy-proof.
Special Case: A Single Item

Consider the Vickrey auction for a single item.

Let $b_1$ denote the highest bid, and $b_2$ the second-highest bid. Agent 1 pays

$$p_{gva} = b_2 - 0 = b_2$$

$\Rightarrow$ sell item to the highest bidder for the second-highest bid.

This is strategy-proof because an agent’s bid defines the range of prices it is willing to accept, but not the actual price.
Computational Problems

- **Winner-determination** problem, selecting bids to maximize reported value, is NP-hard
  - equivalent to maximum weighted set packing
  - technically, the *decision version* is NP-complete ("is there a solution with value at least $V$?")
  - especially problematic in combination with incentive issues

- **Hard problem for agents to compute value**
  - e.g., a bus operator’s value for bundle $S$ might be given by difference between expected revenue and cost, e.g. $rev_i(S) - c_i(S)$ and both may be hard to compute
  - an *exponential* number of routes to consider
  - may also be externalities to worry about
Tractable Winner Determination

- **Restricted bidding languages**
  (Rothkopf et al. 98, Vohra & de Vries 00)
  - limited bid prices, e.g. sub-modular
  - limited bundle types, e.g. consecutive items, etc.

- Implement **approximate** solutions, and compute approximate Vickrey payments and/or change the mechanism.
  (KfirDahav et al. 98, Lehmann et al. 99)

- **Distribute computation** to agents; perhaps issue “challenges”.
  (Brewer 99, Nisan & Ronen 00)
Tractable Agent Problems

- Use **incremental elicitation**
  - ask for some information, perform intermediate computation, ask for some more information, etc.
  - compute the outcome without complete information

- Introduce **concise, expressive languages**, (even programs?) allow auctioneer to compute the value of a particular bundle “on-the-fly”
  - helps if formulation easier than solution
  - but, *shifts computation to the center* and *issues of trust and privacy.*
Research Directions

Best when driven by new domains,...

New domains
– structure \quad \text{new theory}
– temporal issues \quad \text{new algorithms}
– combinatorial
Overview of Initial Lectures

   – strategic form, Nash equil., dominant strategy, Bayesian-Nash.

   – Rev. princ., VCG mechanism

   – Negative and Positive Results

   – revenue equivalence, optimal auctions, efficient auctions
Overview of Technical Papers

- Theory and Practice of Mechanism Design
- Sponsored Search and Bidding Agent Design
- Dynamic mechanisms
I: Theory & Practice

Challenge: Characterization; design.


[7 ] Truthful Characterization II
○ Truthful Approximation Mechanisms for Restricted Combinatorial Auctions, by Ahuva Mu’alem and Noam Nisan In AAAI-02.

[8 ] Optimal Auction Design

[9 ] Digital goods
○ Competitive AuctionsAndrew Goldberg, Jason Hartline Anna Karlin, Mike Saks, and Andrew Wright, Games and Economic Behavior, 2006.
[10] **Computational approach**

- Sequences of Take-It-or-Leave-It Offers: Near-Optimal Auctions without Full Valuation Revelation, Sandholm, T. and Gilpin, A. In AAMAS’06.


[12] **Automated approach**

II: Sponsored Search, Agents


[14] Practical considerations

[15] Bid optimization
  ○ An Adaptive Algorithm for Selecting Profitable Keywords for Search-Based Advertising Services, by Rusmevichientong, Williamson.
[16] **Empirical game theory**

- Empirical game-theoretic analysis of the TAC market games, by M. Wellman, PR Jordan, C Kiekintveld, J Miller, and DM Reeves. GTDT’06.
- Searching for Walverine 2005, by MPW, DM Reeves, KM Lochner, and R Suri. in Han La Poutre, Norman Sadeh and Sverker Janson (eds.), AMEC’06.

[17] **Computational bidding agents**

- Generating Bayes-Nash equilibria to design autonomous trading agents I. Vetsikas, N. R. Jennings and B. Selman, IJCAI’07
- Mertacor: A Successful Autonomous Trading Agent, Toulis P., Kehagias D., Mitkas P. AAMAS06
III: Dynamic Mechanisms

Challenge: Uncertainty, temporal iss., optim.

[18] Online MD

[19] Online MD as Online Optimization
   ○ Reducing Truth-telling Online Mechanisms to Online Optimization, by B. Awerbuch, Y. Azar, and A. Meyerson, STOC’03.

[20] Set-Nash implementation

[21] OSCO
   ○ Online Stochastic Optimization without Distributions. R. Bent and P. Van Hentenryck. ICAPS’05; ○ The Value of Consensus in Online Stochastic Scheduling, R. Bent and P. Van Hentenryck, ICAPS’04.

[22] Revenue maximization

[23] Adaptive mechanisms
Next class

- Fast-Paced intro to Game Theory!