

# Economics and Computation

## Ad Auctions and Other Stories

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UC Berkeley

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Why mix Economics and Theoretical Computer Science?

*Alan Turing, 1936:*

Introduced the Turing Machine as a tool to understand the limits of *Logic*.



*Image Source: Wikipedia*

*Alan Turing, 1936:*

Introduced the Turing Machine as a tool to understand the limits of *Logic*.

*Looking back...*

The limits of Logic cannot be fully understood *without* computational ideas!



*Image Source: Wikipedia*

*Alan Turing, 1936:*

Introduced the Turing Machine as a tool to understand the limits of *Logic*.

*Looking back...*

The limits of Logic cannot be fully understood *without* computational ideas!

*Economics today:*

Many important questions about complex economic systems **require a computational perspective.**



*Image Source: Wikipedia*

## *Sponsored Search Auctions*

- *First-Price Auctions:*  
How can we design first-price auctions that perform well?
- *Coopetitive Ad Auctions:*  
Recognizing complexity may be important for performance.

## *Market Equilibria*

- *Complexity Equilibria in Markets*  
Computational complexity begets stability.

# The Sponsored Search Auction

# Sponsored Search — History

*A long time ago in a galaxy far, far away...*

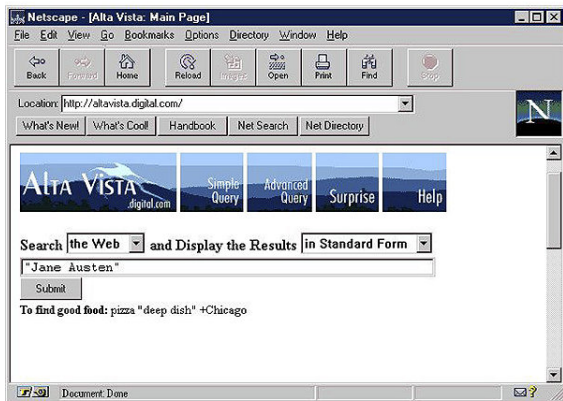


Image Source: Computer History Museum



*Idea:* Willingness to pay is a proxy for relevance and quality.

# Sponsored Search — History

1996: GoTo.com introduces **paid search**.

The screenshot shows the GoTo.com homepage with a yellow background. At the top, there are navigation tabs for "Search", "Shopping", and "Auctions". The "Search" tab is active. On the left is the GoTo logo. In the center is a search bar with the text "Search the Web:" and a "Find It!" button. Below the search bar, it says "Browse our popular search categories:" followed by a grid of category links including Computing, Education & Career, Entertainment, Finance, Health, Homelife, Reference, Shopping, Travel, and Small Business Directory. On the right side, there are sections for "Shopping" (with a shopping bag icon) and "Auctions" (with a gavel icon), each with a brief description and a "GoTo™" link. At the bottom, there is a yellow box with a lightbulb icon and text announcing a traffic increase. The footer contains links for "About GoTo", "Site & Products", "Become a GoTo Affiliate", "Manage Accounts", "Jobs at GoTo", and "Help".

Search Shopping Auctions

GO TO

Search the Web:  Find It!

Browse our popular search categories:

**Computing**  
Web Hosting, Computer Hardware  
Software, Computer Games ...

**Education & Career**  
Job Search, Careers  
Colleges, Arts & Humanities ...

**Entertainment**  
Music, Gambling, Games  
Sports, Movies & TV ...

**Finance**  
Home Finance, Debt, Insurance  
Investing, Personal Finance ...

**Health**  
Women's Health, Men's Health  
Diet & Fitness, Diseases ...

**Homelife**  
Home Improvement, Cooking  
Home Buying, Pets, Gardening ...

**Reference**  
US Govt Agencies, Environment  
History, Lookup, News ...

**Shopping**  
Auto, Sporting Goods, Computers  
Books, Gifts, Electronics ...

**Travel**  
Air Travel, Lodging, US Travel  
Cruises, Adventure Travel ...

**Small Business Directory**  
Marketing, Office Products  
Human Resources, Web Design ...

**Shopping** ▾  
Compare 1,000s of products and  
features side-by-side before you buy.  
[Digital Cameras](#), [Camcorders](#),  
[Laptops](#), [PDAs](#), [Telephones](#)  
[GoTo™ Shopping](#) ▾

**Auctions** ▾  
We search all the best auctions on  
the Web, including eBay, Amazon  
and Yahoo.  
[Playstation](#), [Electronics](#),  
[Toys](#), [Travel Tickets](#)  
[GoTo™ Auctions](#) ▾

**GoTo International**  
  
[United Kingdom](#)

**We've just increased our traffic significantly!**  
Our search results reach 75% of all Internet users  
through our affiliate partner network, which includes  
America Online, Microsoft Internet Explorer,  
EarthLink and we will  
soon be adding Lycos! [List your site now!](#)

[About GoTo](#) | [Site & Products](#) | [Become a GoTo Affiliate](#) | [Manage Accounts](#) | [Jobs at GoTo](#) | [Help](#)

**GoTo International:** [United Kingdom](#)

© 1997-2000 GoTo.com, Inc. All rights reserved. Patent pending.  
[Copyright Act Information](#) | [GoTo Privacy Policy](#) | [Terms of Use](#)

Image Source: Computer History Museum

## *The GoTo.com Model:*

Intel bids \$2 for “INTEL LAPTOP”. When user searches for “INTEL LAPTOP” ...

- Results for “INTEL LAPTOP” **sorted by bid**.
- Intel **pays \$2 if user clicks** on link to `www.intel.com` (pay-per-click, PPC)

# Sponsored Search — History

Today: Ads shown alongside organic results.

The screenshot shows a Google search interface with the query "samsung intel laptop". The search results are displayed in a grid format. On the left side, there is a navigation menu with options like Web, Images, Maps, Videos, News, Shopping, and More. The main content area is divided into two columns. The left column contains organic search results, while the right column contains sponsored search results. The sponsored results are highlighted with red boxes, and the organic results are highlighted with a green box.

**Search** About 56,500,000 results (0.30 seconds)

**Web**

Ads related to samsung intel laptop Why these ads?

**Intel Laptops - The 3rd Gen Intel® Core™ Processors**  
www.intel.com/Laptop  
Get Visibly Smart Performance Today  
375,276 people +113 or follow intel  
Laptops For Home First Level Performance  
Laptops for Extreme Gaming Top of the Line Performance

**Samsung Series 9 w/ Intel | Samsung.com**  
www.samsung.com/Series9Laptop  
Powerful Intel Processing Inside Elegant Design Outside. Get Info  
See Features - See Specs - See Gallery - See Reviews

**Samsung Laptop Sale | Newegg.com**  
www.newegg.com - \$888.99 37,267 seller reviews  
Shop for **Samsung Laptops**. Our Mind Blowing Deals won't last!  
Shop New Ultrabooks - Laptop Accessories - Tablets & Accessories


**Shop for samsung... on Google** Sponsored  
shopping.google.com  
Samsung Series 3 Laptop - Intel Core™ i3 - \$549.00 - Sam's Club Members-Only Pricing at Sam's Club®-Shop Now!  
Samsung 14 In. Notebook - Intel Core™ i3 - \$729.00 - The Home Depot  
Free Shipping on Most Orders Over \$45  
See more shopping results on Google

**Amazon.com: Samsung - Laptop R450 / Intel Pentium Processor / 15.6"**  
www.amazon.com › ... › Computers & Accessories › Laptops  
What's Included \* **Samsung Laptop / Intel® Pentium® Processor / 14" Display / 4GB Memory / 320GB Hard Drive \* 6-cell lithium-ion battery \* 60W adapter ...**

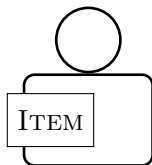
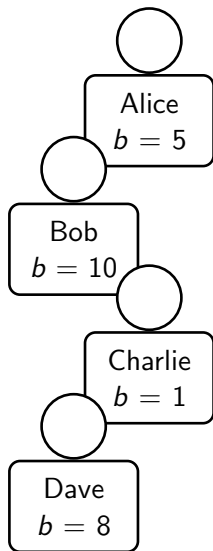
**Samsung - Laptop / Intel® Core™ i3 Processor / 15.6" - Best Buy**  
www.bestbuy.com / -/Samsung-/-Laptops/i/Intel%26%23114...  
**Best Buy - Samsung Laptop / Intel® Core™ i7 Processor / 15.6"**  
reviews.bestbuy.com › ... › Premium Laptops Reviews  
Mar 4, 2011 - Best Buy product reviews and customer ratings for **Samsung Laptop / Intel® Core™ i7 Processor / 15.6" Display / 6GB Memory - Black/Graphite**.

**Samsung ND DF310-600UE Notebook PC - Intel Core i7-720QM**

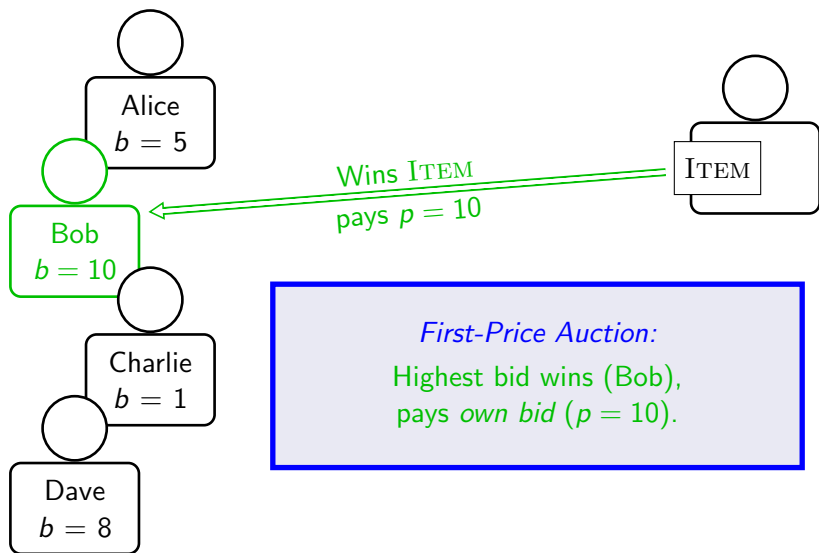
# Sponsored Search — History

- 
- 1996* ● GoTo.com launches first successful search engine with sponsored results.
  - GoTo.com partners with Yahoo!, MSN, AOL, and others to show sponsored results alongside organic ones.
  - 2000* ● Google launches **Adwords** platform
  - 2001* ● GoTo.com changes name to **Overture.com**.
  - 2003* ● Overture purchased by Yahoo!

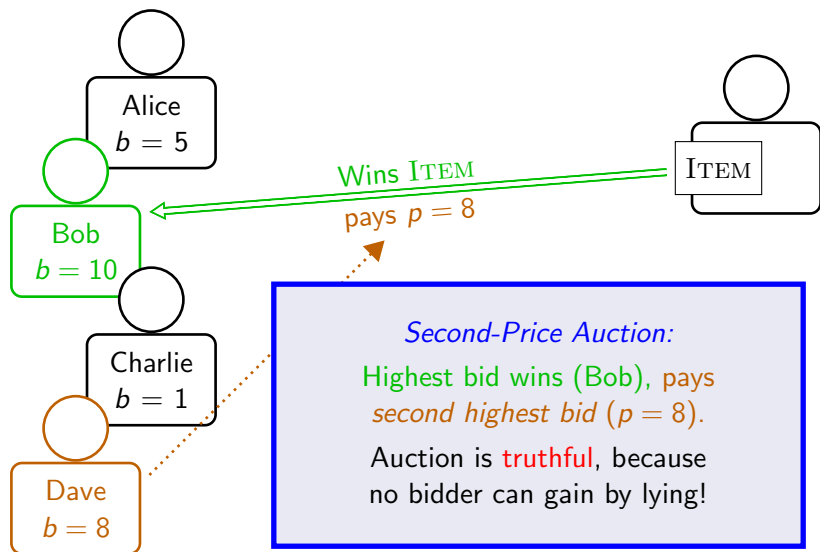
## Aside — Single-Item Auctions



## Aside — Single-Item Auctions



## Aside — Single-Item Auctions





## Aside — The VCG Auction

*Question:* What about truthfulness in complex auctions?

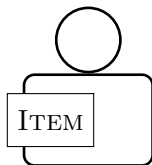
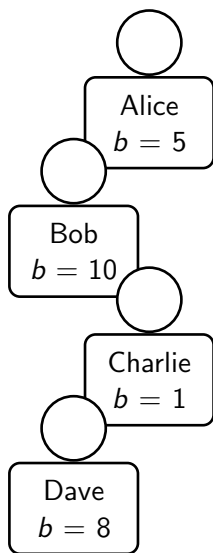
*The Vickrey-Clarke-Groves (VCG) Auction:*

- Pick the socially optimal allocation of goods to bidders.
- Payment is negative externality:

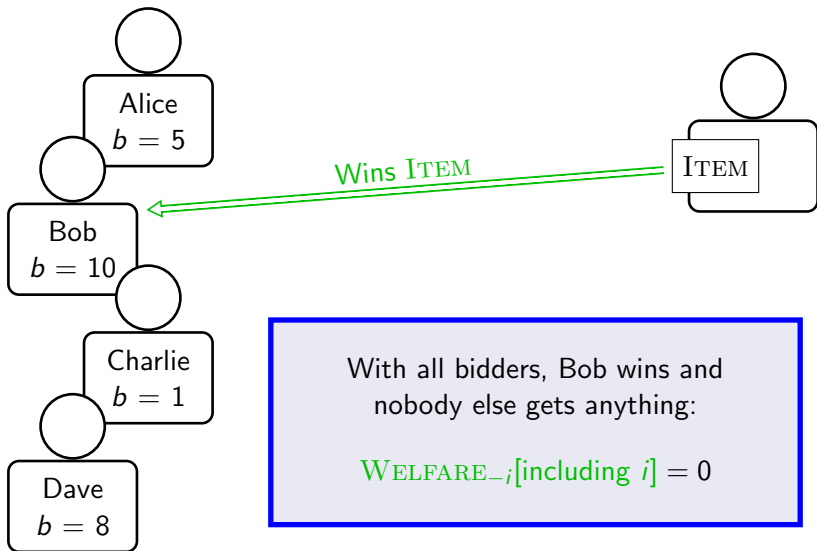
$$p_i = \text{WELFARE}_{-i}[\text{excluding } i] - \text{WELFARE}_{-i}[\text{including } i]$$

$$\left( \text{WELFARE}_{-i} = \sum_{j \neq i} [j\text{'s value for chosen allocation}] \right)$$

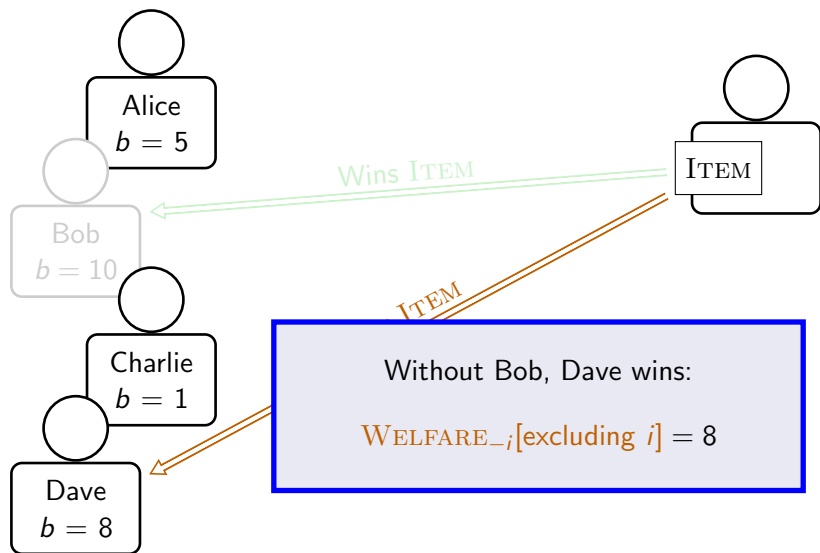
## Aside — The VCG Auction



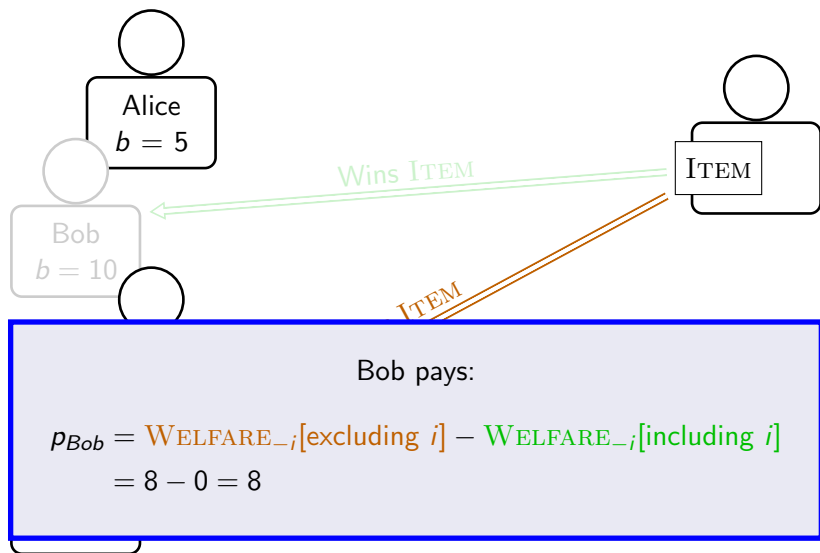
## Aside — The VCG Auction



## Aside — The VCG Auction



## Aside — The VCG Auction



## Sponsored Search — History of the Auction

1996

GoTo.com uses **generalized first-price auction (GFP)** to sell sponsored results. Bids are unstable.

2000

Google's Adwords program sells advertising through **monthly contracts**.

2002

Google introduces **generalized second-price (GSP) auction** for Adwords. Features:

- Results “ranked by revenue.”
- Payment is “next highest bid.”

# Sponsored Search — History of the Auction

## Generalized Second-Price (GSP) Auction:

Company  $i$  bids  $\$b_i$  for QUERY...

- Click-through-rate (CTR) is the likelihood a user clicks on  $i$ 's ad when shown in slot  $j$ :

$$c_{i,j} = \alpha_j \times \beta_i$$

- Expected revenue is

$$R = \sum_i c_{i,j(i)} p_i = \sum_i \alpha_{j(i)} \beta_i p_i$$

- Sort results by  $\beta_i \times b_i$ .
- Per-click payment  $p_i$  is minimum bid required for current rank:

$$p_i = \frac{\beta_{i+1}}{\beta_i} b_{i+1}$$

# Sponsored Search — GSP Example

samsung intel laptop

About 56,500,000 results (0.30 seconds)

Ads related to **samsung intel laptop**

Why these ads?

**Intel Laptops - The 3rd Gen Intel® Core™ Processors**

[www.intel.com/Laptop](http://www.intel.com/Laptop)

Get Visibly Smart Performance Today

375,276 people +1'd or follow Intel

Laptops For Home

First Level Performance

Laptops for Extreme Gaming

Top of the Line Performance

**Samsung Series 9 w/ Intel | Samsung.com**

[www.samsung.com/Series9Laptop](http://www.samsung.com/Series9Laptop)

Powerful Intel Processing Inside Elegant Design Outside. Get Info

See Features - See Specs - See Gallery - See Reviews

**Samsung Laptop Sale | Newegg.com**

[www.newegg.com/](http://www.newegg.com/) - ★★★★★ 37,267 seller reviews

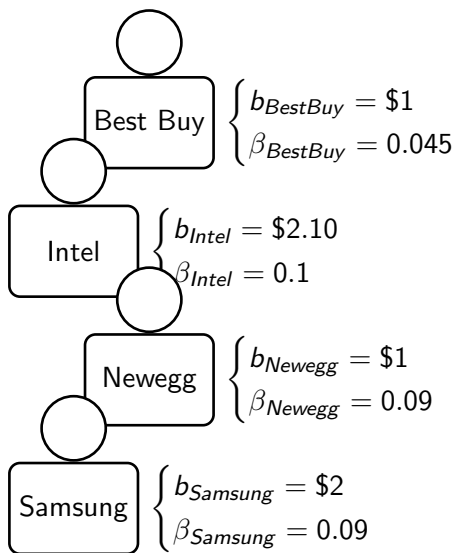
Shop for **Samsung Laptops**. Our Mind Blowing Deals won't last!

Shop New Ultrabooks - Laptop Accessories - Tablets & Accessories

August 7, 2012



# Sponsored Search — GSP Example



Slots

$$\alpha_1 = 0.5$$

$$\alpha_1 = 0.25$$

$$\alpha_1 = 0.10$$

# Sponsored Search — GSP Example

Slots

$$\alpha_1 = 0.5$$

Best Buy

$$\begin{cases} b_{\text{BestBuy}} = \$1 \\ \beta_{\text{BestBuy}} = 0.045 \end{cases}$$

In

*Rank Ads:*

Rank ads by  $\beta \times b$ .

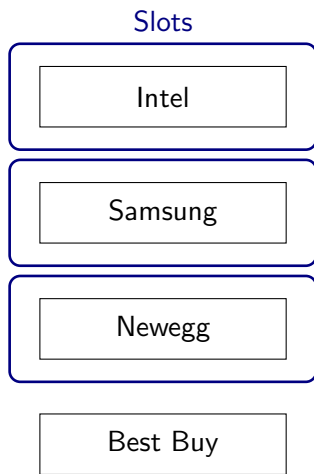
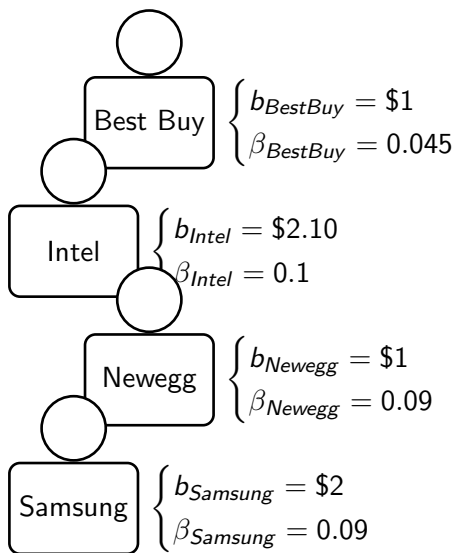
Newegg

$$\begin{cases} b_{\text{Newegg}} = \$1 \\ \beta_{\text{Newegg}} = 0.09 \end{cases}$$

Samsung

$$\begin{cases} b_{\text{Samsung}} = \$2 \\ \beta_{\text{Samsung}} = 0.09 \end{cases}$$

# Sponsored Search — GSP Example



# Sponsored Search — GSP Example

Slots

Best Buy

$$b_{BestBuy} = \$1$$

$$\beta_{BestBuy} = 0.045$$

Intel

*Compute Payments:*

Intel pays minimum bid needed to beat Samsung:

$$p_{Intel} = \frac{\beta_{Samsung}}{\beta_{Intel}} \times b_{Samsung} = \frac{0.09}{0.10} \times 2 = \$1.80$$

Samsung must beat Newegg, etc...

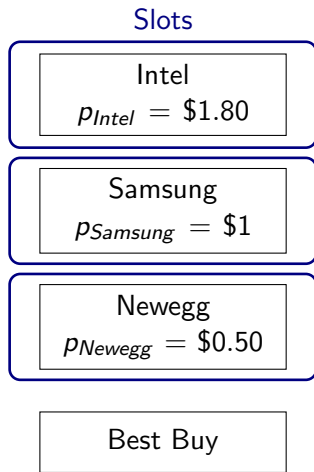
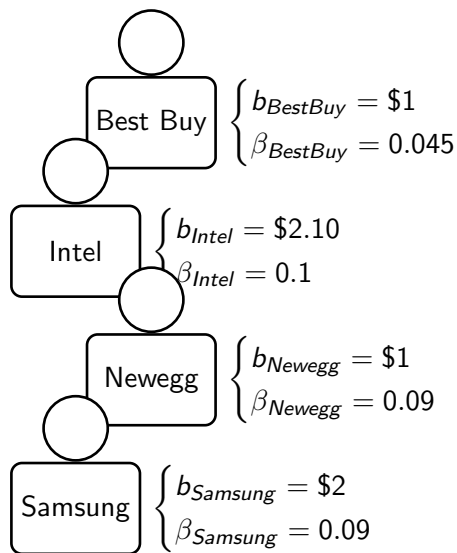
Samsung

$$b_{Samsung} = \$2$$

$$\beta_{Samsung} = 0.09$$

Best Buy

# Sponsored Search — GSP Example



# The Sponsored Search Auction: First-Price Auctions

work with Darrell Hoy and Kamal Jain

# Sponsored Search — First-Price Auctions

*Problem:*

The GFP sponsored search auction is unstable and revenue suffers.

# Sponsored Search — First-Price Auctions

## *Problem:*

The GFP sponsored search auction is unstable and revenue suffers.

## *Solution (Hoy, Jain, and W):*

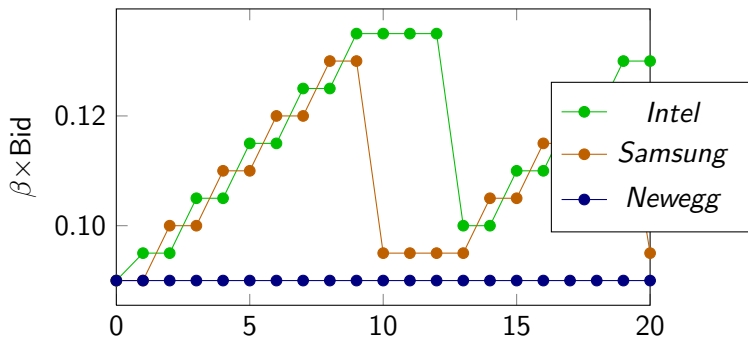
Change the bidding language. Get:

- Strong static performance.
- Dynamic convergence.



# Sponsored Search — First-Price Auctions

*Instability in GFP: a Bidding War*



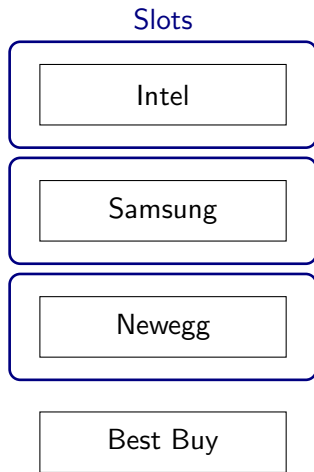
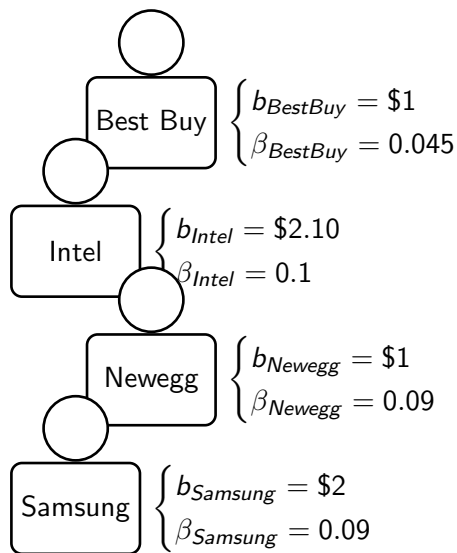
When Intel passes  $\beta_{Intel} \times b_{Intel} = \$0.18$ , Samsung drops its bid...  
...and Intel follows.

# Sponsored Search — First-Price Auctions

*Lahaie 2006, Edelman and Ostrovsky 2007:*

GFP does not have a pure-strategy equilibrium.

# Sponsored Search — GFP Example



# Sponsored Search — GFP Example

## Slots

Intel

$$p_{Intel} = \$2.10$$

Samsung

$$p_{Samsung} = \$2$$

Newegg

$$p_{Newegg} = \$1$$

Best Buy

Best Buy

$$b_{BestBuy} = \$1$$

### Compute Payments:

Intel pays its bid:

$$p_{Intel} = b_{Intel} = \$2.10$$

Samsung also  
pays its bid, etc...

Samsung

$$\begin{cases} b_{Samsung} = \$2 \\ \beta_{Samsung} = 0.09 \end{cases}$$

# Sponsored Search — GFP Example

*Equilibria cannot exist:*

- (a) Samsung must bid minimum to beat Newegg.

45

Slots

Intel

Samsung

$p_{Samsung} = \$1$

Newegg

$p_{Newegg} = \$1$

Best Buy

Samsung

$\beta_{Samsung} = 0.09$

# Sponsored Search — GFP Example

*Equilibria cannot exist:*

- (a) Samsung must bid minimum to beat Newegg.
- (b) Intel must bid minimum to beat Samsung.

45

Slots

Intel

$$p_{Intel} = \$0.90$$

Samsung

$$p_{Samsung} = \$1$$

Newegg

$$p_{Newegg} = \$1$$

Best Buy

Samsung

$$\beta_{Samsung} = 0.09$$

# Sponsored Search — GFP Example

*Equilibria cannot exist:*

- (a) Samsung must bid minimum to beat Newegg.
- (b) Intel must bid minimum to beat Samsung.
- (c) Given (a) and (b), Samsung should raise its bid to beat Intel.

Slots

Intel

$$p_{Intel} = \$0.90$$

Samsung

$$p_{Samsung} = \$1$$

Newegg

$$p_{Newegg} = \$1$$

Best Buy

Samsung

$$\beta_{Samsung} = 0.09$$

# Sponsored Search — First-Price Auctions

*Lahaie 2006, Edelman and Ostrovsky 2007:*

GFP does not have a pure-strategy equilibrium.

*Consequence:*

Some bidder always has an incentive to change her bid.

*Edelman and Ostrovsky 2007:*

VCG would generate more revenue than sawtooth behavior.



# Sponsored Search — First-Price Auctions

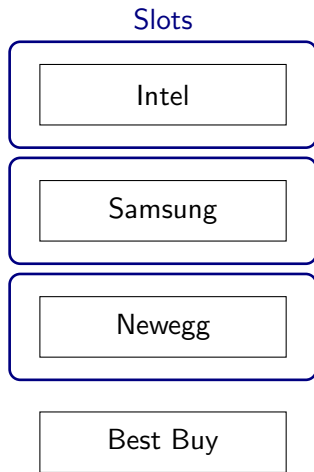
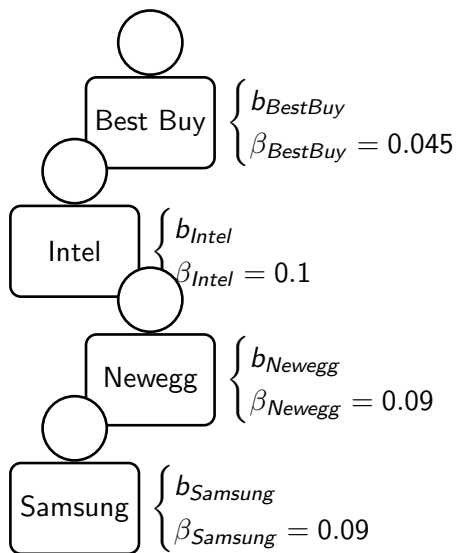
*Observation:*

Equilibria exist if advertisers can place complex bids.

*For example...*

Pure-strategy equilibria exist if advertisers can place a separate bid for each slot. (e.g. Bernheim and Whinston 1986)

# Sponsored Search — GFP Example



# Sponsored Search — GFP Example

Slots

Intel

Samsung

Newegg

Best Buy

Best Buy

$b_{BestBuy}$

*A Pure NE:*

|       | Intel  | Samsung | Newegg |
|-------|--------|---------|--------|
| $b_1$ | \$1.80 | \$2     | \$1    |
| $b_2$ | \$0    | \$1     | \$1    |
| $b_3$ | \$0    | \$0     | \$0.5  |

Samsung

$D_{Samsung}$

$\beta_{Samsung} = 0.09$

# Sponsored Search — First-Price Auctions

*Question:*

How complex must the bidding language be?

*Hoy, Jain, and W:*

Language only needs to encode a bidder's per-click value  $v_i$  and the final utility  $\pi_i$  she requests.

# Sponsored Search — First-Price Auctions

## Definition (Utility-Target Ad Auction)

*Bids:* Player  $i$  bids  $(x_i, \pi_i)$

- $x_i$  represents per-click value
- $\pi_i$  represents target utility

*Payments:* For each slot assignment  $j(i)$ , define payments:

$$p_i = \max \left( x_i - \frac{\pi_i}{\alpha_{j(i)}\beta_i}, 0 \right)$$

*Outcome:* Choose the ranking that maximizes revenue:

$$\operatorname{argmax}_{j(\cdot)} \sum_i \alpha_{j(i)}\beta_i p_i .$$

# Sponsored Search — First-Price Auctions

## Definition (Utility-Target Auction)

*Bids:* Player  $i$  bids  $(x_i, \pi_i)$

- $x_i \in V_i$  represents player  $i$ 's valuation function
- $\pi_i \in \mathfrak{R}^+$  represents target utility

*Payments:* For each outcome  $o$  define payments:

$$p_i(o) = \max(v_i(o) - \pi_i, 0)$$

*Outcome:* Choose the outcome  $o^*$  that maximizes revenue:

$$o^* = \operatorname{argmax}_o \sum_i p_i(o) .$$

*Note:*  $u_i(o) = v_i(o) - p_i(o) = \min(\pi_i, v_i(o))$

# Sponsored Search — First-Price Auctions

## *Question:*

Why do we need  $\pi_i$ ? The bid  $(x_i, \pi_i)$  specifies a payment function  $p_i(o)$ , so why is it not enough to consider bids of the form  $(p_i, 0)$ ?

## *Answer:*

It may not be possible to bid  $(p_i, 0)$ , e.g. GFP requires that  $x_i$  represent the same value for a click on each slot, whereas  $p_i$  can encode different payments (values) for each slot.

# Sponsored Search — First-Price Auctions

## Definition (Quasi-truthfulness)

A utility-target auction is *quasi-truthful* if  $i$  never has an incentive to misreport her valuation, i.e. to report  $x_i \neq v_i$ .

## Theorem (Hoy, Jain, and W)

For any bid  $(x_i, \pi_i)$  that generates utility  $u_i$ , the bid  $(v_i, u_i)$  also generates utility  $u_i$ .

As a consequence, *the utility-target auction is quasi-truthful.*



# Sponsored Search — First-Price Auctions

## Definition (Cooperative Envy-Freeness (CEF))

A set of payments  $p_i(o)$  and an outcome  $o^*$  are *cooperatively envy-free (CEF)* if no coalition is collectively willing to increase bids so an alternate outcome  $o$  wins, i.e.

$$\sum_i \max((v_i(o) - p_i(o)) - (v_i(o^*) - p_i(o^*)), 0) \leq \sum_i p_i(o^*) - p_i(o)$$

for all outcomes  $o$ .

*Remark:* This weaker than equilibrium concepts like strong Nash equilibrium, group strategyproofness, the core, etc.

# Sponsored Search — First-Price Auctions

## Theorem (Hoy, Jain, and W)

*Every utility-target auction has a quasi-truthful CEF pure-strategy equilibrium. Any such equilibrium...*

- is efficient (maximizes bidder welfare), and*
- has revenue at least as large as the VCG mechanism.*

*Remark:* This is analogous to profit-target bidding in package auctions (Bernheim and Whinston 1986, Milgrom 2004,...).

# Sponsored Search — First-Price Auctions

## *Issue:*

The utility-target auction generalizes...

...but beating VCG may not mean much.

## *VCG's Downfall:*

I have a plot of land to sell two ways:

- Alice is willing to pay \$20k.
- Bob, Charlie, and Dave are willing to pay \$33k total (\$11k each) and share the property.

Since B/C/D wins even if one person drops out, VCG charges \$0.

# Sponsored Search — First-Price Auctions

*The Second-Price Threat Benchmark:*

$$\gamma = \max_o \sum_i \max(v_i(o) - v_i(o^*), 0)$$

*Idea:* How much would bidders be willing to pay (in total) to ensure that  $o$  was chosen instead of  $o^*$ ? (e.g. \$20k)

Theorem (Hoy, Jain, and W)

*Revenue of the utility-target auction in any envy-free equilibrium is at least  $\gamma$ .*

# Sponsored Search — First-Price Auctions

*Is equilibrium a credible prediction?*

Yes, by a dynamic argument!

*Dynamic Properties of Bidder Behavior:*

- 1 A “loser” will only decrease the utility she requests.  
A “winner” will only increase the utility she requests.
- 2 A loser will always try to raise her bid.
- 3 Losers are less patient than winners.
- 4 A loser’s patience is inversely related to her requested utility.

Theorem (Hoy, Jain, and W)

- (1)-(2)  $\Rightarrow$  bids eventually exceed revenue benchmarks.
- (1)-(4)  $\Rightarrow$  bids converge to the egalitarian equilibrium.

# Sponsored Search — First-Price Auctions

## *Lessons:*

- The complexity of bids is important:
  - Bids may be more complex than valuations...
  - ...but need not be too much more complex.
- Simple properties of bidder behavior have implications for convergence and revenue.

## *Open Questions:*

- What happens when properties (1)-(4) are relaxed?
- Does bidder behavior satisfy properties (1)-(4)?

# The Sponsored Search Auction: Coopetitive Ad Auctions

work with Darrell Hoy and Kamal Jain

# Sponsored Search — Coopetitive Ad Auctions

*Question:* What's wrong with this picture?

samsung intel laptop

About 56,500,000 results (0.30 seconds)

Ads related to **samsung intel laptop**

Why these ads?

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[www.intel.com/Laptop](http://www.intel.com/Laptop)

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Laptops For Home

First Level Performance

Laptops for Extreme Gaming

Top of the Line Performance

**Samsung Series 9 w/ Intel | Samsung.com**

[www.samsung.com/Series9Laptop](http://www.samsung.com/Series9Laptop)

Powerful Intel Processing Inside Elegant Design Outside. Get Info

See Features - See Specs - See Gallery - See Reviews

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[www.newegg.com/](http://www.newegg.com/) - ★★★★★ 37,267 seller reviews

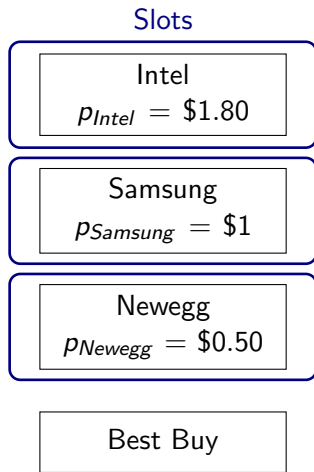
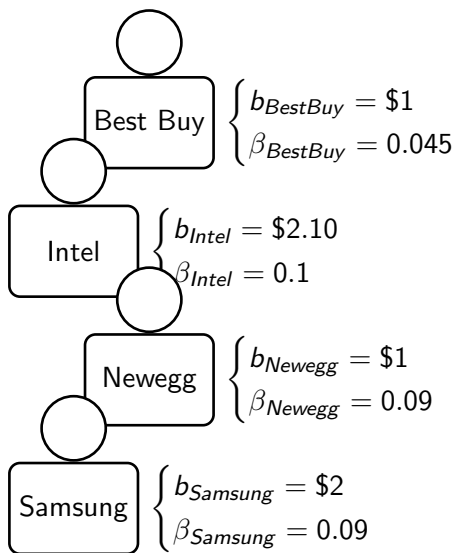
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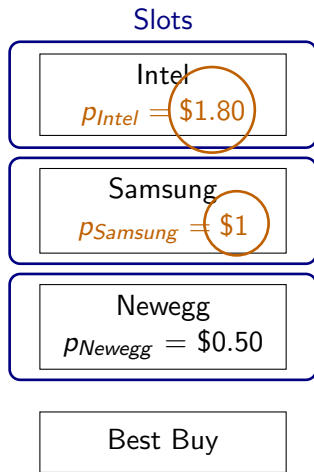
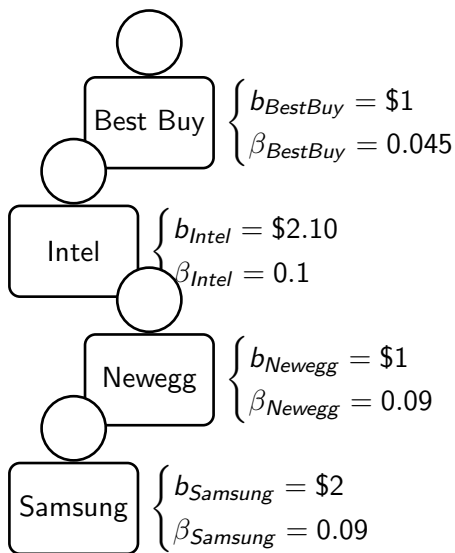
August 7, 2012



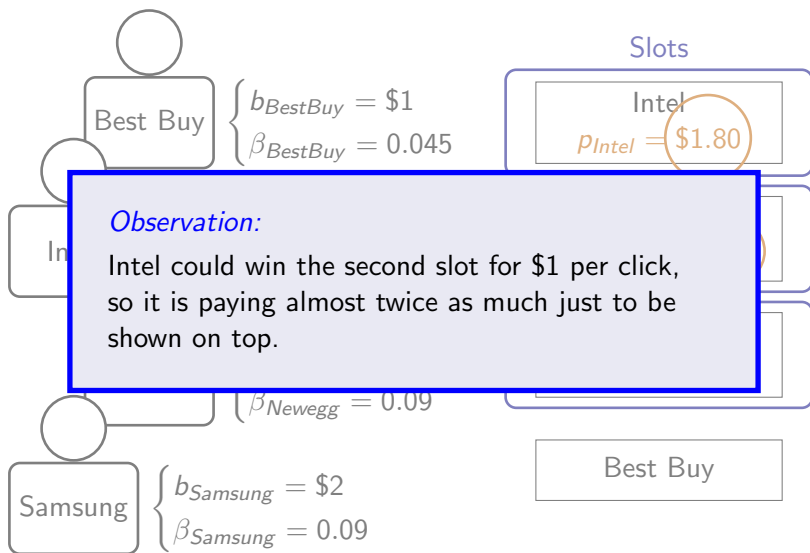
# Sponsored Search — GSP Example



# Sponsored Search — GSP Example



# Sponsored Search — GSP Example



# Sponsored Search — Coopetitive Ad Auctions

*Answer:* Intel paid too much!

samsung intel laptop

About 56,500,000 results (0.30 seconds)

Ads related to **samsung intel laptop**

Why these ads?

**Intel Laptops - The 3rd Gen Intel® Core™ Processors**

[www.intel.com/Laptop](http://www.intel.com/Laptop)

Get Visibly Smart Performance Today

375,276 people +1'd or follow Intel

Laptops For Home

First Level Performance

Laptops for Extreme Gaming

Top of the Line Performance

**Samsung Series 9 w/ Intel | Samsung.com**

[www.samsung.com/Series9Laptop](http://www.samsung.com/Series9Laptop)

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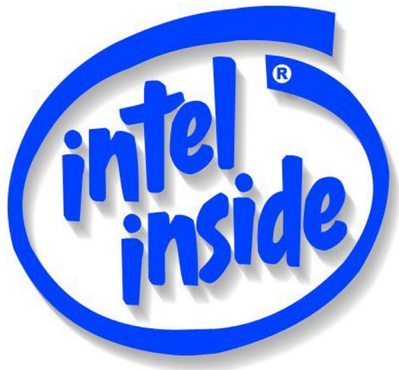
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# Sponsored Search — Cooperative Ad Auctions



# Sponsored Search — Cooperative Ad Auctions

## *Intel Inside:*

Intel pays fraction of advertising costs...

...as long as the advertiser includes “Intel Inside” branding.

# Sponsored Search — Coopetitive Ad Auctions

Is this part of “Intel Inside”?

samsung intel laptop

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# Sponsored Search — Cooperative Ad Auctions

*If this is Intel Inside...*

Intel will pay some of Samsung's costs...

...so Samsung bids higher...

...so Intel's payment goes up!



# Sponsored Search — Coopetitive Ad Auctions

*Answer 2:* Intel may be competing with itself!

samsung intel laptop

About 56,500,000 results (0.30 seconds)

Ads related to **samsung intel laptop**

[Why these ads?](#)

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# Sponsored Search — Cooperative Ad Auctions

## *Cooperative Advertising:*

Estimated \$15B spent in 2000 in US alone. (Nalger 2006)

## *Prior work...*

Modeled as Stackelberg game, upstream manufacturer (e.g. Intel) is first-mover. (survey by He et al. 2007)

## *New question:*

How should an advertising platform sell ads when a single ad can benefit many advertisers?

# Sponsored Search — Cooperative Ad Auctions

## *Goal:*

Auction format that maintains **competition** between ads while encouraging **cooperation** within a single ad.

...i.e. we want **coopetition**.

# Sponsored Search — Cooperative Ad Auctions

## *Possible Solutions:*

Keep the status quo...

...but **we show cooperation may fall apart, hurting performance.**

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*Open Question:* Better solutions?

# Complexity Equilibria

work with Christos Papadimitriou



# Complexity Equilibria

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An equilibrium is stable because nobody can benefit by deviating.

# Complexity Equilibria

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## *Question:*

Are there “pseudo-equilibria” that are stable because it is too hard to find a good deviation?

## *Papadimitriou and W (2011):*

...in markets with economies of scale in production, yes!

# Complexity Equilibria

## Definition (Market Equilibrium, paraphrased)

A *market equilibrium* is a set of prices where supply equals demand when people selfishly optimize their own behavior.

# Complexity Equilibria

## Definition (Market Equilibrium, paraphrased)

*A market equilibrium is a set of prices where supply equals demand when people selfishly optimize their own behavior.*

## Theorem (First Welfare Theorem)

*In market equilibrium, it is impossible to make one person happier without hurting someone else.*

- This is called **Pareto efficiency**.
- Pareto efficiency is the gold standard for acceptable economic outcomes.

# Complexity Equilibria

## *Issue:*

Arrow and Debreu proved that equilibria always exist assuming *no* economies of scale.

...with economies of scale, equilibria may not exist.

## *Guessnerie (1975):*

Can we at least achieve Pareto Efficiency through a decentralized process?

# Complexity Equilibria

## *Observation:*

Pareto efficiency is a notion of stability where a “good deviation” means improving for someone without hurting anyone.

...i.e. a **Pareto improvement**.

## Theorem (Papadimitriou and W, 2011)

*In a family of markets with economies of scale in production, there exist **complexity equilibria** from which it is NP-hard to compute a Pareto improvement.*

## *Proof Intuition:*

A factory may produce cars or TV's, but cannot produce both well, i.e. **producers may face discrete choices**.

*Abstract Interpretation:*

NP-hardness implies it is intractable to determine whether a Pareto-improvement exists...



*Abstract Interpretation:*

NP-hardness implies it is intractable to determine whether a Pareto-improvement exists...

...so what?

# Complexity Equilibria

*Economies of scale are huge...*

Google, Facebook, Microsoft, etc. have huge economies of scale, and the internet is just making them bigger.

*Startups...*

Startups try to solve

$$\text{NEXTBIGTHING}(x) = \text{TRUE} .$$

Startups spring up all the time, surviving if they achieve sufficient scale.

# Complexity Equilibria

## *Lessons:*

- Complexity theory (NP-hardness) gives us a generalization of stability.
- Economies of scale are real, and may lead to complexity equilibria.

## *Open Question:*

Can we demonstrate complexity equilibria in real settings, like startups or power markets?

## Conclusion

## *Sponsored Search Auctions*

- *First-Price Auctions:*  
A more complex bidding language improves stability, and dynamic arguments offer alternative performance guarantees.
- *Coopetitive Ad Auctions:*  
Recognizing complexity may be important for performance.

## *Market Equilibria*

- *Complexity Equilibria in Markets*  
Computational complexity begets stability.

Thank You.