YAHOO! Research

The Automated Economy

Case Studies: Advertising and Finance

David M. Pennock

Yahoo!

Economics and computation

- Two faces of **economics**

  - ***Analysis*** of economic behavior
    Why Yahoo!?: Scale + data make possible entirely new science
  - ***Design*** of economic mechanisms
    Why Yahoo!?: Ad systems, Commerce, Community Incentives

- And now a third
  - ***Computation***: Internet infrastructure, Massive Scale, Optimization, Machine Learning/Stats, Comp. Complexity

How is automation happening?

- Phase 0: Invention, manual execution

Auctions

Advertising

Finance

WALL STREET

bookstores, banks, grocery stores, ...

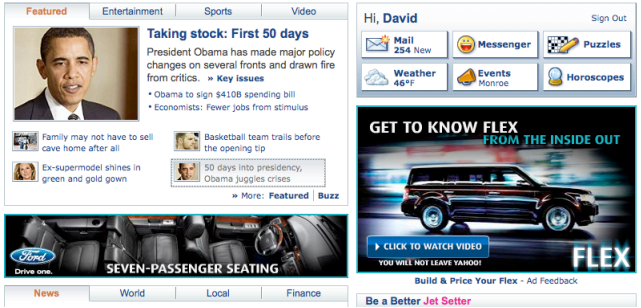
How is automation happening?

- Phase 1: Computers mimic it

(Cheaper, faster)

Auctions

Advertising



Finance

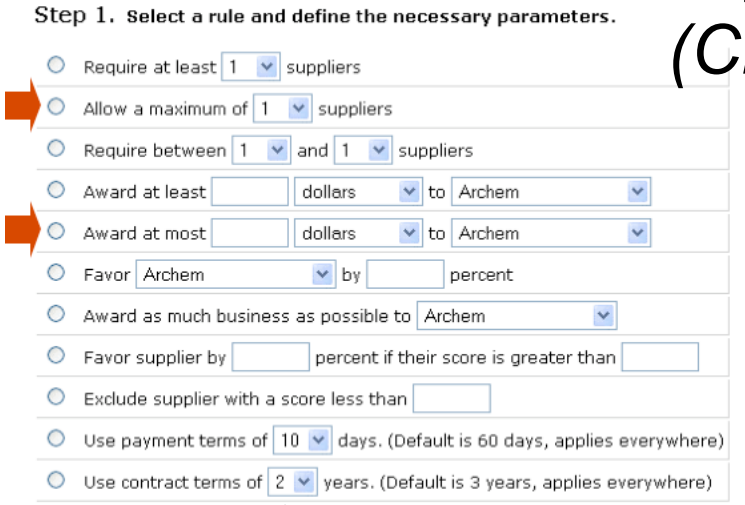
ECN

Amazon, ATMs, auto checkout, ...

How is automation happening?

- Phase 2: Computers improve it

(Cheaper, faster, better)



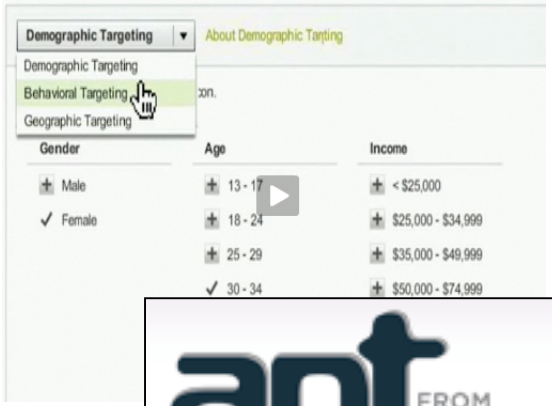
Auctions

COMBINENET

Expressive auctions for chemicals, packaging, ingredients, technology, services, medical, transport, materials, ...

Source: Sandholm, T. "Expressive Commerce and Its Application to Sourcing: How We Conducted $35 Billion of Generalized Combinatorial Auctions." *AI Magazine*, 28(3): 45-58, 2007

Advertising



apt FROM YAHOO!

Finance

weatherbill

custom Amazon, e-banking, RFID, ...

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Two stories of automation

Advertising

- Designed for analog media, manual negotiation
- Phase 1: Replicate model online
- Phase 2: Replace with optimization engine
- **Linear programming**

Finance

- CDA: Uber-hammer: used everywhere
  -- Designed for people
- Phase 1: Replicate CDA in a computer
- Phase 2: Replace with optimization engine
- **Linear programming**

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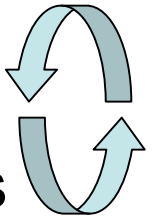
Evolution of advertising

- Phase 0: Broadcast media. Real estate on page/screen/billboard. Phone calls, negotiation. “Half doesn’t work”
- Phase 1: Online media. Mimic broadcast. Add targeting and measurement.
- Phase 2: Computer optimization
  - Advertisers buy *contextual events*: User i [attributes] views/clicks/converts on page j [attributes] at time t
  - Computer... learns what ad is best
    ...mediates ad sales: Auction
    ...measures clicks and conversions



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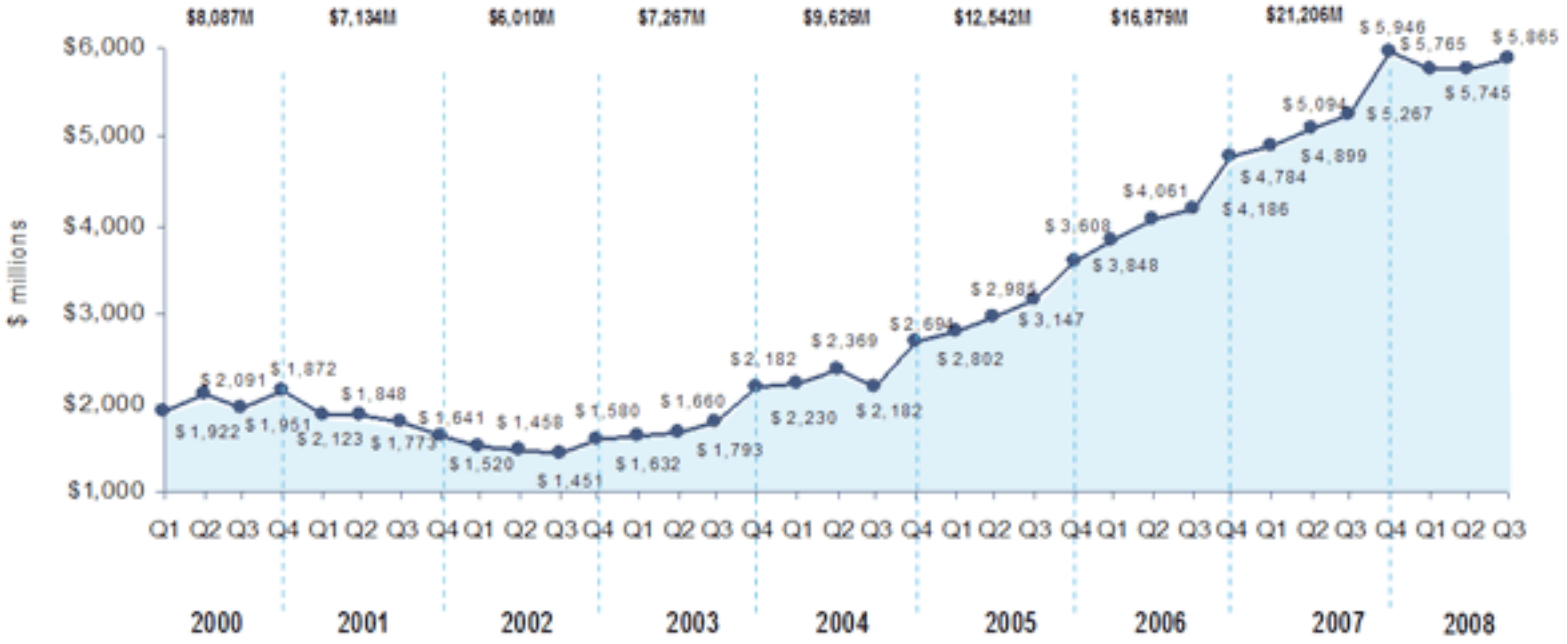
Online advertising revenue



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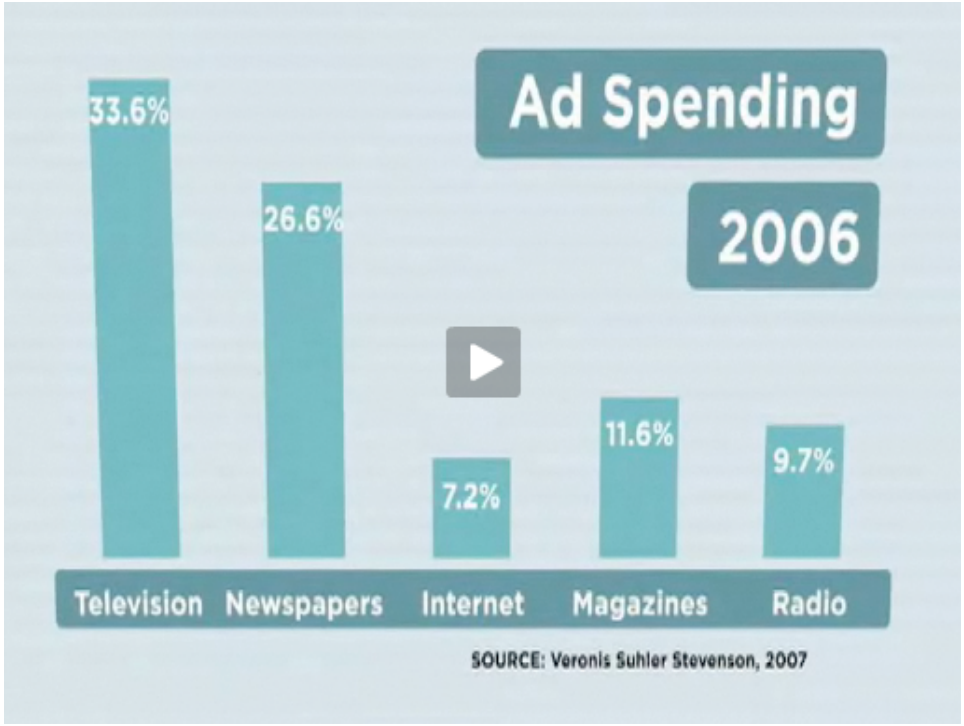
Online advertising share



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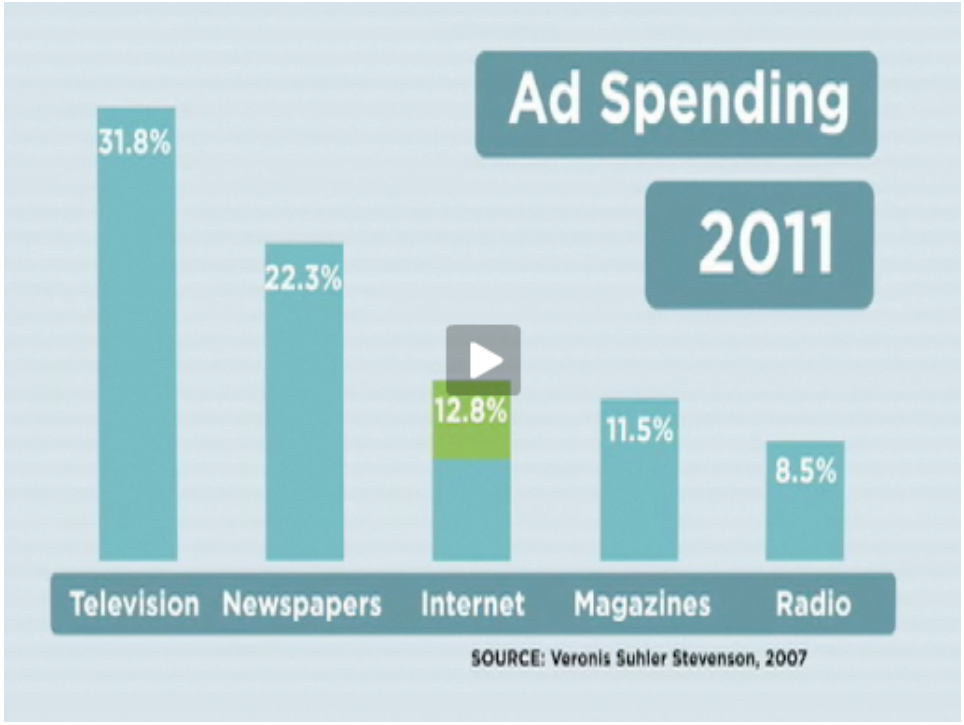
Online advertising share



http://apt.yahoo.com/apt_showcase_video_player.php?type=publisher

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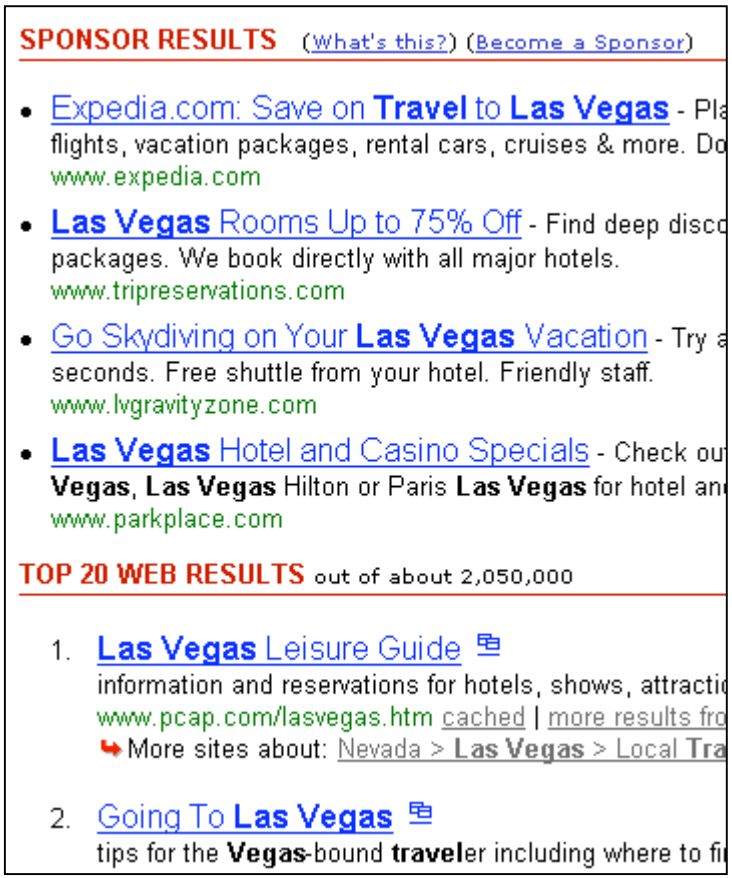
Two examples

1. **Sponsored search advertising**
   Spot market: real time
2. **Display advertising**
   Forward market: demand constraints; batch processing

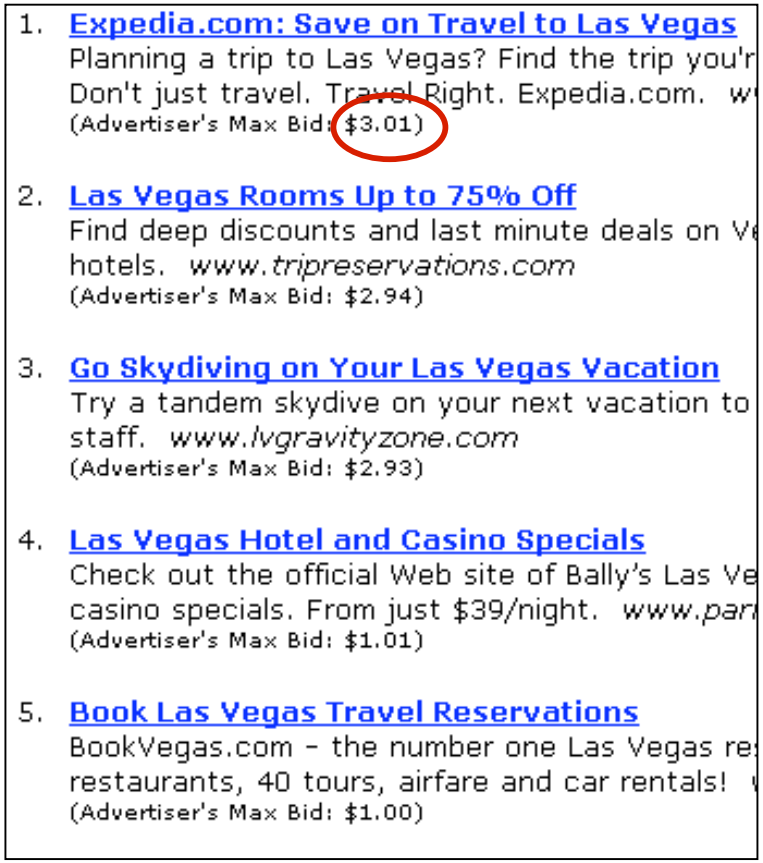
Example: YAHOO! SEARCH MARKETING

Space next to search results is sold at auction

search “las vegas travel”, Yahoo!



“las vegas travel” auction



YAHOO!

Example: YAHOO! SEARCH MARKETING

Space next to search results is sold at auction

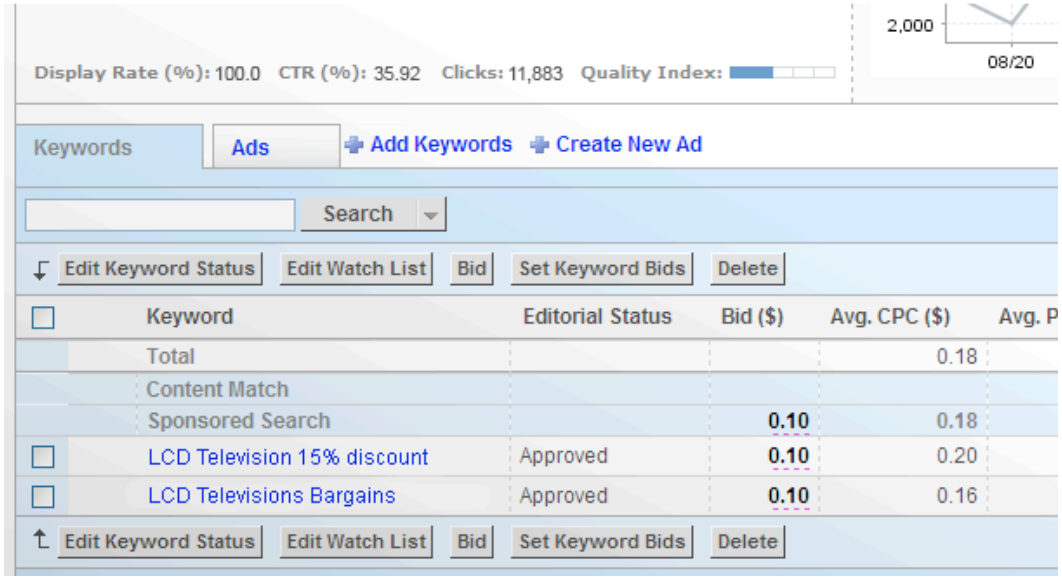
search “las vegas travel”, Yahoo!

SPONSOR RESULTS (What's this?) (Become a Sponsor)

- Expedia.com: Save on **Travel** to **Las Vegas** - Pla
  flights, vacation packages, rental cars, cruises & more. Do
  www.expedia.com
- **Las Vegas** Rooms Up to 75% Off - Find deep disco
  packages. We book directly with all major hotels.
  www.tripreservations.com
- Go Skydiving on Your **Las Vegas** Vacation - Try a
  seconds. Free shuttle from your hotel. Friendly staff.
  www.lvgravityzone.com
- **Las Vegas** Hotel and Casino Specials - Check ou
  Vegas, **Las Vegas** Hilton or Paris **Las Vegas** for hotel an
  www.parkplace.com

TOP 20 WEB RESULTS out of about 2,050,000

1. **Las Vegas** Leisure Guide
   information and reservations for hotels, shows, attracti
   www.pcap.com/lasvegas.htm cached | more results fro
   More sites about: Nevada > **Las Vegas** > Local Tra
2. Going To **Las Vegas**
   tips for the **Vegas**-bound **travel**er including where to fi



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Sponsored search auctions

- Search engines auction off space next to search results, e.g. “digital camera”
- Higher bidders get higher placement on screen
- Advertisers pay per click: Only pay when users click through to their site; don’t pay for uncliked view (“impression”)

Sponsored search auctions

- Sponsored search auctions are dynamic and continuous: In principle a new “auction” clears for each new search query
- Prices can change minute to minute; React to external effects, cyclical & non-cyc
  - “flowers” before Valentines Day
  - Fantasy football
  - People browse during day, buy in evening
  - Vioxx

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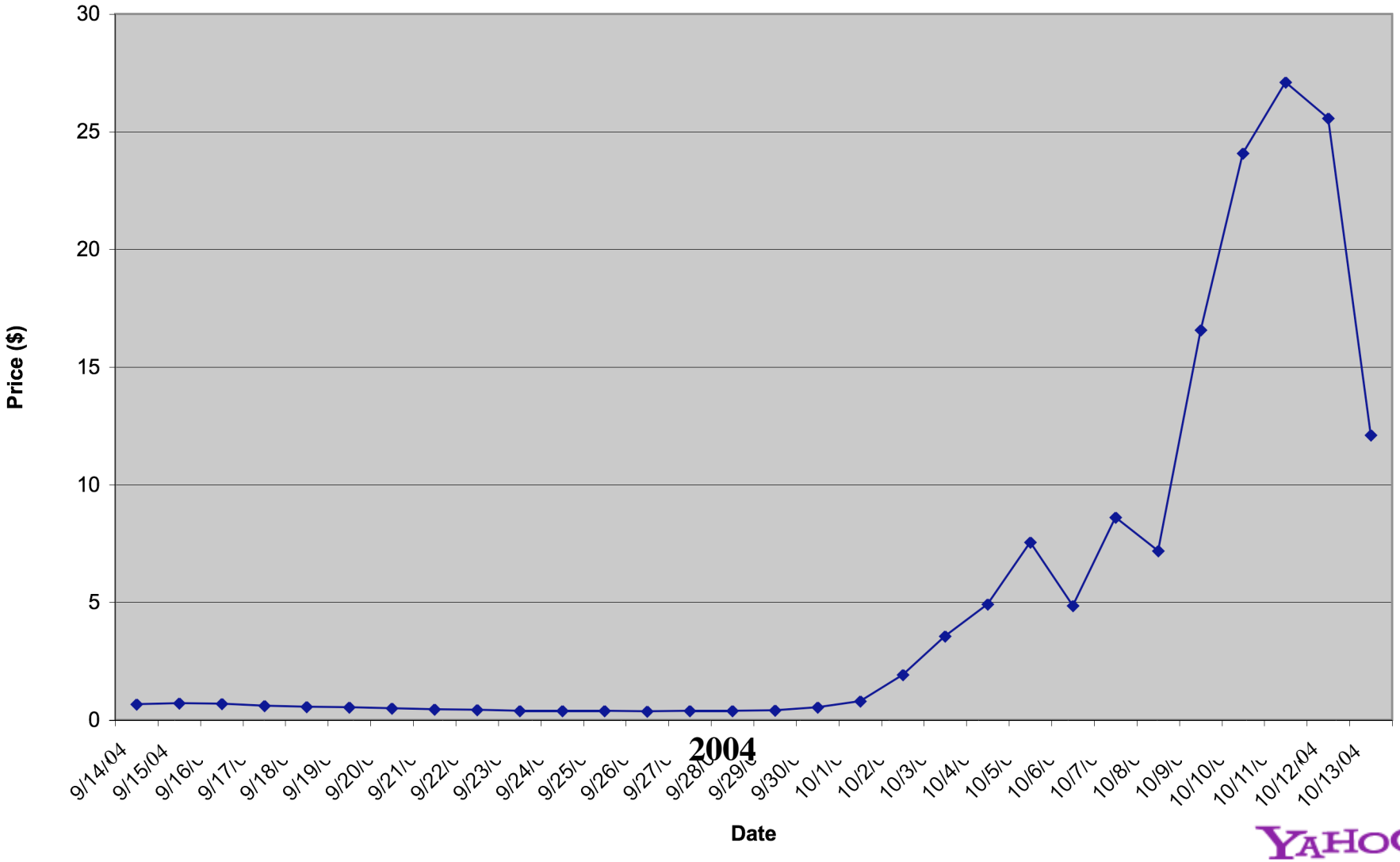
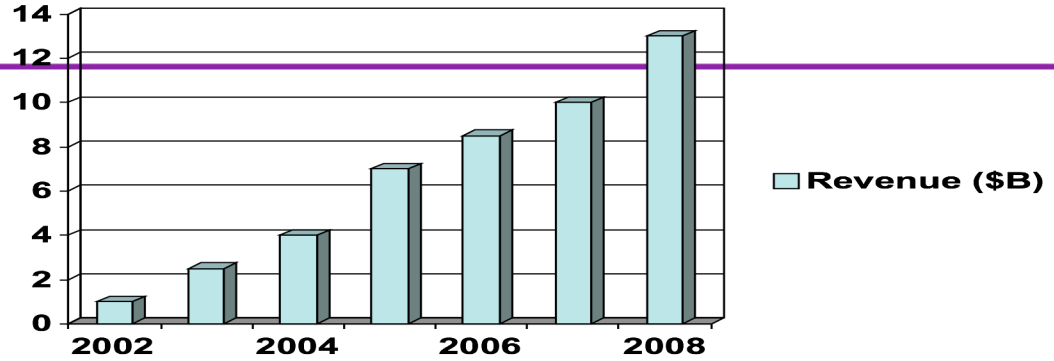
Example price volatility: Vioxx



Sponsored search industry



- >$10 billion 2008 US ad revenue (40% of US online ads; 2% of all US ads)
- Resurgence in web search, web advertising
- Online advertising spending still trailing consumer movement online
- For many businesses, substitute for eBay
- Like eBay, mini economy of 3rd party products & services: SEO, SEM

Ranking and pricing

- Ranking
  - Rank by decreasing bid * click-weight
    ("expected bid per impression")
- Pricing
  - Pay "next price": Min price to keep you in current position

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Ranking

"las vegas travel" auction

= "relevance"

1. **Expedia.com: Save on Travel to Las Vegas**
   Planning a trip to Las Vegas? Find the trip you'r
   Don't just travel. Travel Right. Expedia.com. w
   (Advertiser's Max Bid: $3.01) x clickw =E[bid/imp]

2. **Las Vegas Rooms Up to 75% Off**
   Find deep discounts and last minute deals on Ve
   hotels. *www.tripreservations.com*
   (Advertiser's Max Bid: $2.94) x clickw =E[bid/imp]

3. **Go Skydiving on Your Las Vegas Vacation**
   Try a tandem skydive on your next vacation to
   staff. *www.lvgravityzone.com*
   (Advertiser's Max Bid: $2.93) x clickw =E[bid/imp]

4. **Las Vegas Hotel and Casino Specials**
   Check out the official Web site of Bally's Las Ve
   casino specials. From just $39/night. *www.par*
   (Advertiser's Max Bid: $1.01) x clickw =E[bid/imp]

5. **Book Las Vegas Travel Reservations**
   BookVegas.com - the number one Las Vegas re
   restaurants, 40 tours, airfare and car rentals!
   (Advertiser's Max Bid: $1.00) x clickw =E[bid/imp]

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Ranking

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   Planning a trip to Las Vegas? Find the trip you'r
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   (Advertiser's Max Bid: $3.01) x .1 = .301

2. **Las Vegas Rooms Up to 75% Off**
   Find deep discounts and last minute deals on Ve
   hotels. *www.tripreservations.com*
   (Advertiser's Max Bid: $2.94) x .2 = .588

3. **Go Skydiving on Your Las Vegas Vacation**
   Try a tandem skydive on your next vacation to
   staff. *www.lvgravityzone.com*
   (Advertiser's Max Bid: $2.93) x .1 = .293

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   Check out the official Web site of Bally's Las Ve
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   (Advertiser's Max Bid: $1.01) x E[CTR] = E[RPS]

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   (Advertiser's Max Bid: $1.00) x E[CTR] = E[RPS]

search "las vegas travel"

TripReservations

pays 3.01*.1/.2+.01 = 1.51 per click

Expedia

pays 2.93*.1/.1+.01 = 2.94

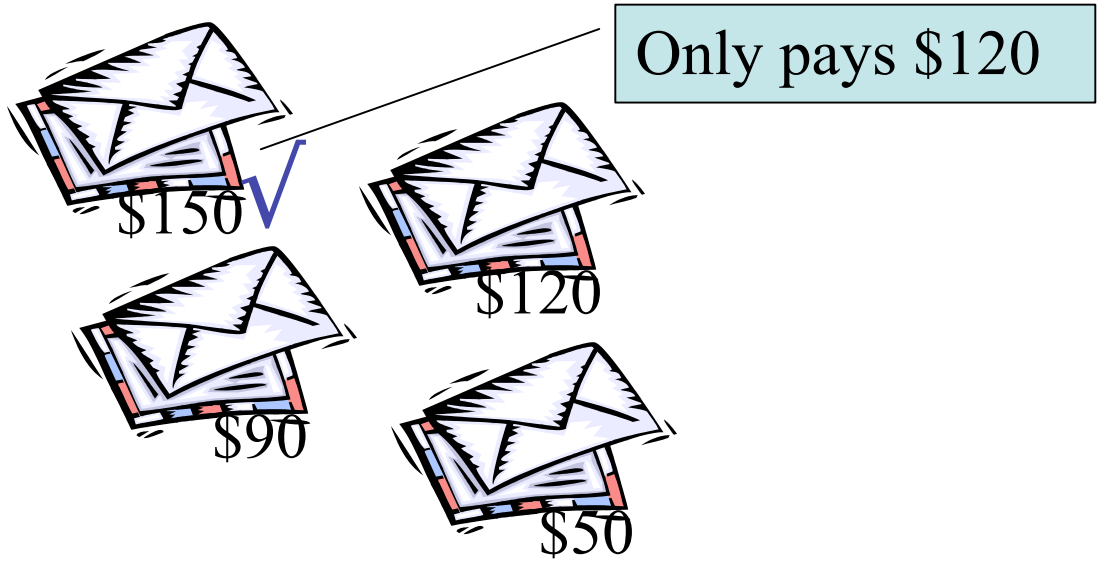
LVGravityZone

etc...

pays $bid_{i+1} * w_{i+1} / w_i + .01$

Aside: Second price auction (Vickrey auction)

- All buyers submit their bids privately
- buyer with the highest bid wins; pays the price of the *second* highest bid



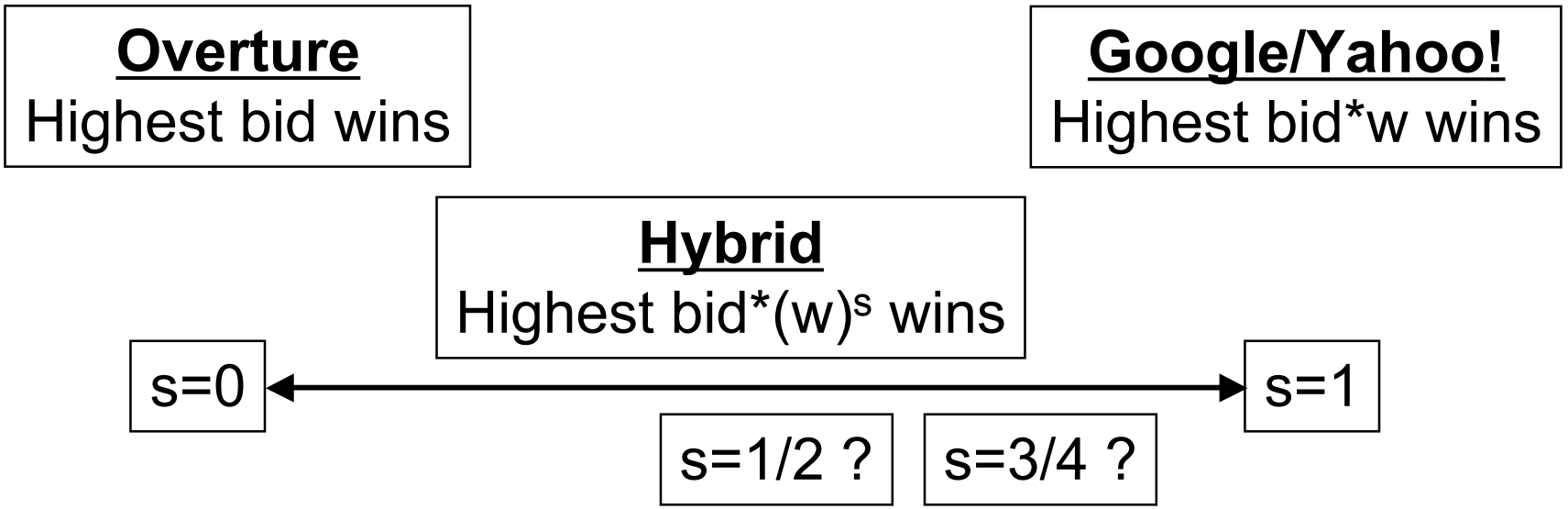
Incentive Compatibility (Truthfulness)

- Telling the truth is *optimal* in second-price (Vickrey) auction
- Suppose your value for the item is $100;
  if you win, your net gain (loss) is $100 - price
- If you bid more than $100:
  - you increase your chances of winning at price >$100
  - you *do not* improve your chance of winning for < $100
- If you bid less than $100:
  - you reduce your chances of winning at price < $100
  - there is *no effect* on the price you pay if you do win
- Dominant optimal strategy: bid $100
  - Key: the price you pay is out of your control
- Vickrey's Nobel Prize due in large part to this result

Is next-price auction truthful?

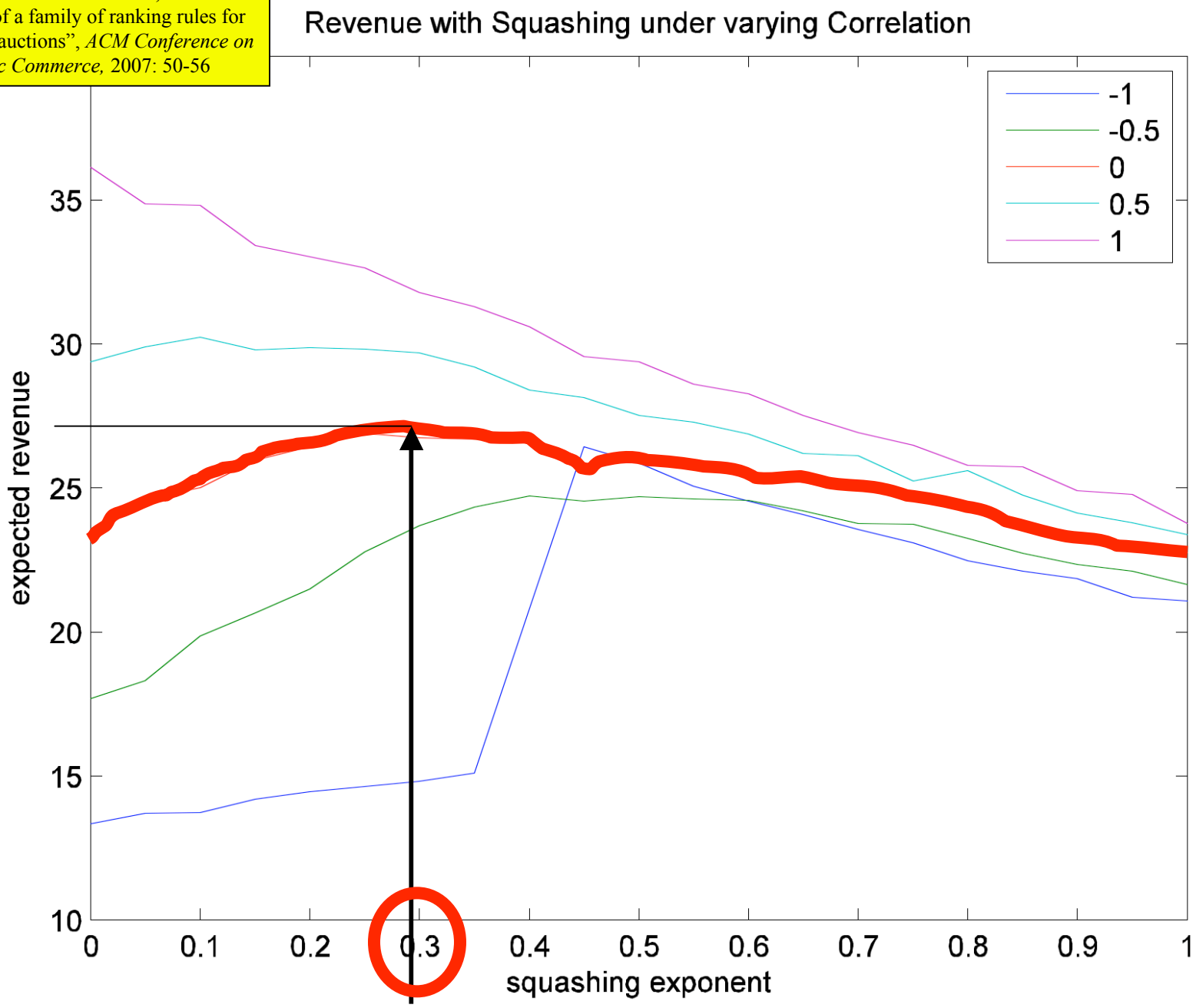
- No!
- One can generalize Vickrey auction to multiple items (VCG), but it's not "next price"
- If bidders aren't truthful, how can we model their behavior?: Nash equilibrium
- **Locally envy-free equilibrium** [Edelman, Ostrovsky, Schwarz 2005]
  Symmetric equilibrium [Varian 2006]
  Fixed point where bidders don't want to move ↑ , ↓

Rank by revenue ?=? Highest revenue



- What gives most **revenue**?
  - **Key**: If rules change, advertiser bids will change
  - Use Edelman et al. **envy-free equilibrium** solution

Source: Lahaie and Pennock, "Revenue analysis of a family of ranking rules for keyword auctions", *ACM Conference on Electronic Commerce,* 2007: 50-56



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Two examples

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   Forward market: demand constraints; batch processing

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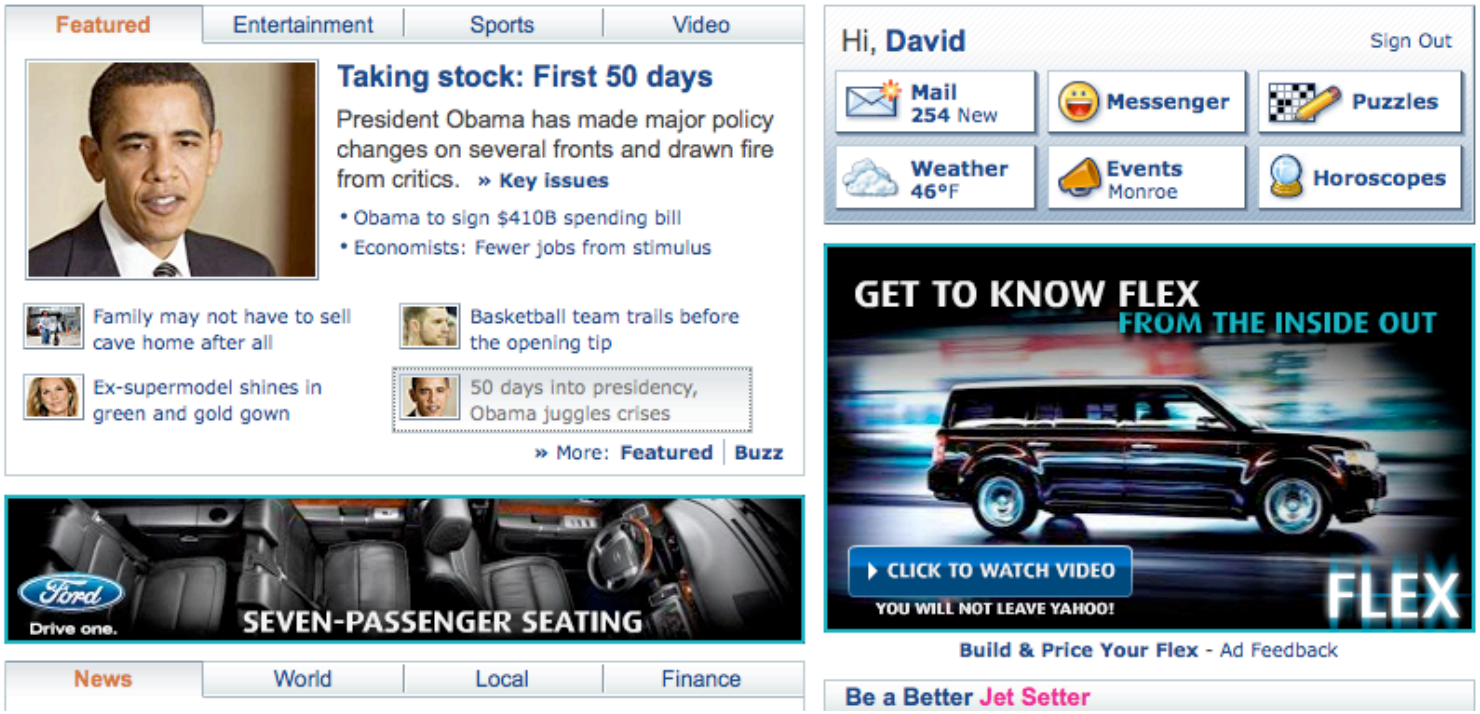
Display advertising

- Targeting criteria
- Minimum delivery requirements



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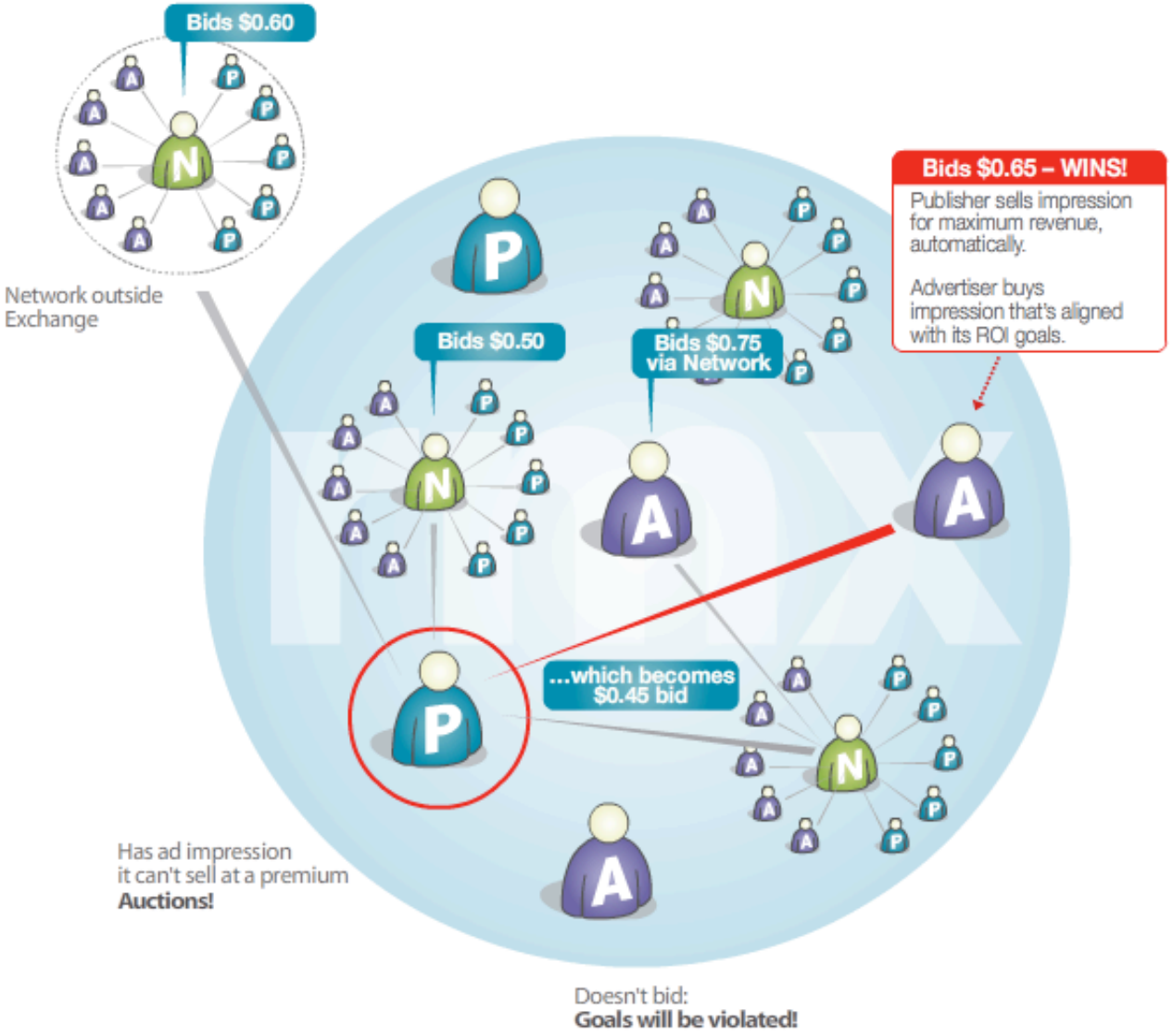
Evolution of online advertising

- Direct: Publishers sell owned & operated (O&O) inventory
- Ad networks: Big publishers place ads on affiliate sites, share revenue
  - Google AdSense, Y!PN, Ad.com, Doubleclick
- Ad exchanges: Match buy orders from advertisers with sell orders from publishers and ad networks
- Gray distinction

Example: Yahoo! Right Media



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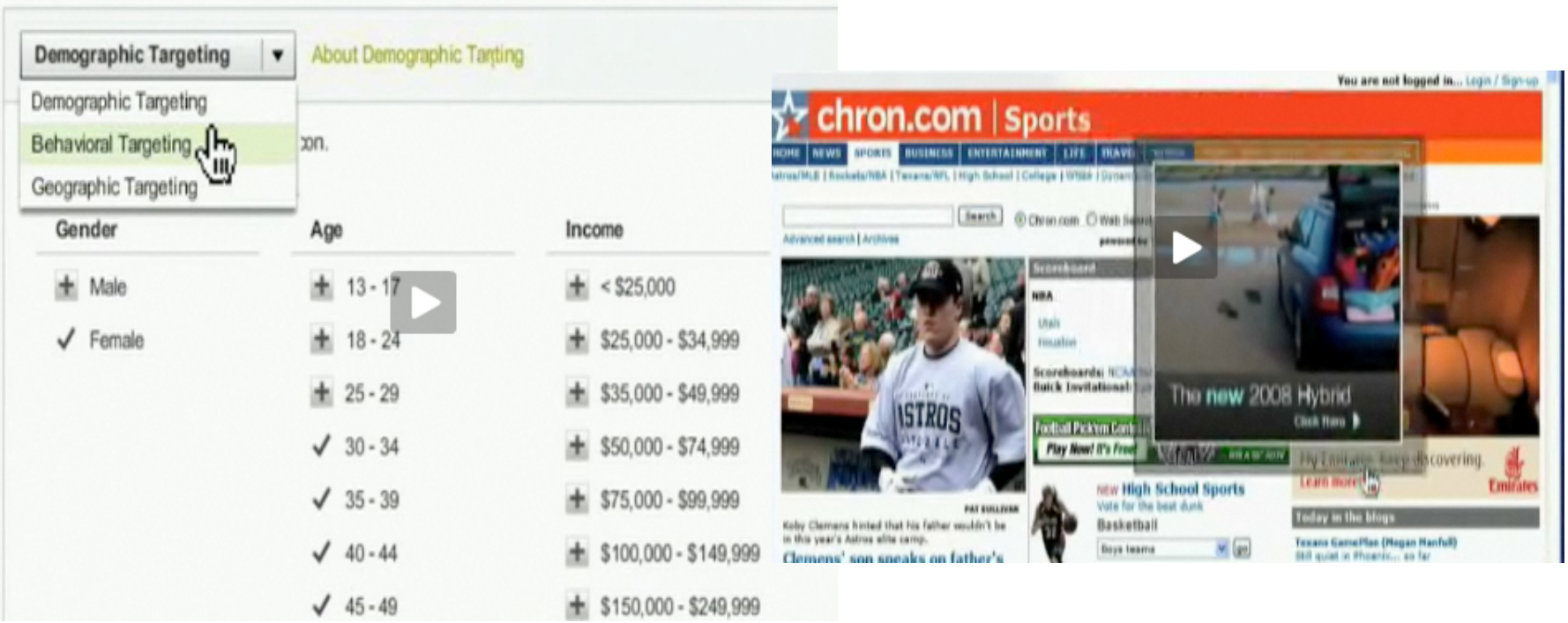
Example: apt FROM YAHOO!



http://apt.yahoo.com/apt_showcase_video_player.php?type=publisher

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Targeting criteria

- User attributes
  - Gender
  - Age
  - Income
  - Interests
  - Behavior
- Time attributes
  - workday/evening
  - weekday/weekend
  - month/season
- Content attributes
  - URL/domain
  - Topic (sports)
  - Words on page
  - Typical users
- Opportunity attributes
  - Impression
  - Click
  - Conversion

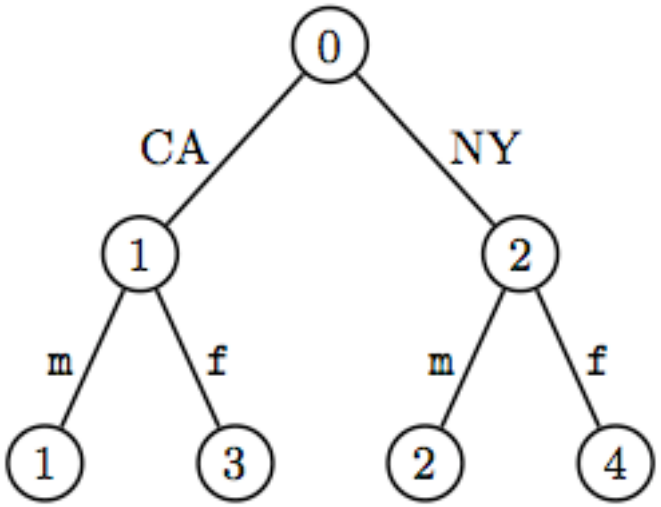
Expressiveness

- “I’ll pay 10% more for Males 18-35”
- “I’ll pay $0.05 per impression, $0.25 per click, and $5.25 per conversion”
- “I’ll pay 50% more for exclusive display, or w/o Acme”
- “My marginal value per click is decreasing/increasing”
- “Never/Always show me next to Acme”
  “Never/Always show me on adult sites”
  “Show me when Amazon.com is 1st algo search result”
- “I need at least 10K impressions, or none”
- “Spread out my exposure over the month”
- “I want three exposures per user, at least one in the evening”

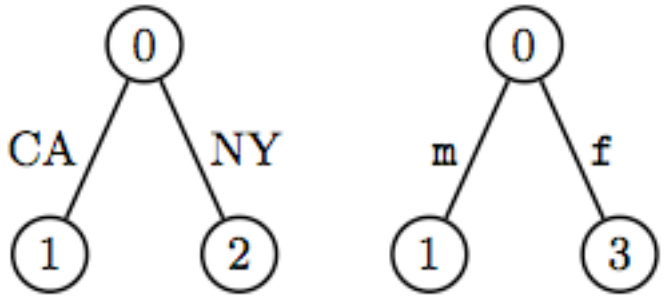
Design parameters: Advertiser needs/wants, computational/cognitive complexity, Y! revenue

Tree-based bidding

- Tree structure



- Forest (additive)



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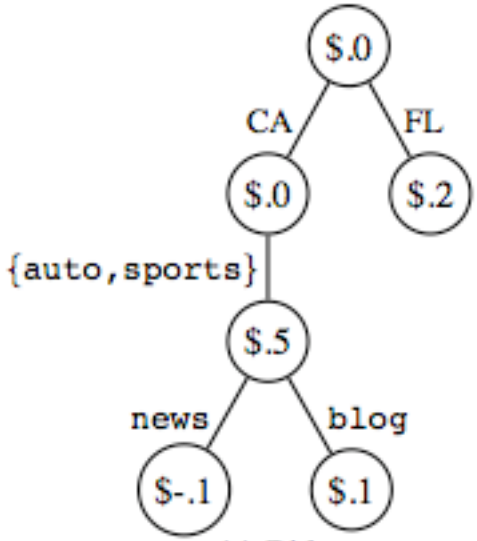
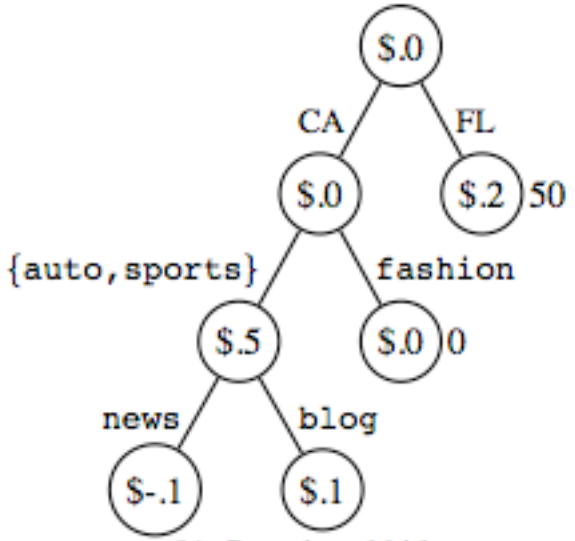
Tree-based bidding

- With demand constraints



(a) Bid tree.



(b) Capacitated bid tree.

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Efficiency

- Static checking for logical errors
- Allocation depends on network interpretation: How to convert values on individual contextual events to values on bundles?
  - Greedy online allocation (sponsored search, ad exchange model)
  - Volume constraints only => Polynomial time
    See: Lahaie et al., "An Expressive Auction Design for Online Display Advertising", *National Conference on Artificial Intelligence*, 2008
    Linear programming
  - Budget constraints only => Polynomial time
    See Vazirani

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Machine learning inner loop

- Optimal allocation (ad-user match) depends on: bid, E[clicks], E[sales], relevance, ad, advertiser, user, context (page, history), ...
- Expectations must be learned
- Learning in dynamic setting requires exploration/exploitation tradeoff
- Mechanism design must factor all this in! Nontrivial.

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- CDA: Uber-hammer: used everywhere
  -- Designed for people
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Continuous Double Auction

Uber-Hammer of the Financial World

- Buy offers

ACME stock

$150

$120

$90

$50

- Sell offers

$300

$170

$160

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Continuous Double Auction

Uber-Hammer of the Financial World

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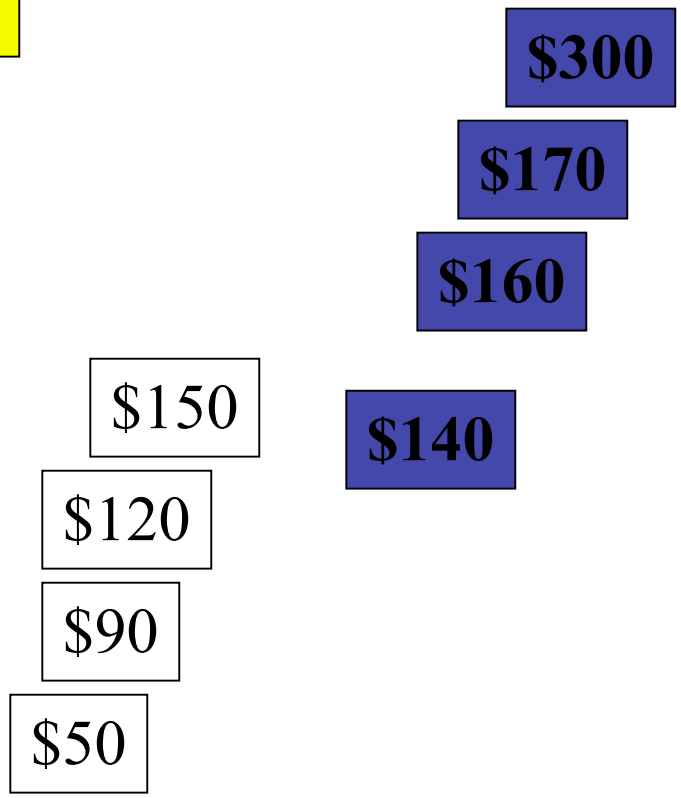

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Continuous Double Auction

Uber-Hammer of the Financial World

- Buy offers

ACME stock

price = $150

✓ $150

$120

$90

$50

- Sell offers

$300

$170

$160

$140 ✓ Winning traders

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Continuous Double Auction

Uber-Hammer of the Financial World

- Buy offers

ACME stock

$120

$90

$50

- Sell offers

$300

$170

$160

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Continuous Double Auction

Uber-Hammer of the Financial World

- Used everywhere
  - Stocks, options, futures, derivatives
  - Gambling: BetFair, InTrade
- Related bets? Just use two CDAs
  - Max[YHOO-10], Max[YHOO-20]
  - Horse wins, Horse finishes 1st or 2nd
  - “Power set” instruments: Mutual funds, ETFs, butterfly spreads, “Western Conference wins”
  - Treats everything like apples and oranges, even ‘fish’ and ‘fish and chips’

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Continuous Double Auction

Uber-Hammer of the Financial World

- CDA was invented when auctioneers were people
- Had to be dead simple
- Today, auctioneers are computers...

- ...Yet CDA remains the standard

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A Prediction Market

- **Take a random variable, e.g.**

  2009 one of five warmest years?
  (Y/N)

- **Turn it into a financial instrument payoff = realized value of variable**

I am entitled to:			
$1 if	2009 among 5 warmest	$0 if	not among 5 warmest

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intrade™ The Prediction Market

http://intrade.com

Climate and Weather - Global Temperatures

2009 Global Average Temperature

Contract		Bid	Ask	Last	Vol	Chge
2009.GLOBALTEMP.TOP5 Average Global Temperature for 2009 to be among five warmest years on record	Trade	8.0	10.0	11.0	122	0

Jun 08 - 4:38PM IST

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Prediction Markets

With Money

?	Contract	B Qty	Bid	Ask	A Qty	Last	Vol	Chge
Trade	US.RECESSION.08	1	72.2	73.9	2	74.0	34.9k	+3.0
Trade	BIRDFLU.USA.JUN08	100	6.0	14.0	5	10.0	1323	0
Trade	BIRDFLU.USA.SEP08	10	6.5	16.0	5	11.2	430	0

?	Contract	B Qty	Bid	Ask	A Qty	Last	Vol	Chge
Trade	OSAMA.CAPTURE.MAR08	5	1.9	3.3	1	2.6	4888	0
Trade	OSAMA.CAPTURE.JUN08	4	5.1	5.7	25	5.5	2019	0
Trade	OSAMA.CAPTURE.SEP08	5	8.3	8.8	4	9.1	822	0

?	Contract	B Qty	Bid	Ask	A Qty	Last	Vol	Chge
Trade	2008DEM.NOM.OBAMA	22	71.8	72.0	55	72.0	403.0k	-1.3
Trade	2008DEM.NOM.CLINTON	50	28.5	28.9	4	28.9	549.1k	+1.1

?	Contract	B Qty	Bid	Ask	A Qty	Last	Vol	Chge
Trade	ALABAMA.DEM	0	-	10.0	20	10.0	56	0
Trade	ALABAMA.REP	20	90.0	95.0	5	90.0	22	0
Trade	ALABAMA.FIELD	5	0.1	5.0	20	0.1	0	0
Trade	ALASKA.DEM	20	5.0	10.0	17	7.5	23	0
Trade	ALASKA.REP	20	85.0	95.0	20	92.5	45	0
Trade	ALASKA.FIELD	5	0.1	5.0	20	0.1	0	0

intrade™ The Prediction Market

Without

Androids Beat Humans in Soccer (BOTS)

Will a team of androids beat the human World Cup champs at a game of soccer by 2050?

Price: POP$ 47.75 **Status:** ACT

Fuel-Cell-Powered Laptop (FCELL)

Will the first fuel-cell-powered laptop go on sale in the U.S. by the end of 2008?

Price: POP$ 43.75 **Status:** ACT

Barack Obama will be the Democratic Presidential Nominee in 2008

PPX THE POPSCI PREDICTIONS EXCHANGE

newsfutures

Combinatorial market: Like Ordering a Wendy's Hamburger

- Informal definition: A *combinatorial market* is one where users construct their own bets by mixing and matching options in myriad ways
- Wendy's bags circa March 2008: *"We figured out that there are 256 ways to personalize a Wendy's hamburger. Luckily someone was paying attention in math class."*

Example: weatherbill

at weather do you need to protect against?

Select a Contract
Pick the contract that best suits your needs

Rainy Day

Description

A Rainy Day Contract will pay you a specified amount for every day that the precipitation level is above a specified threshold.

Choose Dates of Coverage

06/30/08 to 07/04/08 including weekends and weekdays
(5 days)

Select Location
(please read disclaimer)

USA
postal/zip code
find weather station
or NJ - Atlantic City Intl AP

Choose Payment Terms

Pay me USD 100.00 for every day when the precipitation level is above 0.5 inches.
Only start paying me after 0 rainy days, and pay me a maximum amount of 500.00.

Price

$42.62 BUY NOW

Year	Payout	Year	Payout
2007	$0	1992	$0
2006	$0	1991	$0
2005	$100	1990	$0
2004	$0	1989	$0
2003	$100	1988	$0
2002	$0	1987	$100
2001	$100	1986	$100
2000	$100	1985	$0
1999	$0	1984	$0
1998	$0	1983	$0
1997	$0	1982	$100

YAHOO!

Example: March Madness

YAHOO! Research

Example: March Madness

- Typical today Non-combinatorial
  - Team wins Rnd 1
  - Team wins Tourney
  - A few other "props"
  - Everything explicit (By def, small #)
  - Every bet indep: Ignores logical & probabilistic relationships
- Combinatorial
  - *Any* property
  - Team wins Rnd k
    Duke > {UNC,NCST}
    ACC wins 5 games
  - $2^{2^{63}}$ possible props (implicitly defined)
  - 1 Bet effects related bets "correctly"; e.g., to enforce logical constraints

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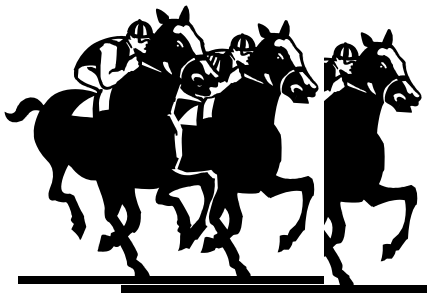
Example: Ranking

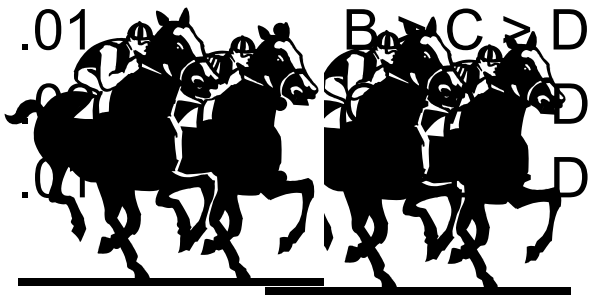
- A > B > C .1
- A > C > B .2
- B > A > C .1
- B > C > A .3
- C > A > B .1
- C > B > A .2



YAHOO! Research

Example: Ranking

- D > A > B > C .01
- D > A > C > B .02
- D > B > A > C .01
- A > D > B > C .01
- A > D > C > B .02
- B > D > A > C .05
- A > B > D > C .01
- A > C > D > B .2
- B > A > D > C .01
- A > B > C > D .01
- A > C > B > D .0
- B > A > C > D .0
- D > B > C > A .05
- D > C > A > B .1
- D > C > B > A .2
- B > D > C > A .03
- C > D > A > B .1
- C > D > B > A .02
- B > C > D > A .03
- C > A > D > B .01
- C > B > D > A .02
- B > C > D > A .03
- D > B .01
- D > A .02



Example: Ranking

- Traders want to bet on *properties* of orderings, not explicitly on orderings: more natural, more feasible
  - A will win ; A will “show”
  - A will finish in [4-7] ; {A,C,E} will finish in top 10
  - A will beat B ; {A,D} will both beat {B,C}
- *Buy 6 units of “$1 if A>B” at price $0.4*
- Supported to a limited extent at racetrack today, but *each in different betting pools*
- Want centralized auctioneer to improve liquidity & information aggregation

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[Thanks: Yiling Chen]

Automated market maker

- An *auctioneer* only matches buyers & sellers: never takes on any risk. CDA is an example.
- An *automated market maker* is always willing to accept both buy and sell orders at some prices
- Why an institutional market maker? Liquidity!
  - Without market makers, the more expressive the betting mechanism is the less liquid the market is (few exact matches)
  - Illiquidity discourages trading: Chicken and egg
  - Subsidizes information gathering and aggregation: Circumvents no-trade theorems
- Market makers bear risk. But smart pricing algorithms can bound the loss of market makers
  - Market scoring rules [Hanson 2002, 2003, 2006]
  - Family of bounded-loss market makers [Chen & Pennock 2007]
  - Dynamic pari-mutuel market [Pennock 2004]

Combinatorial Bids vs. Combinatorial Outcomes

- Combinatorial *bids*
  - Bundling: “Western conference will win”, “Gas prices between 1.75-2.50”
  - If bids are divisible, almost no disadvantage: use **linear programming**
- Combinatorial *outcomes*
  - Outcome space exponential: March Madness, horse racing
  - Needs combinatorial bids too
  - Usually intractable but don’t give up hope

- **Combinatorial outcomes**
- March Madness bet constructor
- Bet on any team to win any game
  - Duke wins in Final 4
- Bet “exotics”:
  - Duke advances further than UNC
  - ACC teams win at least 5
  - A 1-seed loses in round 1

Overview: Complexity Results

	Permutations			Boolean			Taxonomy		
	General	Pair	Subset	General	2-clause	Restrict Tourney	General	Tree	
Auction-eer	NP-hard EC'07	NP-hard EC'07	Poly EC'07	NP-hard DSS'05	co-NP-complete DSS'05	?	?	?	
Market Maker (LMSR)	#P-hard EC'08	#P-hard EC'08	#P-hard EC'08	#P-hard EC'08 **Approx STOC'08**	#P-hard EC'08	Poly STOC'08	#P-hard AAMAS '09	Poly AAMAS '09	

YAHOO!

Advantages

- More choices -- better hedges
- More information
- Better processing of information: Let traders focus on predicting whatever they want, however they want: Mechanism takes care of logical/probabilistic inference
- Smarter budgeting

More Info

What is (and what good is) a combinatorial prediction market?

http://blog.oddhead.com/2008/12/22/what-is-and-what-good-is-a-combinatorial-prediction-market/

YAHOO!

Phase 0

Mechanism
(Rules)
e.g. Auction,
Exchange, ...

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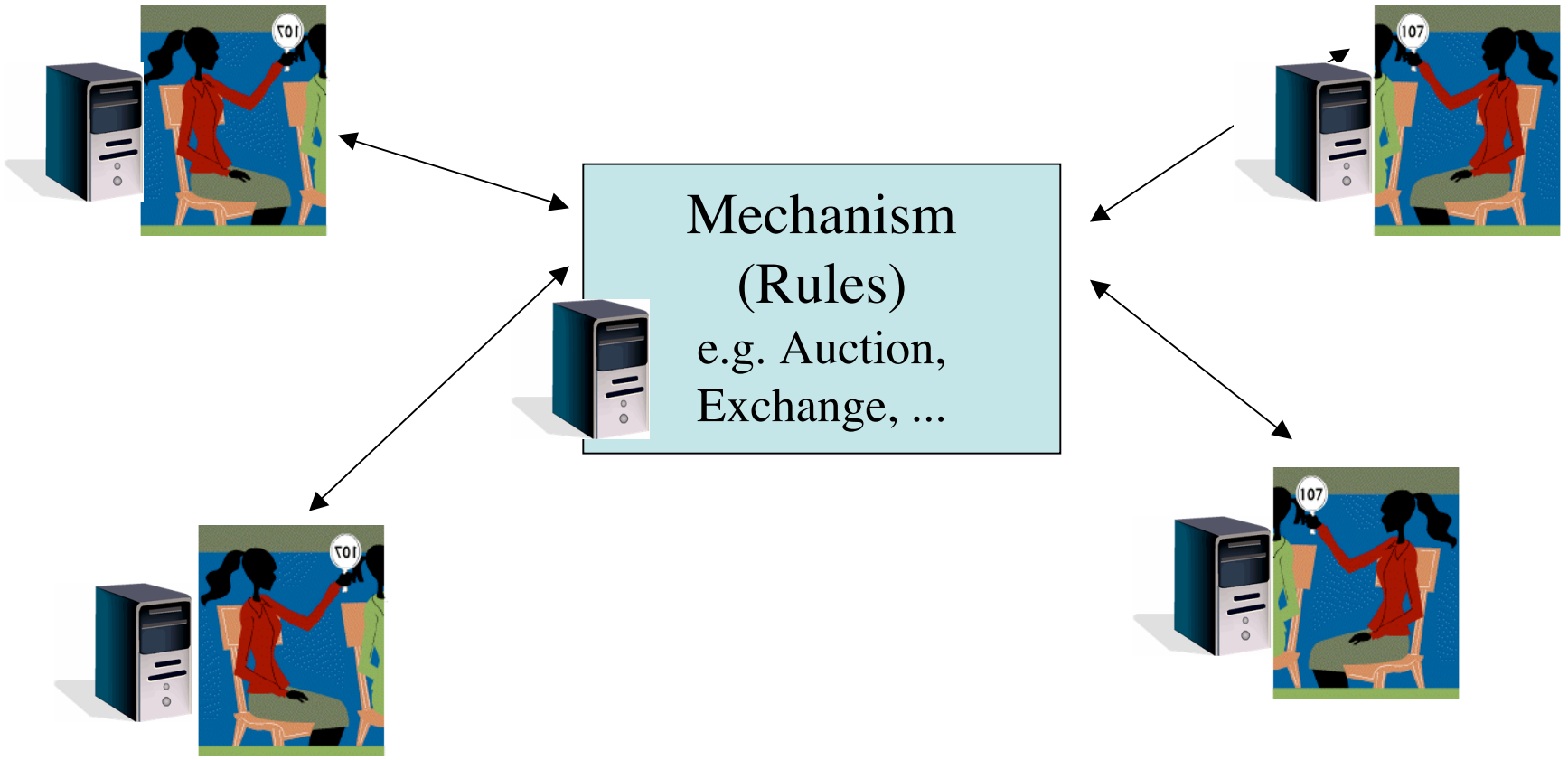
Phase 1



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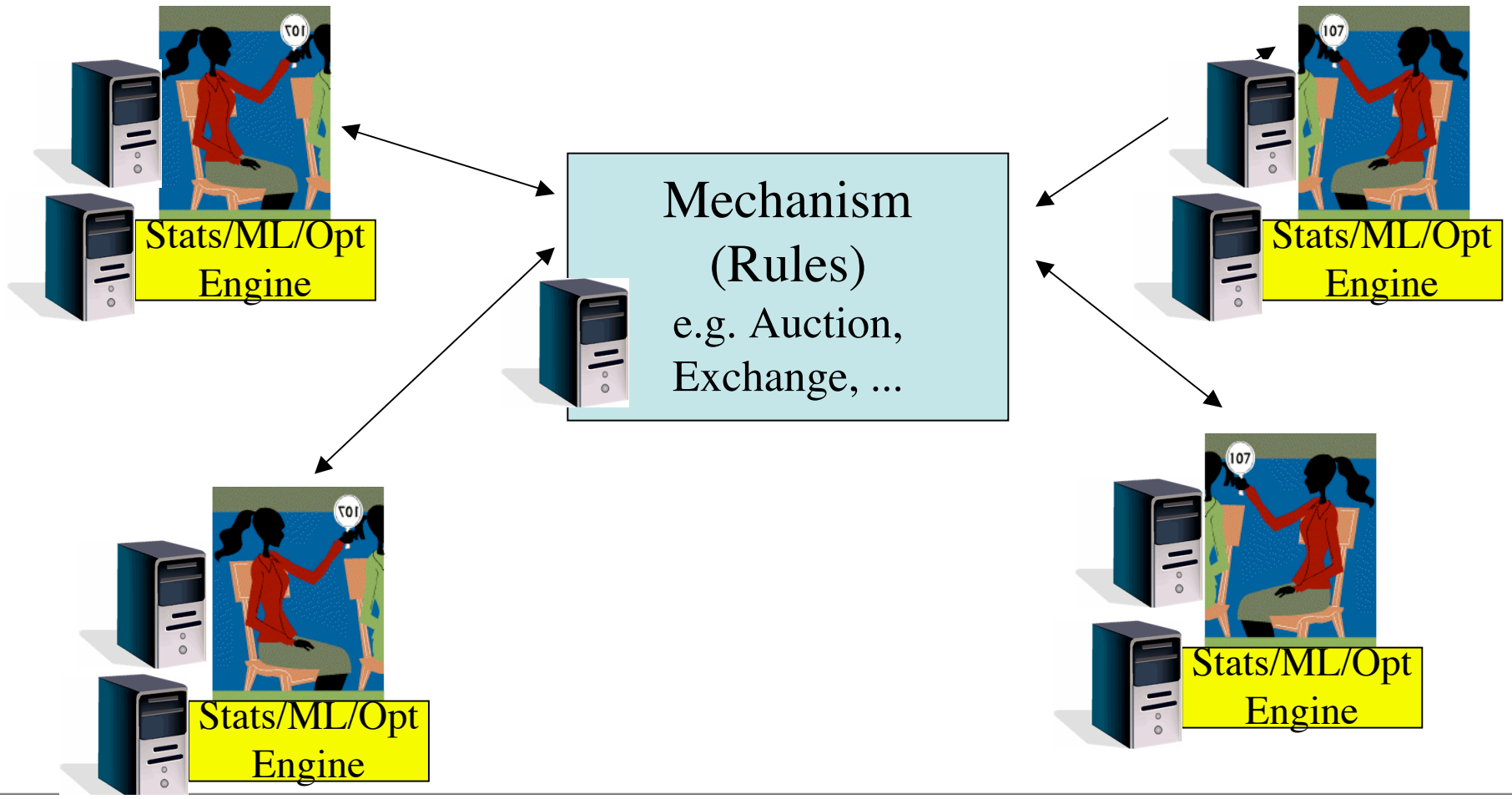
Phase 1.5



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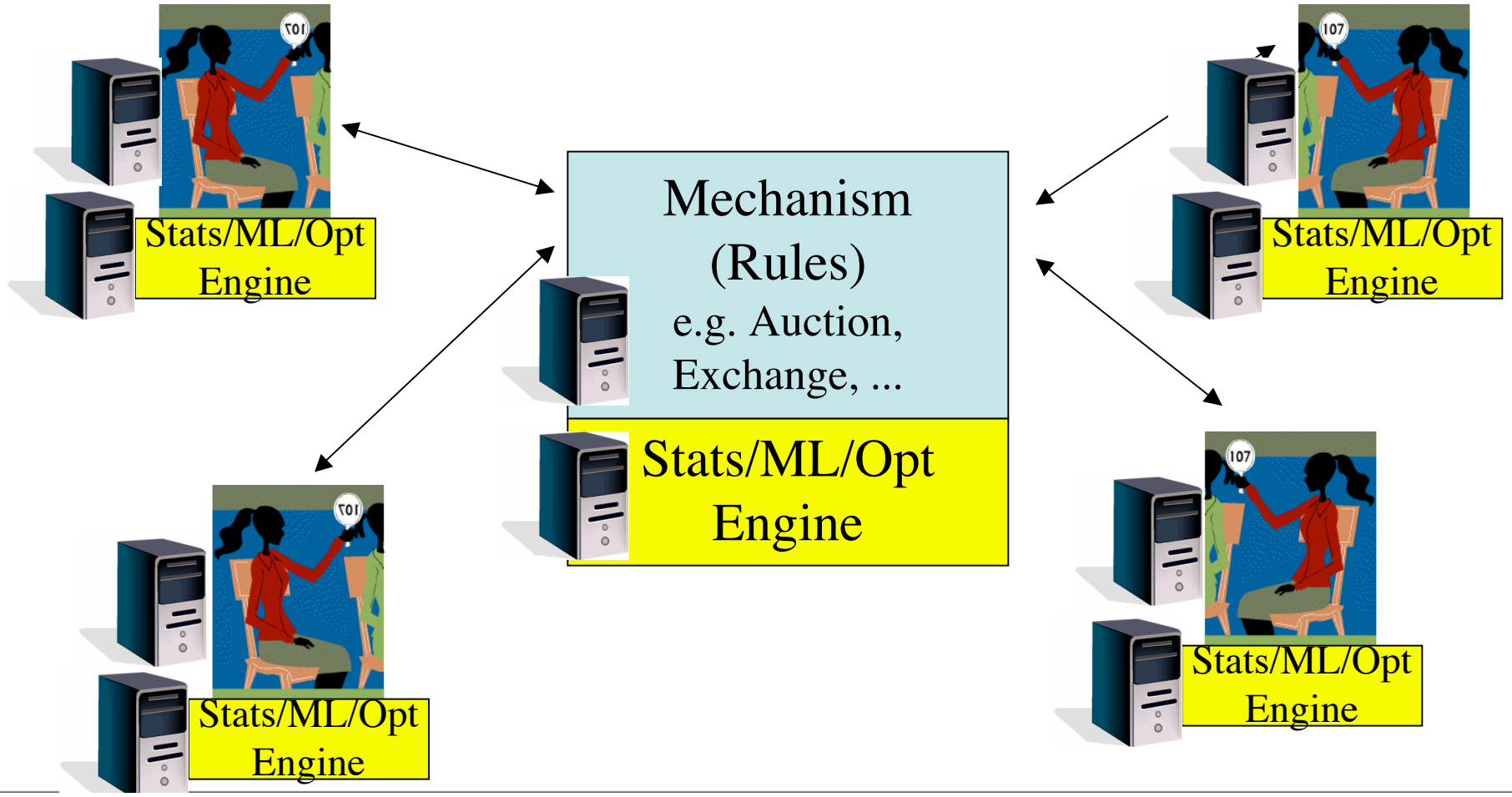
Phase 2



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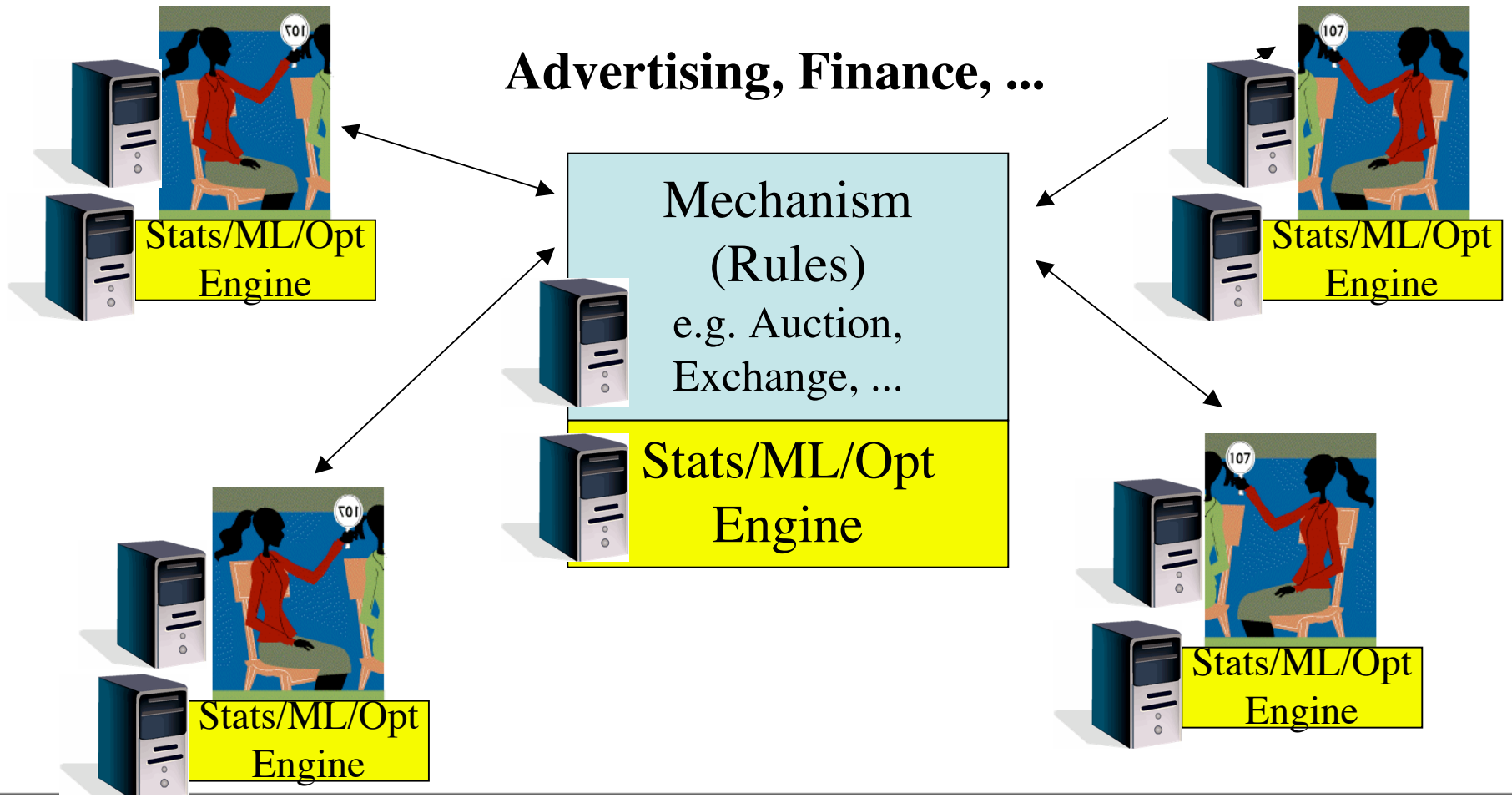
Phase 2