Prediction Markets and the Wisdom of Crowds

David M. Pennock, Yahoo! Research

Yiling Chen, Lance Fortnow, Evdokia Nikolova, Daniel Reeves
Hammers and Nails

Tool: Prediction

Application: Markets

e.g. Dynamic Price Forecasts in Online Auctions: an Application to Indian Art Auctions of Heterogeneous Products, Mayukh Dass, Srinivas Reddy, U. Georgia, Wolfgang Jank, Galit Shmueli, Shanshan Wang, U. Maryland
Hammers and Nails

Application: Prediction

Tool: Markets
A Prediction Market

• Take a random variable, e.g.

  Bird Flu Outbreak US 2007? (Y/N)

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

<table>
<thead>
<tr>
<th>I am entitled to:</th>
<th>Bird Flu US ’07</th>
<th>$1 if</th>
<th>$0 if</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bird Flu US ’07</td>
</tr>
<tr>
<td>Contract</td>
<td>B Qty</td>
<td>Bid</td>
<td>Ask</td>
</tr>
<tr>
<td>------------------</td>
<td>-------</td>
<td>-----</td>
<td>-----</td>
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<tr>
<td>BIRDFLU.U.SA.30JUN07</td>
<td>10</td>
<td>1.5</td>
<td>4.0</td>
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<tr>
<td>BIRDFLU.U.SA.30SEP07</td>
<td>5</td>
<td>2.0</td>
<td>13.5</td>
</tr>
<tr>
<td>BIRDFLU.U.SA.31DEC07</td>
<td>5</td>
<td>13.5</td>
<td>26.0</td>
</tr>
</tbody>
</table>
Outline

- The Wisdom of Crowds
- The Wisdom of Markets
  - Prediction Markets: Examples & Research
- Mechanism Design
  - Betting on Permutations
  - Dynamic Parimutuel Market
- The Coming Convergence of Stats & Mechanism Design
A WOC Story

• ProbabilitySports.com
• Thousands of probability judgments for sporting events
  • Alice: Jets 67% chance to beat Patriots
  • Bob: Jets 48% chance to beat Patriots
  • Carol, Don, Ellen, Frank, ...
• Reward: Quadratic scoring rule:
  Best probability judgments maximize expected score
Individuals

- Most individuals are poor predictors
- 2005 NFL Season
  - Best: 3747 points
  - Average: -944  Median: -275
  - 1,298 out of 2,231 scored below zero (takes work!)
Individuals

- Poorly calibrated (too extreme)
  - Teams given < 20% chance actually won 30% of the time
  - Teams given > 80% chance actually won 60% of the time
The Crowd

• Create a *crowd predictor* by simply averaging everyone’s probabilities
  • Crowd = \( \frac{1}{n}(\text{Alice} + \text{Bob} + \text{Carol} + \ldots) \)
  • 2005: Crowd scored 3371 points (7th out of 2231)!

• *Wisdom of fools*: Create a predictor by averaging everyone who scored below zero
  • 2717 points (62nd place)!
  • (the best “fool” finished in 934th place)
The Crowd: How Big?

Expected score vs Number of experts aggregated (2004 data)

More:
http://www.overcomingbias.com/2007/02/how_and_when_to.html
Can We Do Better?: ML/Stats

[Dani et al. UAI 2006]

- Maybe Not
  - CS “experts algorithms”
  - Other expert weights
  - Calibrated experts
  - Other averaging fn’s (geo mean, RMS, power means, mean of odds, ...)
  - Machine learning (NB, SVM, LR, DT, ...)

- Maybe So
  - Bayesian modeling + EM
  - Nearest neighbor (multi-year)
Can we do better?: Markets

Prediction Performance of Markets Relative to Individual Experts

Week into the NFL season

Rank
NewsFutures
Tradesports
Prediction Markets: Examples & Research
Quotes current as of 06:45:00 CST, Friday, May 18, 2007.

### RConv08
2008 US Republican National Convention Market

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Bid</th>
<th>Ask</th>
<th>Last</th>
<th>Low</th>
<th>High</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>GIUL NOM</td>
<td>0.261</td>
<td>0.269</td>
<td>0.270</td>
<td>---</td>
<td>---</td>
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<tr>
<td>MCCA NOM</td>
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<td>0.285</td>
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<tr>
<td>ROMN NOM</td>
<td>0.176</td>
<td>0.180</td>
<td>0.180</td>
<td>---</td>
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<tr>
<td>RROF NOM</td>
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<td>0.337</td>
<td>0.310</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
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</table>

### DConv08
2008 US Democratic National Convention Market

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Bid</th>
<th>Ask</th>
<th>Last</th>
<th>Low</th>
<th>High</th>
<th>Average</th>
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<tbody>
<tr>
<td>CLIN NOM</td>
<td>0.470</td>
<td>0.480</td>
<td>0.480</td>
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<td>---</td>
<td>---</td>
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<tr>
<td>EDWA NOM</td>
<td>0.072</td>
<td>0.100</td>
<td>0.099</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>OBAM NOM</td>
<td>0.283</td>
<td>0.300</td>
<td>0.288</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>DROF NOM</td>
<td>0.166</td>
<td>0.173</td>
<td>0.166</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>
Example: IEM 1992

[Diagram showing a scatter plot with labels for IPSM, Harris, ABC, CBS/NYT, NBC/WSJ, Washington Post, and Gallup. The plot is centered around the popular vote share of Bush and Clinton.]
IEM versus Polls: 1996
(Berg, Nelson and Rietz, 2001)

Polls:
A = ABC
C = CBS
N = NBC
G = Gallup
H = Harris
T = Time
L = Hotline
P = CNN/Princeton
Z = Zogby
Predictive Accuracy
Berg, Forsythe, Nelson and Rietz (2001)

[Source: Berg, DARPA Workshop, 2002]
### Intrade Contracts

<table>
<thead>
<tr>
<th>Contract</th>
<th>B Qty</th>
<th>Bid</th>
<th>Ask</th>
<th>A Qty</th>
<th>Last</th>
<th>Vol</th>
<th>Chge</th>
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</thead>
<tbody>
<tr>
<td>Osama.Capture.Jun07</td>
<td>2</td>
<td>2.1</td>
<td>2.5</td>
<td>25</td>
<td>2.4</td>
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<td>Osama.Capture.Sep07</td>
<td>95</td>
<td>6.5</td>
<td>8.0</td>
<td>7</td>
<td>7.1</td>
<td>943</td>
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<td>Osama.Capture.Dec07</td>
<td>4</td>
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<td>12.7</td>
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<td>10.5</td>
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<td>0</td>
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<tr>
<td>Xm-Sirius.Merger.Mar08</td>
<td>20</td>
<td>35.0</td>
<td>45.0</td>
<td>19</td>
<td>40.0</td>
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<tr>
<td>Xm-Sirius.Merger.Jun08</td>
<td>20</td>
<td>50.0</td>
<td>60.0</td>
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<td>55.0</td>
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<td>Us.Recession.07</td>
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<td>15.0</td>
<td>5</td>
<td>14.5</td>
<td>1183</td>
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<tr>
<td>Libby.Dec07.Pardon</td>
<td>5</td>
<td>9.0</td>
<td>14.0</td>
<td>12</td>
<td>10.0</td>
<td>1064</td>
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<tr>
<td>Libby.Eot.Pardon</td>
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<td>62.8</td>
<td>1</td>
<td>61.1</td>
<td>1023</td>
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</table>

### Tradesports Contracts

<table>
<thead>
<tr>
<th>Contract</th>
<th>BQty</th>
<th>Bid</th>
<th>Offer</th>
<th>AQty</th>
<th>Last</th>
<th>Vol</th>
<th>Chge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trade MLB.RedSox</td>
<td>2</td>
<td>14.1</td>
<td>14.2</td>
<td>44</td>
<td>13.0</td>
<td>4417</td>
<td>0</td>
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<tr>
<td>Trade MLB.Mets</td>
<td>5</td>
<td>13.0</td>
<td>14.0</td>
<td>150</td>
<td>13.7</td>
<td>1910</td>
<td>0</td>
</tr>
<tr>
<td>Trade MLB.Yankees</td>
<td>5</td>
<td>10.3</td>
<td>11.0</td>
<td>151</td>
<td>12.4</td>
<td>2082</td>
<td>0</td>
</tr>
</tbody>
</table>
Silver will close ABOVE 1375
in: 4hr 55min

Fed Funds Rate will close ABOVE 5.25
in: 123 day 7hr 29min

Miami will close ABOVE 385000
in: 87 day 7hr 31min

Risk: 2.00
Reward: 98.00

Risk: 7.00
Reward: 93.00

Risk: 92.00
Reward: 8.00

Screen capture 2007/05/18
Play money;
Real predictions

http://www.hsx.com/
Cancer cured by 2010

Machine Go champion by 2020

Earthquake Prediction
A 6.4- or greater-magnitude quake will occur in the Mojave Desert by Sept. 5

To participate in the trading of this outcome with other players, you must first login or open an account (it's free).
Yahoo!/O’Reilly Tech Buzz Game

http://buzz.research.yahoo.com/

Market: Digital Video Recorders

**TiVo** $14.91 ↑ 0.21 (1%)

- **Symbol:** TIVO
- **52-Week Range:** $10.00 - $34.86
- **Shares Outstanding:** 41861
- **Mkt Cap TIVO:** $587823.46
- **Mkt Cap DVR:** $1585195.65
- **Buzz score for TIVO:** 53

**Announcements for TiVo**

- 2005/03/18 15:50: Price sync with buzz search volume.

**Yahoo! News for tivo**

- **TiVo marketing promo goes awry**
  CNET - 2005/03/22 11:41

- **Suddenly, It's Fast Forward at TiVo**
  TechNewsWorld.com - 2005/03/22 05:15

- **TiVo advances as Japan expansion reported; sector mixed**
  CBS Market Watch - 2005/03/21 07:49

- **TiVo Lost in Translation**
  The Motley Fool - 2005/03/21 06:20

**Buy**

- **Dollars to Invest:** $[
- **Est Shares:**
- **Available Cash:** $7,720.78

**Sell**

- **Shares to Sell:**
- **Est Proceeds:**
- **Shares owned:** 0
More Prediction Market Games

- BizPredict.com
- CasualObserver.net
- FTPredict.com
- InklingMarkets.com
- ProTrade.com
- StorageMarkets.com
- TheSimExchange.com
- TheWSX.com
- Alexadex, Celebdaq, Cenimar, BetBubble, Betocracy, CrowdIQ, MediaMammon, Owise, PublicGyan, RIMDEX, Smarkets, Trendio, TwoCrowds
Does it work? Yes...

• Evidence from real markets, laboratory experiments, and theory indicate that markets are good at gathering information from many sources and combining it appropriately; e.g.:
  – Markets like the Iowa Electronic Market predict election outcomes better than polls
  – Futures and options markets rapidly incorporate information, providing accurate forecasts of their underlying commodities/securities
  – Sports betting markets provide accurate forecasts of game outcomes
    [Gandar 1998][Thaler 1988][Debnath EC’03][Schmidt 2002]
Does it work?
Yes...

• E.g. (cont’d):
  – Laboratory experiments confirm information aggregation
  – And field tests [Plott 2002]
  – Theoretical underpinnings: “rational expectations”
  – Procedural explanation: agents learn from prices
    [Hanson 1998][Mckelvey 1986][Mckelvey 1990][Nielsen 1990]
  – Proposals to use information markets to help science [Hanson 1995],
    policymakers, decision makers [Hanson 1999], government [Hanson 2002],
    military [DARPA FutureMAP, PAM]
  – Even market games work! [Servan-Schreiber 2004][Pennock 2001]
Catalysts

- Markets have long history of predictive accuracy: why catching on now as tool?
- No press is bad press: Policy Analysis Market ("terror futures")
- Surowiecki's "Wisdom of Crowds"
- Companies:
  - Google, Microsoft, Yahoo!; CrowdIQ, HSX, InklingMarkets, NewsFutures
- Press: BusinessWeek, CBS News, Economist, NYTimes, Time, WSJ, ...

http://us.newsfutures.com/home/articles.html
Mechanism Design I: Betting on Permutations
# Mech Design for Prediction

<table>
<thead>
<tr>
<th></th>
<th>Financial Markets</th>
<th>Prediction Markets</th>
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</thead>
<tbody>
<tr>
<td><strong>Primary</strong></td>
<td>Social welfare (trade) Hedging risk</td>
<td>Information aggregation</td>
</tr>
<tr>
<td><strong>Secondary</strong></td>
<td>Information aggregation</td>
<td>Social welfare (trade) Hedging risk</td>
</tr>
</tbody>
</table>
Mech Design for Prediction

- Standard Properties
  - Efficiency
  - Inidiv. rationality
  - Budget balance
  - Revenue
  - Comp. complexity

- Equilibrium
  - General, Nash, ...

- PM Properties
  - #1: Info aggregation
  - Expressiveness
  - Liquidity
  - Bounded budget
  - Indiv. rationality
  - Comp. complexity

- Equilibrium
  - Rational expectations

Competes with: experts, scoring rules, opinion pools, ML/stats, polls, Delphi
Predicting Permutations

• Predict the ordering of a set of statistics
  • Horse race finishing times
  • Number of votes for several candidates
  • Daily stock price changes
  • NFL Football quarterback passing yards
  • Any ordinal prediction

• Chen, Fortnow, Nikolova, Pennock, EC’07
Market Combinatorics

Permutations

- $A > B > C$ .1
- $A > C > B$ .2
- $B > A > C$ .1
- $B > C > A$ .3
- $C > A > B$ .1
- $C > B > A$ .2
Market Combinatorics

Permutations

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

• 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}
• \textit{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
Auctioneer Problem

• Auctioneer’s goal:
  Accept orders with non-negative worst-case loss (auctioneer never loses money)

• *The Matching Problem*

• Formulated as LP

• Generalization: *Market Maker Problem*: Accept orders with bounded worst-case loss (auctioneer never loses more than b dollars)
Example

• A three-way match
  • Buy 1 of “$1 if A>B” for 0.7
  • Buy 1 of “$1 if B>C” for 0.7
  • Buy 1 of “$1 if C>A” for 0.7
Pair Betting

- All bets are of the form “A will beat B”
- Cycle with sum of prices > k-1 ==> Match (Find best cycle: Polytime)
- Match =/= Cycle with sum of prices > k-1

- Theorem: The Matching Problem for Pair Betting is NP-hard (reduce from min feedback arc set)
Subset Betting

• All bets are of the form
  • “A will finish in positions 3-7”, or
  • “A will finish in positions 1,3, or 10”, or
  • “A, D, or F will finish in position 2”

• Theorem: The Matching Problem for Subset Betting is polytime (LP + maximum matching separation oracle)
Hammers and Nails

Tool: Prediction
Application: Prediction

Tool: Markets
Application: Markets
Coming Convergence: Stats and Mechanism Design

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

Stats/ML/Opt Engine

Stats/ML/Opt Engine

Stats/ML/Opt Engine

Stats/ML/Opt Engine
Convergence: Advertising

search “las vegas travel”, Yahoo!

SPONSOR RESULTS

- **Expedia.com: Save on Travel to Las Vegas** - Plan your trip with flights, vacation packages, rental cars, cruises & more. Do it all at www.expedia.com
- **Las Vegas Rooms Up to 75% Off** - Find deep discounts on Las Vegas hotels. We book directly with all major hotels. www.tripreservations.com
- **Go Skydiving on Your Las Vegas Vacation** - Try a tandem skydive now! Free shuttle from your hotel. Friendly staff. www.lvgravityzone.com
- **Las Vegas Hotel and Casino Specials** - Check out Las Vegas, Las Vegas Hilton or Paris Las Vegas for hotel and casino specials. www.parkplace.com

TOP 20 WEB RESULTS

1. **Las Vegas Leisure Guide**
   - Las Vegas, Las Vegas Hilton or Paris Las Vegas for hotel and casino specials. From just $39/night. www.parkplace.com
   (Advertiser's Max Bid: $1.01)
2. **Going To Las Vegas**
   - tips for the Vegas-bound traveler including where to find

“las vegas travel” auction

1. **Expedia.com: Save on Travel to Las Vegas**
   - Planning a trip to Las Vegas? Find the trip you're looking for. Don't just travel, Travel Right. Expedia.com. www.expedia.com
   (Advertiser's Max Bid: $3.01)
2. **Las Vegas Rooms Up to 75% Off**
   - Find deep discounts and last minute deals on Vegas hotels. www.tripreservations.com
   (Advertiser's Max Bid: $2.94)
3. **Go Skydiving on Your Las Vegas Vacation**
   - Try a tandem skydive on your next vacation to Las Vegas. www.lvgravityzone.com
   (Advertiser's Max Bid: $2.93)
4. **Las Vegas Hotel and Casino Specials**
   - Check out the official Web site of Bally's Las Vegas casino specials. From just $39/night. www.parkplace.com
   (Advertiser's Max Bid: $1.01)
5. **Book Las Vegas Travel Reservations**
   - Book Vegas.com - the number one Las Vegas resource for restaurants, 40 tours, airfare and car rentals! www.bookvegas.com
   (Advertiser's Max Bid: $1.00)
ML Inner Loop

• Optimal allocation (ad-user match) depends on: bid, $E[\text{clicks}]$, $E[\text{sales}]$, 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.
Adversarial Machine Learning

- Learning in a game theoretic environment
  - Spam!
  - Click fraud
  - Shilling
Incentive-Centered Design

<table>
<thead>
<tr>
<th>Technology</th>
<th>Manipulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Email</td>
<td>Spam</td>
</tr>
<tr>
<td>Web/Altavista</td>
<td>Keyword spam</td>
</tr>
<tr>
<td>Web/Google</td>
<td>Link spam</td>
</tr>
<tr>
<td>Reviews/recommendations</td>
<td>Shilling</td>
</tr>
<tr>
<td>Sponsored search</td>
<td>Click spam</td>
</tr>
<tr>
<td>Blogs</td>
<td>Comment/trackback spam</td>
</tr>
<tr>
<td>Tags (Flickr)</td>
<td>Tag spam</td>
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<tr>
<td>Social Aggregators (Digg)</td>
<td>Shilling</td>
</tr>
<tr>
<td>Semantic Web</td>
<td>??</td>
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</tbody>
</table>

- This is not vandalism! All based on economic incentives
- Haven’t we learned? Needed: Incentive-centered design
- See UM SI: http://www.si.umich.edu/research/area.htm?AreaID=4
- Yahoo! Research Microeconomics & Sociology
Conclusion

- Market Prediction: hammer = prediction, nail = market
- Prediction Markets: hammer = market, nail = prediction
  - Great empirical successes
  - Momentum in academia and industry
  - Fascinating (algorithmic) mech design questions
- Convergence Happening
  - hammer & nail = prediction & market
  - Prediction in inner loop of mechanism design
  - Nowhere more clear than online advertising