# Combinatorial Information Market Design

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# Wanted: E[Outcome|Decision]

Outcomes

- Stock price
- Product sales
- Unemployment
- Economic growth
- Crime rate

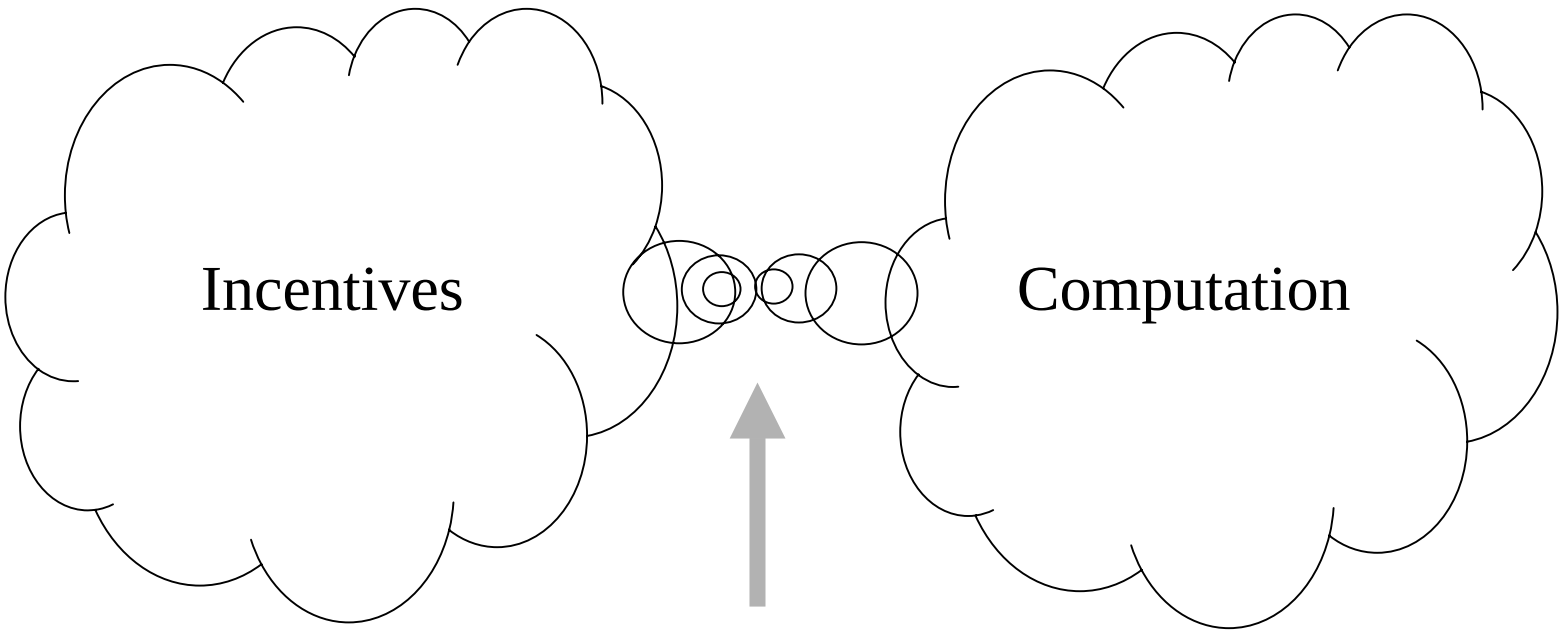
Decisions

- Dump CEO
- Which ad campaign
- Who elected president
- Fed raise/lower rates
- More gun control

# Info Tech ≠ Bit Tech!

- E.g., *E[ US terror deaths | invade Iraq ]*
- Bit tech = move/map bits (telecom/computer)
  - Now much easier to find what people say, but …
- Info tech ideal: p(E) for all events E
  - Full joint probability distribution over events
  - Combines all anyone knows or could learn
  - Key: *incentives* to learn, reveal, combine

# Economics & Computer Science




Seek tractable interface

# Old Tech: Proper Scoring Rules

- Assume: ex post verifiable vars, give states i
- When report **r**, state is i, reward is $s_i(\mathbf{r})$

  $\mathbf{p} = \text{argmax}_{\mathbf{r}} \Sigma_i p_i s_i(\mathbf{r}), \quad \Sigma_i p_i s_i(\mathbf{p}) \geq 0$
- E.g., log rule (Good 1952) $s_i = \alpha \log(r_i)$
- Long used in weather/business forecasting, student test scoring, economics experiments

# Old Tech Issues

*Problems*

- Incentives
- Number shy
- Non risk-neutral
- State-varying utility
- Cognitive bias
- Combo explosion
- Disagreements

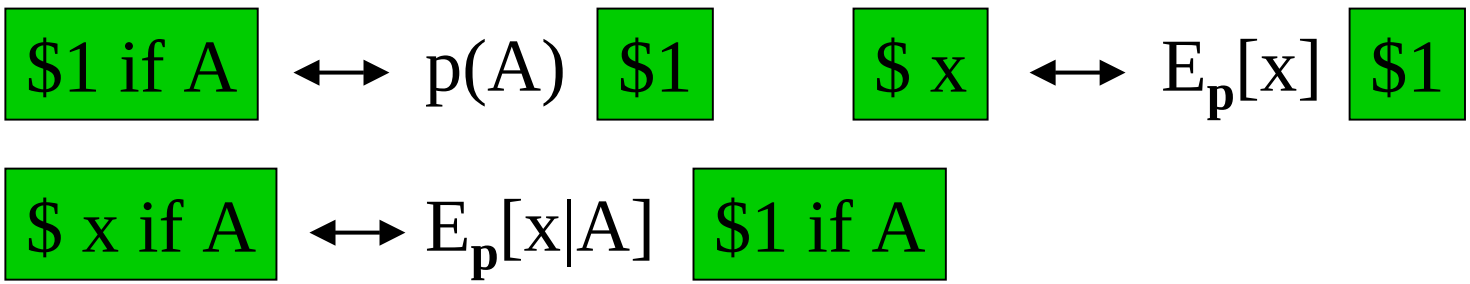
*Solutions*

- Proper scoring rules
- Prob wheel, word menu
- Lottery payoffs
- Lottery insurance game
- Corrections
- Dependence network
- Dictator per Q, ??

centralized

# New Tech: Information Markets

- Most markets aggregate info as side effect
- Info markets beat competing institutions
  - OJ futures improve weather forecast (Roll 1984)
  - HP market beat sales forecast 6/8 (Plott 2000)
  - I.E.M. beat president polls 451/596 (Berg etal 2001)



# Coming Soon ...

*E[ US terror deaths | invade Iraq ]* for real!

- DARPA, Net Exchange, Caltech, GMU
- Two year field test, starts spring 2003
- Open to public, real money markets
- ~20 nations, 8 quarters, ~5 variables each:
  - Economic, political, military, US actionss
- Want many combos (> $2^{500}$ states!)

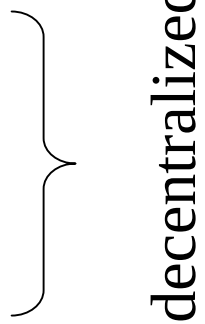
# New Tech Issues

*Problems*

- Incentives
- Shy, complex utility
- Who expert on what
- Cognitive bias
- Disagreements
- Thin markets
- Combo explosion

*Solutions*

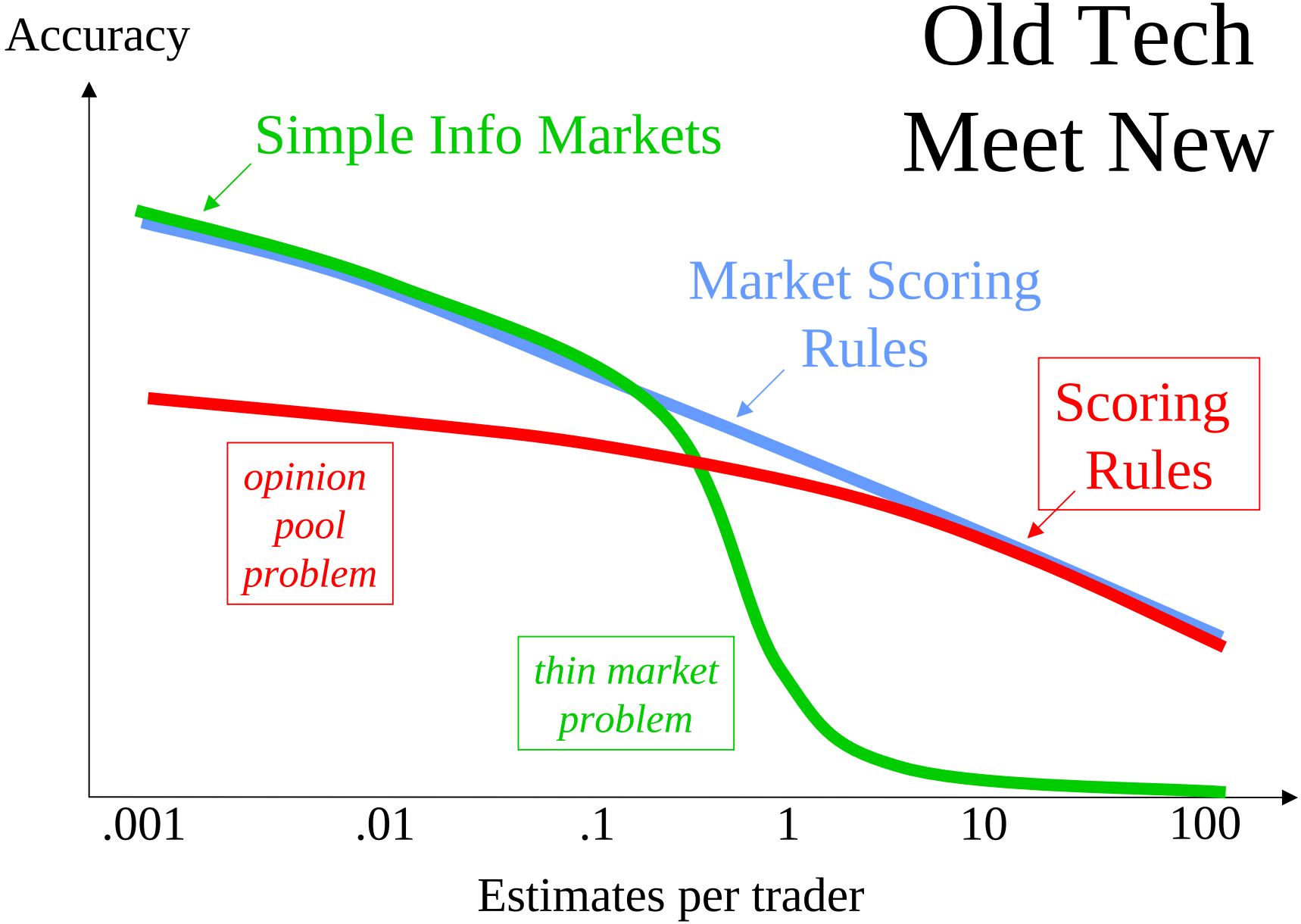
- Bet?  irrational, subsidy
- Same solutions
- Self-select
- Arbitrageurs
- Equilibrate, risk
- Market scoring rules
- Structure dictator, ??



# Thin Market Problem

- Trade requires *coordinate* in *Assets* and
  - *Time*: waiting offers suffer adverse selection
  - Call markets, combo match, can help some, but
- Most possible info markets do not exist
  - Most are illegal, and for most of the rest
  - Expect few traders, so don't make offer
- *If known that only one person has opinion on a topic, simple price not reveal it!*

# Old Tech Meet New



# Market Scoring Rules

- MSRs combine scoring rules, info markets
- User t faces $ rule: $\Delta s_i = s_i(\mathbf{p}^t) - s_i(\mathbf{p}^{t-1})$

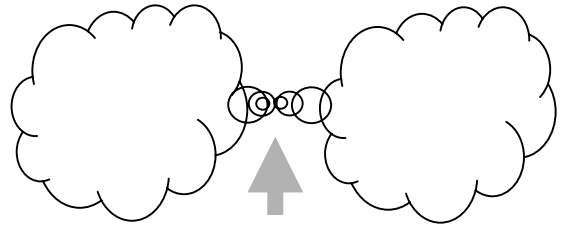
  *"Anyone can use scoring rule if pay off last user"*
- Is auto market maker, price from net sales **s**
  - Tiny sale $\$ \epsilon_i$ if i  fee: $\cong p_i(\mathbf{s})\, \epsilon_i$  $(s_i \rightarrow s_i + \epsilon_i)$
  - Big sale $\$ \mathbf{s}(1) - \mathbf{s}(0)$  fee: $\int_0^1 \Sigma_i\, p_i(\mathbf{s}(t))\, s_i'(t)\, dt$
  - Log MSR is: $p_i(\mathbf{s}) = \exp(\lambda s_i) / \Sigma_k \exp(\lambda s_k)$

# Log MSR Cost & Modularity

- Cost = $s_{true}(\mathbf{p}^{end}) - s_{true}(\mathbf{p}^{start})$
  - Expected cost: $E_{\boldsymbol{\pi}}[C] \leq \Sigma_i \pi_i (s_i(\mathbf{1}_i) - s_i(\boldsymbol{\pi}))$
  - Log cost bound $\propto$ entropy: $S(\boldsymbol{\pi}) = -\Sigma_i \pi_i \log(\pi_i)$
  - $S(\boldsymbol{\pi}_{all}) \leq \Sigma_{var} S(\boldsymbol{\pi}_{var})$, so all combos $\leq$ rule per var!
- Log is modular

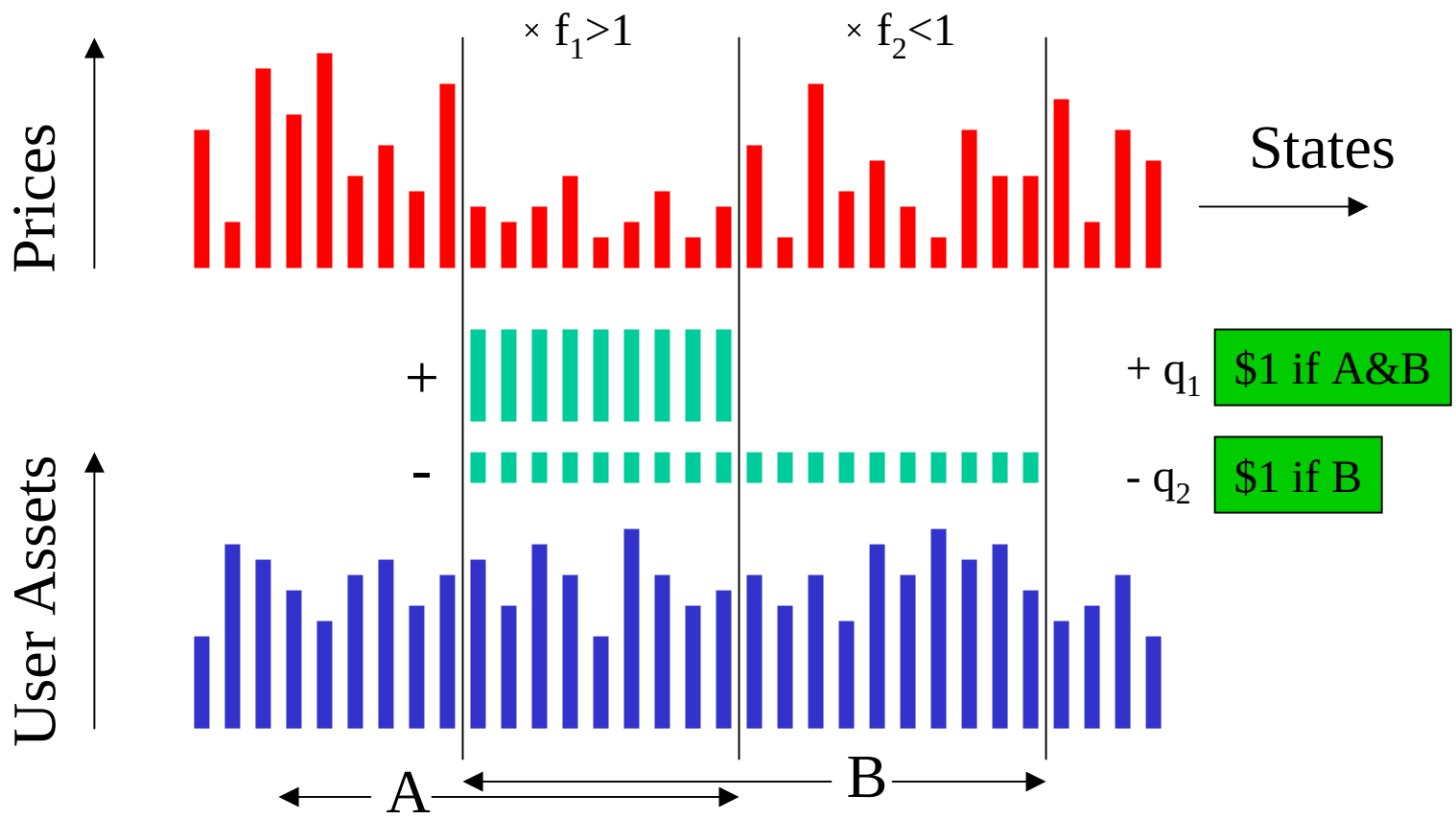
  \$1 if A&B $\leftrightarrow$ p(A|B) \$1 if B
  - Changes p(A|B), but not p(B), p(C|A&B), p(C|¬A&B), p(C|¬B), I($\mathcal{A},\mathcal{B},\mathcal{C}$), I($\mathcal{B},\mathcal{A},\mathcal{C}$)

# MSR Compute Tasks

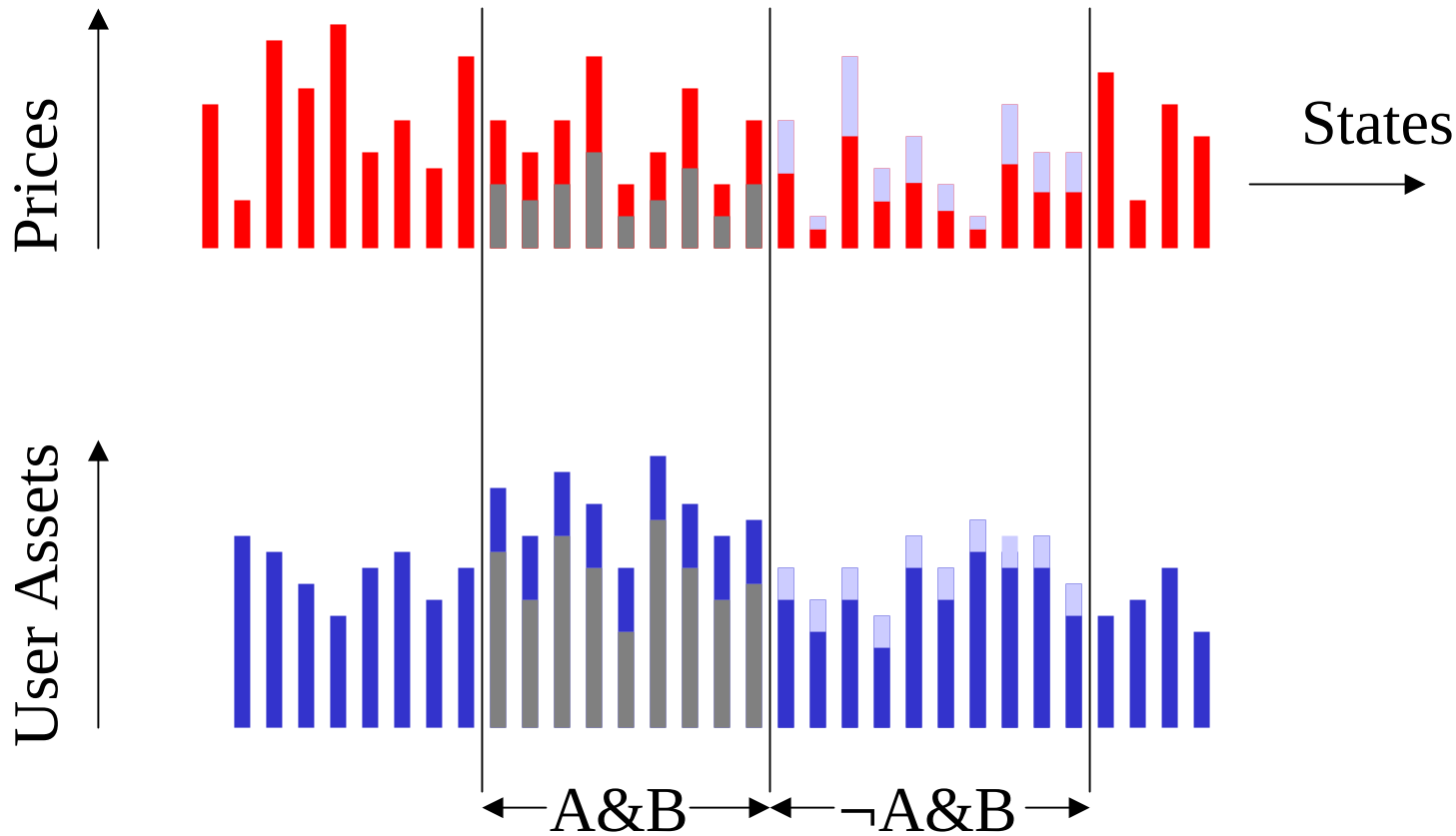


- Trade - change P(A|B) from *p* to *p'*
  - Update user asset holdings + $q_1$ $1 if A&B - $q_2$ $1 if B
  - Update all prices (avoid being money pump)
- Prepare for trade
  - Show prices (browse B scenario, seeking an A)
  - Collect/identify assets can support certain trade
  - Browse assets, see if now long/short on P(A|B)
- Misc: add var, decide value, abstractions

# A Simple Implementation

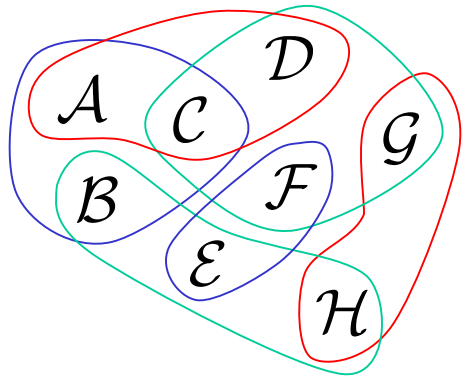


# A Simple Implementation

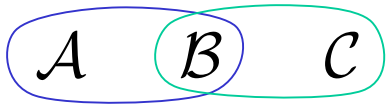


# A Scaleable Implementation

- Overlapping variable patches
- A simple MSR for each patch
- Arbitrage neighbor patches
  - Limits profits to users who find inconsistencies
- Only allow trade if all vars in same patch?
- User assets per patch, move via overlap
- Regroup patches from request activity?



# Arbitraging Patches



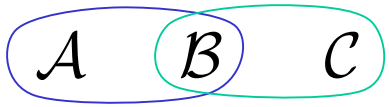

| | A | A | | | | C | C | |
|---|---|---|---|---|---|---|---|---|
| B | .02 | .08 | .1 → | .2 | ← .4 | .3 | .1 | B |
| B | .2 | .7 | .9 → | .734 | ← .6 | .3 | .3 | B |

.065

1.000

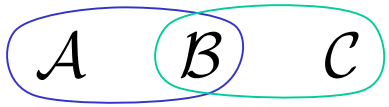
*Cash extracted*

# Arbitraging Patches



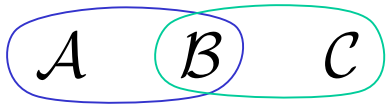

| | A | A | | | | C | C | |
|---|---|---|---|---|---|---|---|---|
| B | .043 | .171 | .214 ⟵ | .214 | ⟶ .214 | .160 | .053 | B |
| B | .175 | .611 | .786 ⟵ | .786 | ⟶ .786 | .393 | .393 | B |

# Moving Assets Between Patches




| | A | A | | | C | C | |
|---|---|---|---|---|---|---|---|
| B | 1 | 0 | 0 | 1 | 2 | 1 | B |
| B | 3 | 2 | 2 | 0 | 0 | 4 | B |

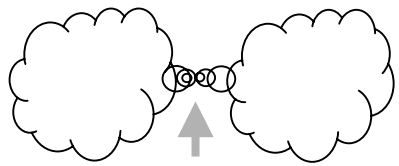
# Moving Assets Between Patches

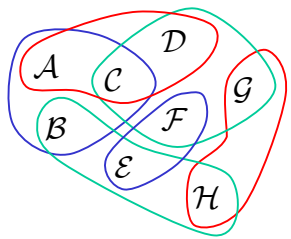



| | A | A | | | | C | C | |
|---|---|---|---|---|---|---|---|---|
| B | 2 | 1 | 1 | ← 1 | ← 0 | 1 | 0 | B |
| B | 3 | 2 | 2 | | 0 | 0 | 4 | B |

# Summary

- Want info tech, not just bit tech: *E[x|A]*
  - DARPA field test soon
- Combine scoring rules, info markets: MSR
  - Solves: opinion pool, thin market, subsidy
  - Decentralized: fix bias, who expert
- Defines computational problem
  - Exists one scaleable approach
  - Can we do better?





# Opinion Pool “Impossibile”

- Task: pool prob. T(A) from opinions $p^n(A)$
- Any 2 of IPP, MP, EB $\Rightarrow$ dictator ($T = p^d$) !

  IPP = if A,B indep. in all $p^n$ , are indep. in T

  MP = commutes: pool, coarsen states ($\sigma$–field)

  EB = commutes: pool, update on info
- MP $\Rightarrow T = \Sigma_{n=0} w_n p^n$ , with $w_n$ indep. of A