SciCast:
A Combinatorial Prediction Market for Science and Technology Forecasting

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Buy Low, Sell High

Will Amazon deliver its first package using an unmanned aerial vehicle by Dec 31 2017?

"Pays $1 if UAV delivery by end of 2017"

price

Will price rise or fall?

sell

buy

sell

buy

E[price change | ??]

Lots of ?? Are considered, price includes all!

What do you think?

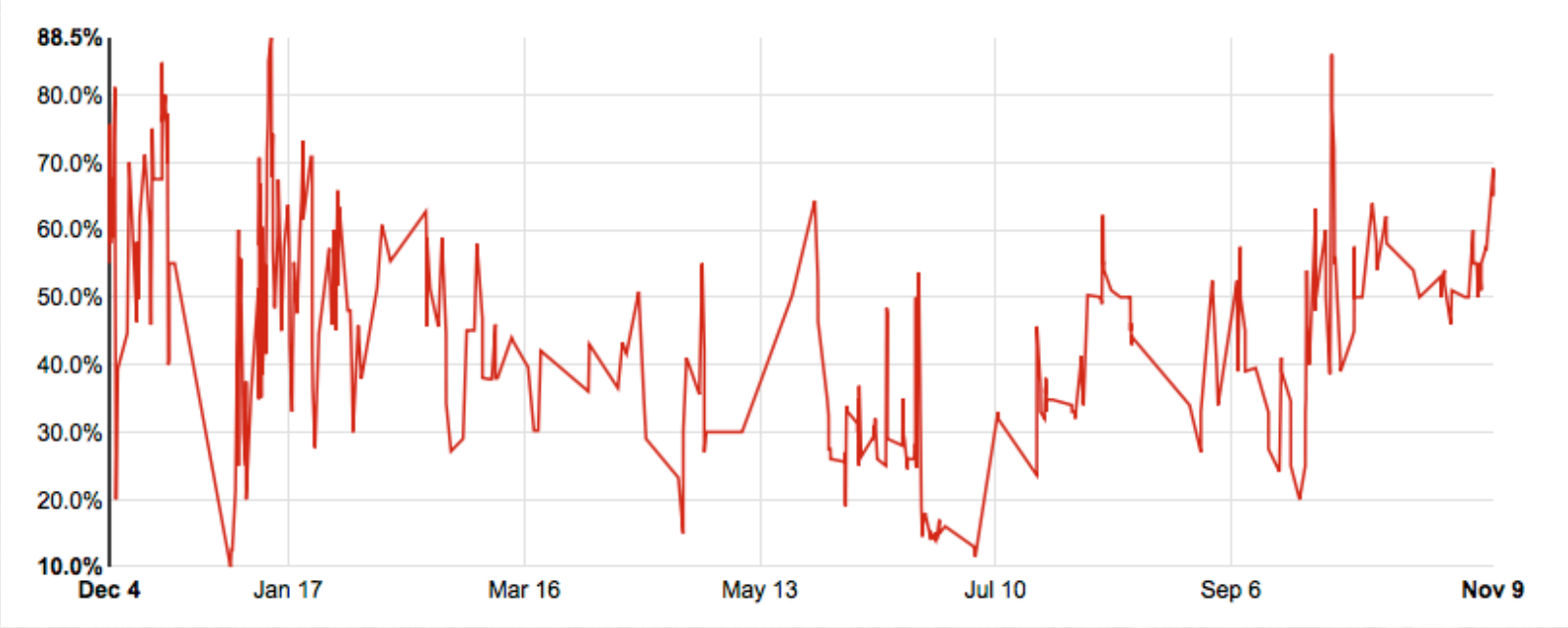
Will Amazon deliver its first package using an unmanned aerial vehicle by DEC 31 2017?

65% Chance

Unchanged today

QUICK FORECAST

Status: Open • Closed after: December 31 2017 • 383 Forecasts • 25 Comments



http://scicast.org

SciCast

- Prediction market focused on Science and Technology
  - > 10K users
  - ~ 800 questions
  - ~ 200 forecasts per day
- Sponsored by IARPA
- Users (mainly) play for points
- Experimenting with incentives
  - Small monetary incentives for activity generate dramatic activity spikes
  - Other rewards (badges; thank-you notes) have little effect
  - Currently testing incentives for accuracy

Partners

Example Forecast Challenges*

Will developments in the super material Graphene make a shot-detection system possible that offers an order of magnitude improvement in one or more critical system performance specifications by 2019?

71% Chance

Unchanged today

Will DARPA's Mobile Hotspot program enter Phase 3 by the end of June 2015?

59% Chance

Up12% today

Status: Open • Closed after: March 31 2015 • 51 Forecasts • 0 Comments

Will cyber threats be more costly than physical threats to the U.S. national electric grid in 2014?

31% Chance

Unchanged today

Status: Open • Closed after: December 31 2014 • 92 Forecasts • 4 Comments

What will be the highest reported efficiency achieved by a metamaterial power harvester by DEC 1 2015?

46.0% Forecast

Unchanged today

Status: Open • Closed after: November 30 2015 • 42 Forecasts • 1 Comments

Will the ALPHA and AEgIS experiments conducted by CERN indicate that the ratio of gravitational mass to inertial mass of antihydrogen is positive or negative?

Status: Open • Closed after: December 31 2017 • 214 Forecasts • 13 Comments

Positive

67% Chance

Unchanged today

Negative

2% Chance

Unchanged today

No conclusive results will be reported by DEC 31 2017

31% Chance

Unchanged today

** A small sample as of August 2014*

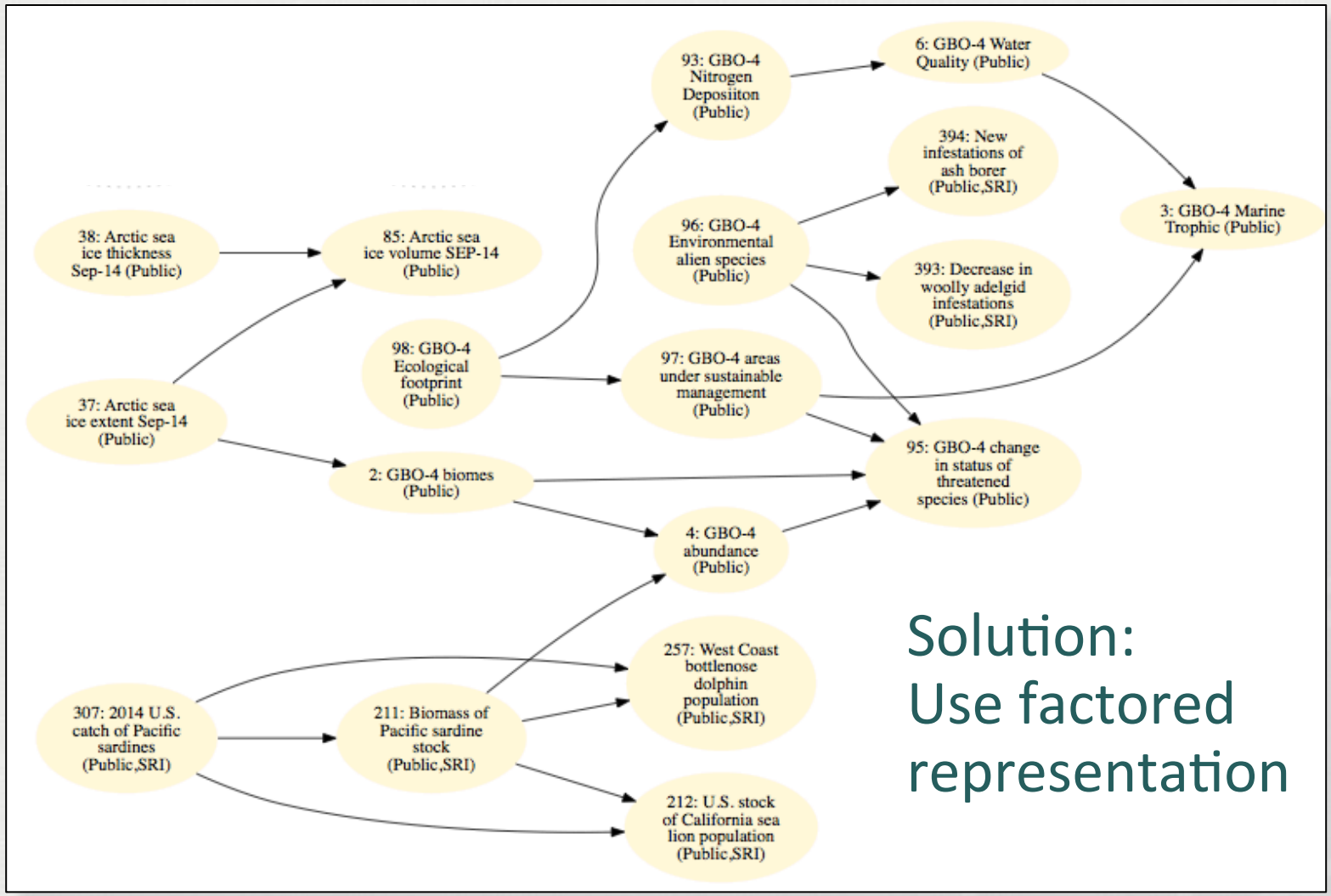
PM with LMSR Market Maker

- Market probability distribution on states
  - $\sum_i p_i = 1$, $i = 1, \ldots, N$
- State-dependent user assets $a_i^{(k)}$ for user k in state i
- User updates probability of state i [buys/sells security that pays off if i occurs]
  - Automated market maker pays off according to logarithmic market scoring rule (LSMR)
  - Moving $p_i \rightarrow x_i$ changes $a_i^{(k)} \rightarrow a_i^{(k)} + b*\log(x_i/p_i)$
  - Disallow if new assets $a_i^{(k)} + b*\log(x_i/p_i) < 0$ in any state i
- User who disagrees with market probability has incentive to trade
  - Because based on *proper* scoring rule
- With uniform initial distribution, market maker loss is bounded by $b*\log(N)$

Combinatorial Prediction Market

- Often interested in many related questions (A,B,C,…)
- Want to allow user to express joint and/or conditional beliefs on small subsets of variables
  - Increase P(A&B) ⇔ increase assets in states with A&B; decrease assets in states with ¬A or ¬B
  - Increase P(A|B) ⇔ increase assets in states with A&B; decrease assets in states with ¬A&B, no change in states with ¬B
- ***Issue***: state space explosion
- ***Issue:*** asset reuse

Issue: State Space Explosion



Solution:
Use factored representation

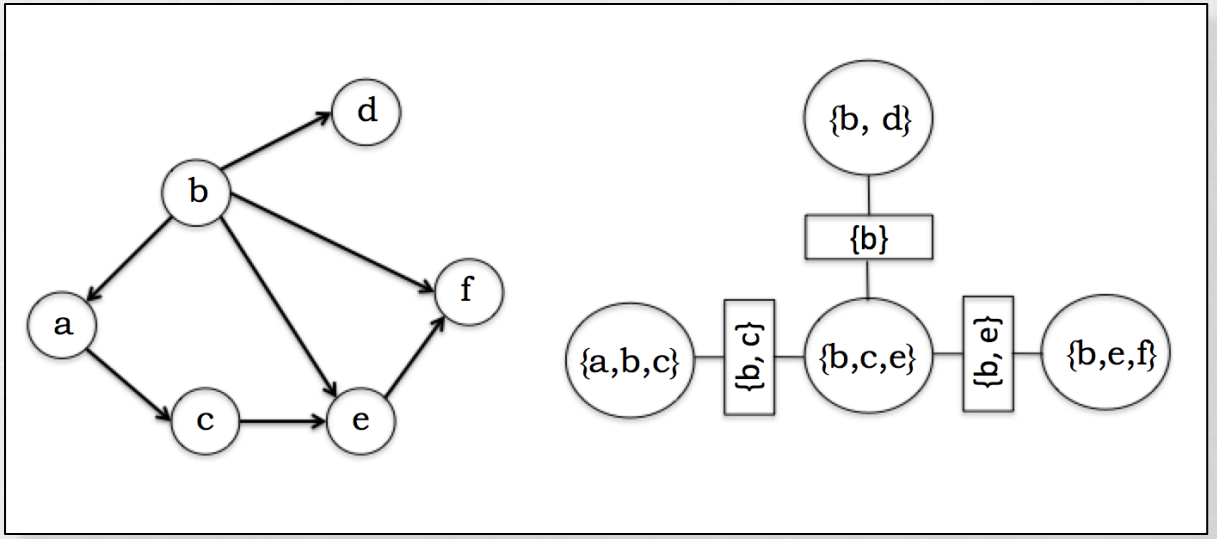
Issue: Asset Reuse

- Current market consensus $P(B) = x$
- User wants to make *conditional* forecast:
  - Change $P(B|A)$ to $y > x$
  - Change $P(B|\neg A)$ to $z < x$
- Express as separate trades:
  - Trade 1:
    - Pays $b \log (y/x)$ if $B\&A$
    - Pays $b \log ((1-y)/(1-x))$ if $\neg B\&A$
    - Called off if $\neg A$
    - Worst case is $b \log ((1-y)/(1-x))$
  - Trade 2:
    - Pays $b \log (z/x)$ if $B\&\neg A$,
    - Pays $b \log ((1-z)/(1-x))$ if $\neg B\&\neg A$
    - Called off if A
    - Worst case is $b \log (z/x)$
  - Naïve asset manager reserves $- [b(\log ((1-y)/(1-x)) + \log (z/x))]$ to cover trade
  - But max loss is $\min[- b \log ((1-y)/(1-x)), - b \log (z/x)]$

Key Operations for CPM

- Compute minimum assets
  - Reuse assets, prevent bankruptcy
- Compute expected assets
  - Tell users how they are doing
- Resolve question when outcome becomes known
  - Set state for resolved question
  - Update probabilities for other questions
  - Settle accounts with users
  - Recalculate forecasters' min and expected assets

Probability and Asset Management in CPM

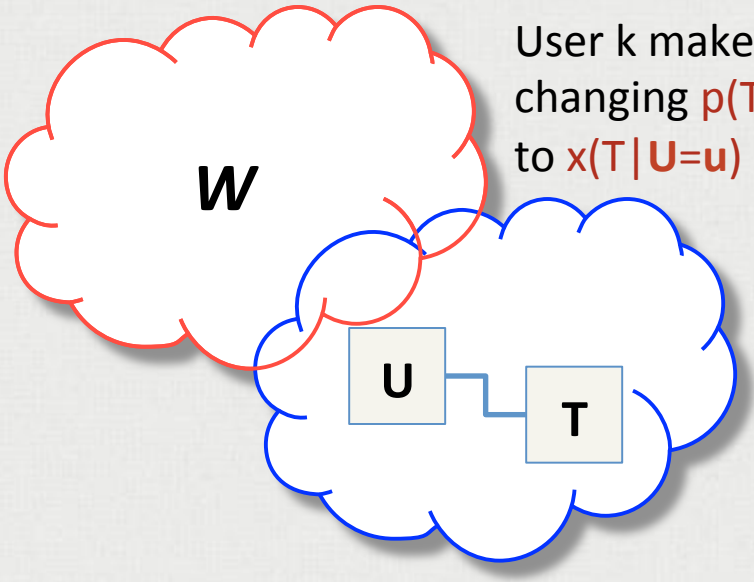


- Sun et al (2012) adapted JT algorithm to manage probabilities and assets
  - Conditional forecasts P(T|A) → P'(T|A) allowed if T, A in same clique
  - Apply soft evidence to implement P(T|A) → P'(T|A)
  - Use min-propagation (Dawid, 1992) to find minimum assets
    - Works becaue LMSR decomposes additively
    - Disallow trade if minimum assets less than zero
  - Use expectation propagation (Dawid, 1992) to calculate expected assets

More Efficient Asset Management

- Sun et al. (2012) used same JT for assets and probabilities
  - Very inefficient when each user trades on only a small proportion of questions
- Solution:
  - Global JT maintains probability information
  - User-specific asset structure maintains assets for joint space of variables on which user has traded
- Key questions:
  - Representing basic asset structure
  - Assembling asset structure from trades
  - Performing basic operations

Basic Unit – Trade Asset Block



User k makes edit, changing p(T|**U=u**) to x(T|**U=u**)

Trade Asset Block:

U \ T			
	-20	50	-10
	77	-23	-23
	…	…	…

$$\frac{x_i}{p_i} = \frac{x(\mathbf{w},t,\mathbf{u})}{p(\mathbf{w},t,\mathbf{u})} = \frac{p(\mathbf{w}\mid t,\mathbf{u})x(t\mid\mathbf{u})p(\mathbf{u})}{p(\mathbf{w}\mid t,\mathbf{u})p(t\mid\mathbf{u})p(\mathbf{u})} = \frac{x(t\mid\mathbf{u})}{p(t\mid\mathbf{u})}$$

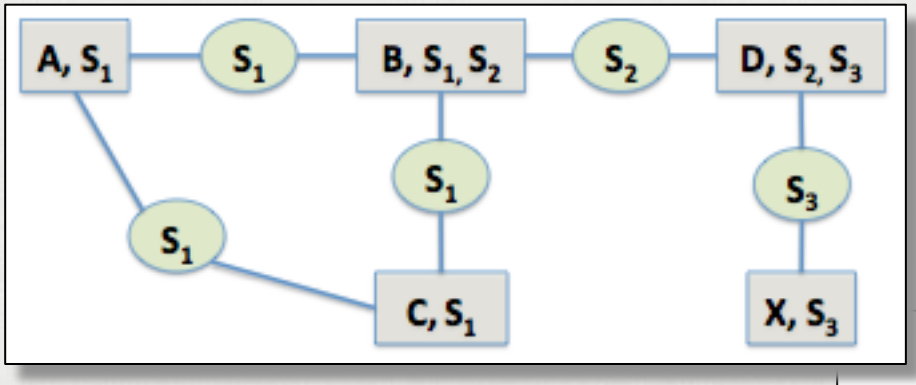
where x_i is new probability, p_i is current probability, of joint state i

User k's new assets in state i:

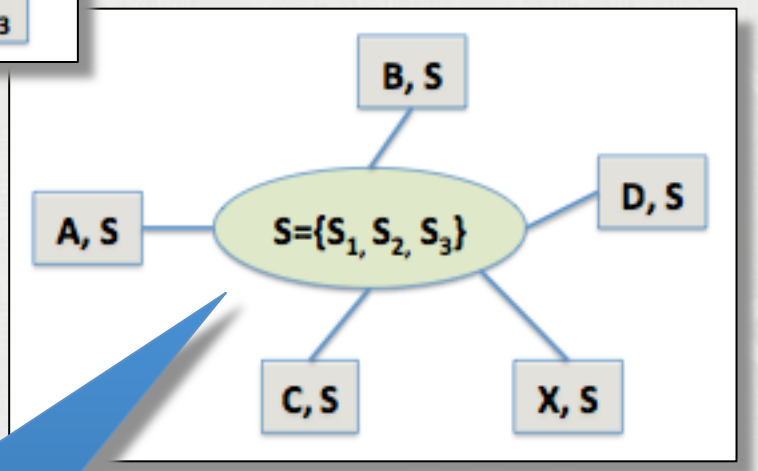
$$a_i^{(k)} + b\log\left(\frac{x_i}{p_i}\right) = a_i^{(k)} + b\log\left(\frac{x(t\mid\mathbf{u})}{p(t\mid\mathbf{u})}\right)$$

“Quick and Dirty” Solution: Global Separator

Collection of asset blocks



GS Tree



Key operations straight-forward to compute

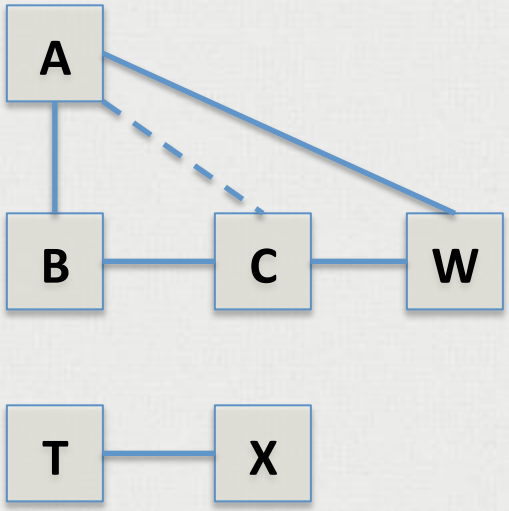
- Min assets
- Expected assets
- Effect of resolution

Very fast for small S

Brute force iteration over intersection

Approximate when intersection is large (lower bound on min assets)

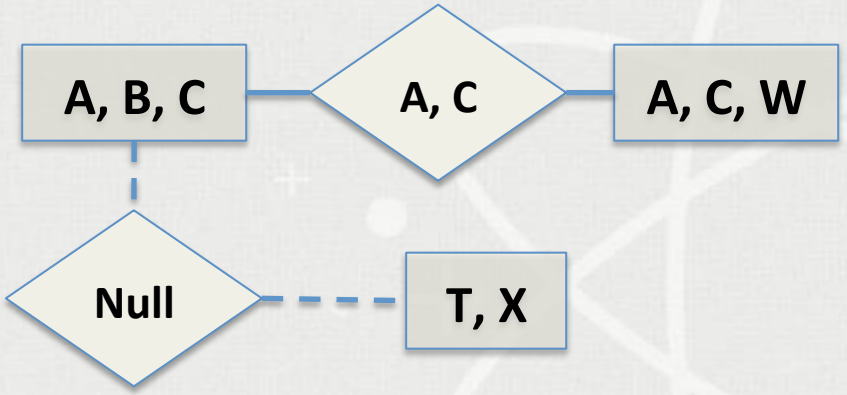
Dynamic Asset Cluster (DAC)



Trading history:

- P(A)
- P(A|B)
- P(B)
- P(B|C)
- P(C|W)
- P(A|W)
- P(T|X)

Asset junction tree:

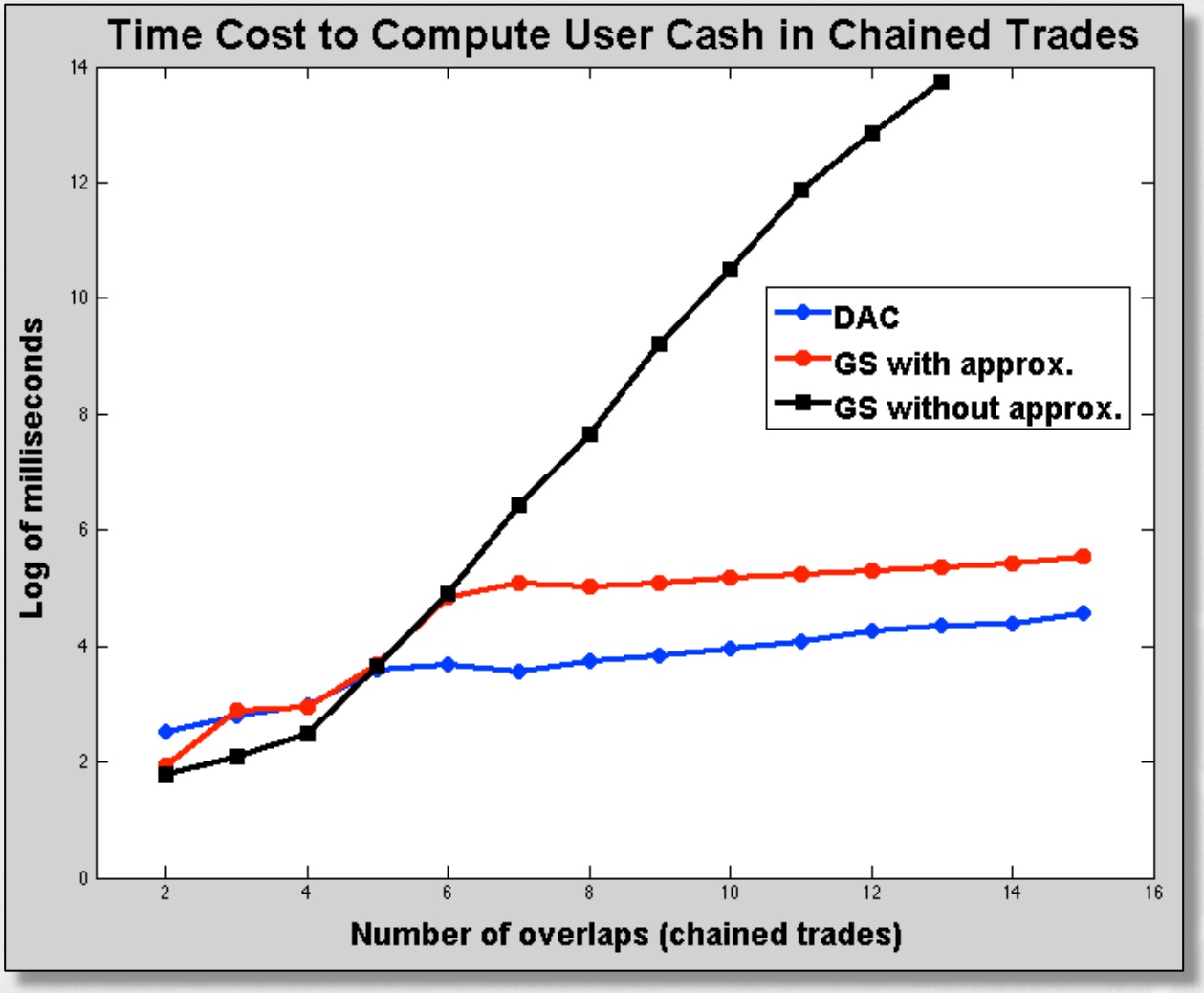


- Pair-wise connect variables in each trade block
- Compile into junction tree

Key Operations

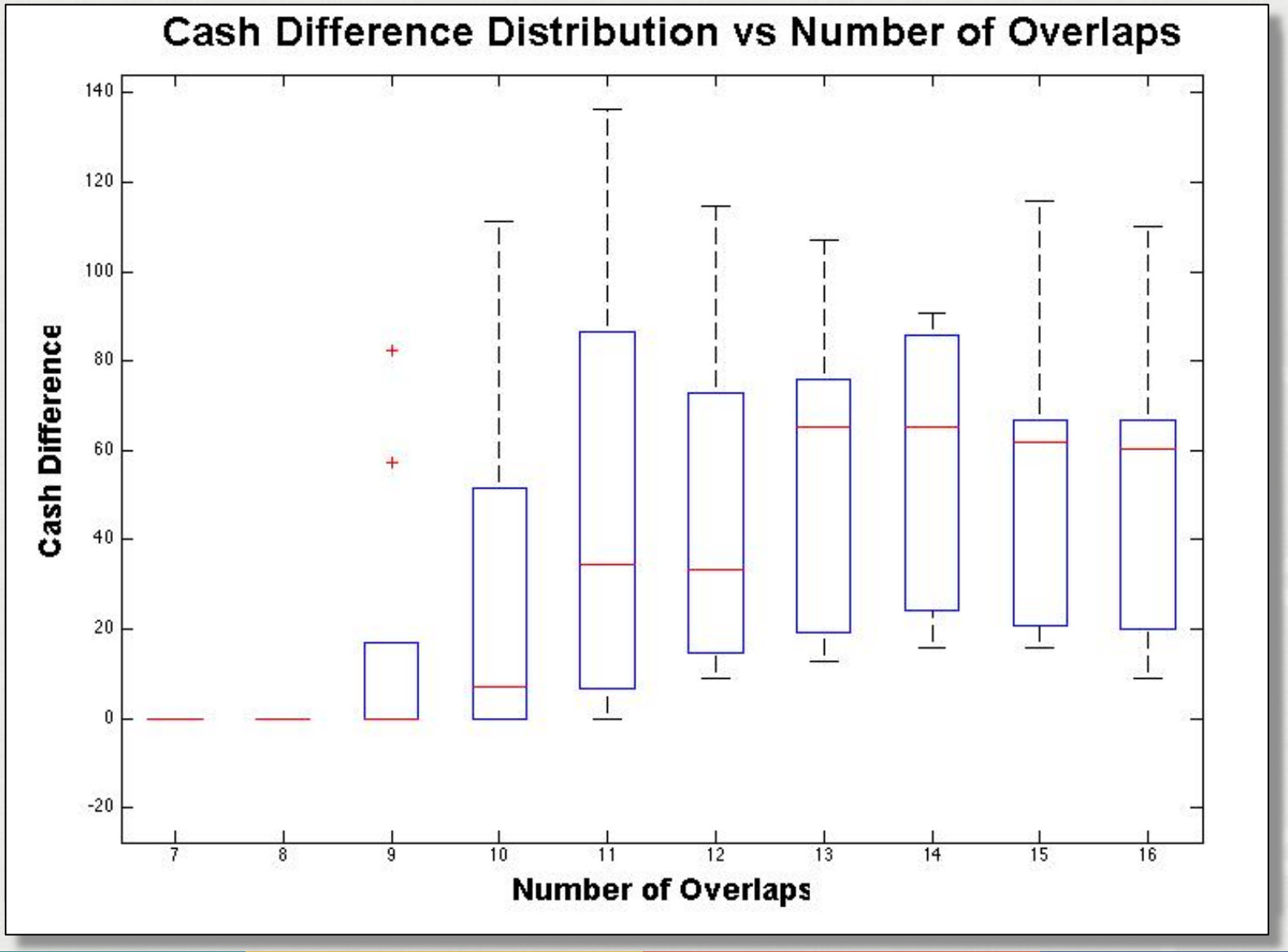
- Compute cash, a.k.a. minimum assets
  - Perform min-propagation over asset junction tree.
- Compute score, a.k.a. expected assets
  - Query belief structure for joint probabilities on trade blocks
  - Multiply assets times probabilities and add
- Resolve question
  - Shrink asset block by instantiating the resolved dimension.

DAC vs GS – Chained Trades

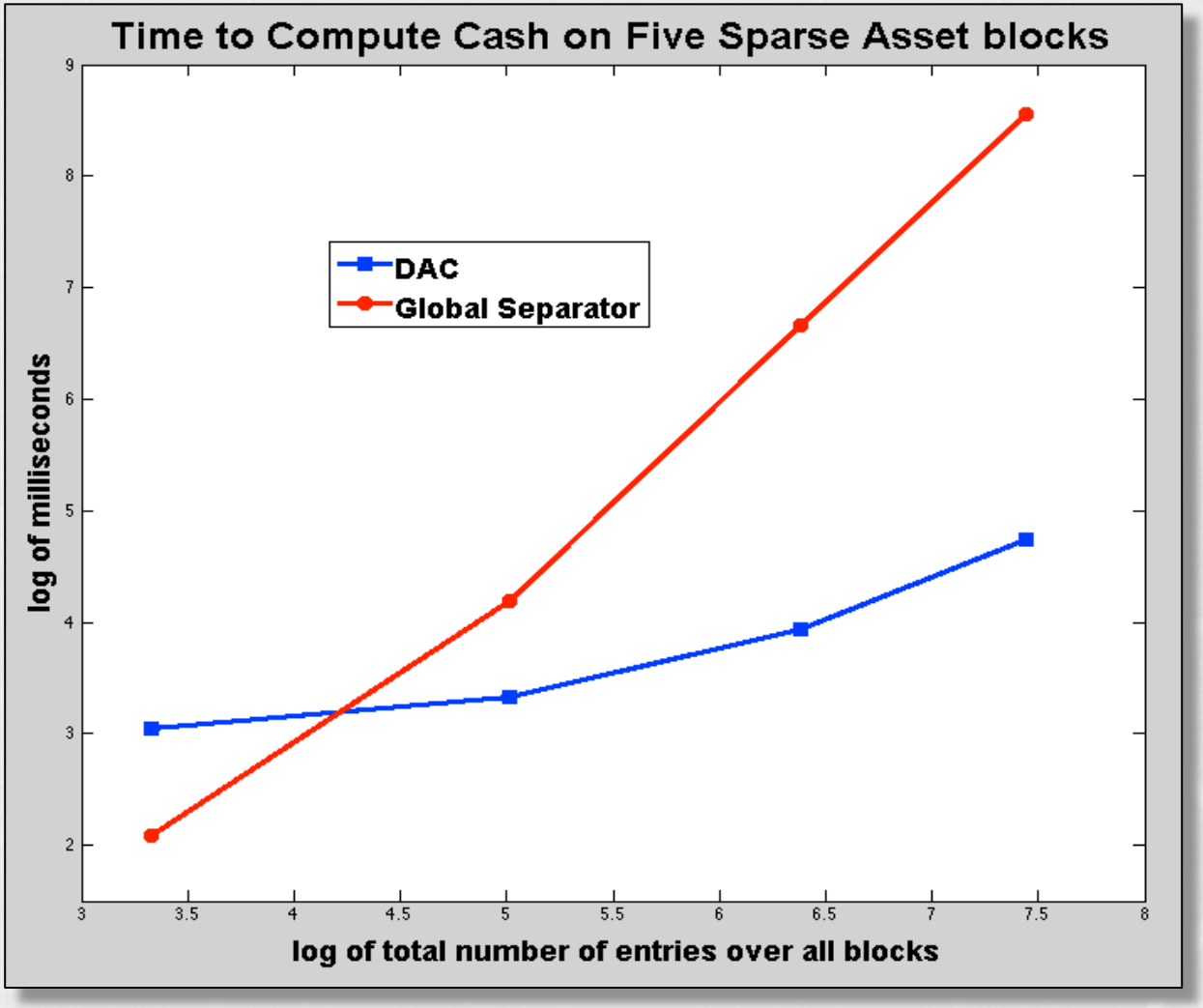


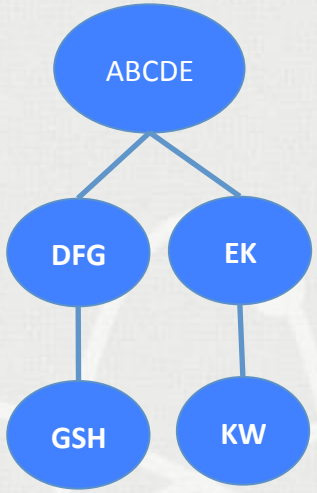
DAC has exponential savings on chains vs GS

DAC vs GS – Accuracy on Chained Trades



DAC vs GS – Five Sparsely Traded Blocks

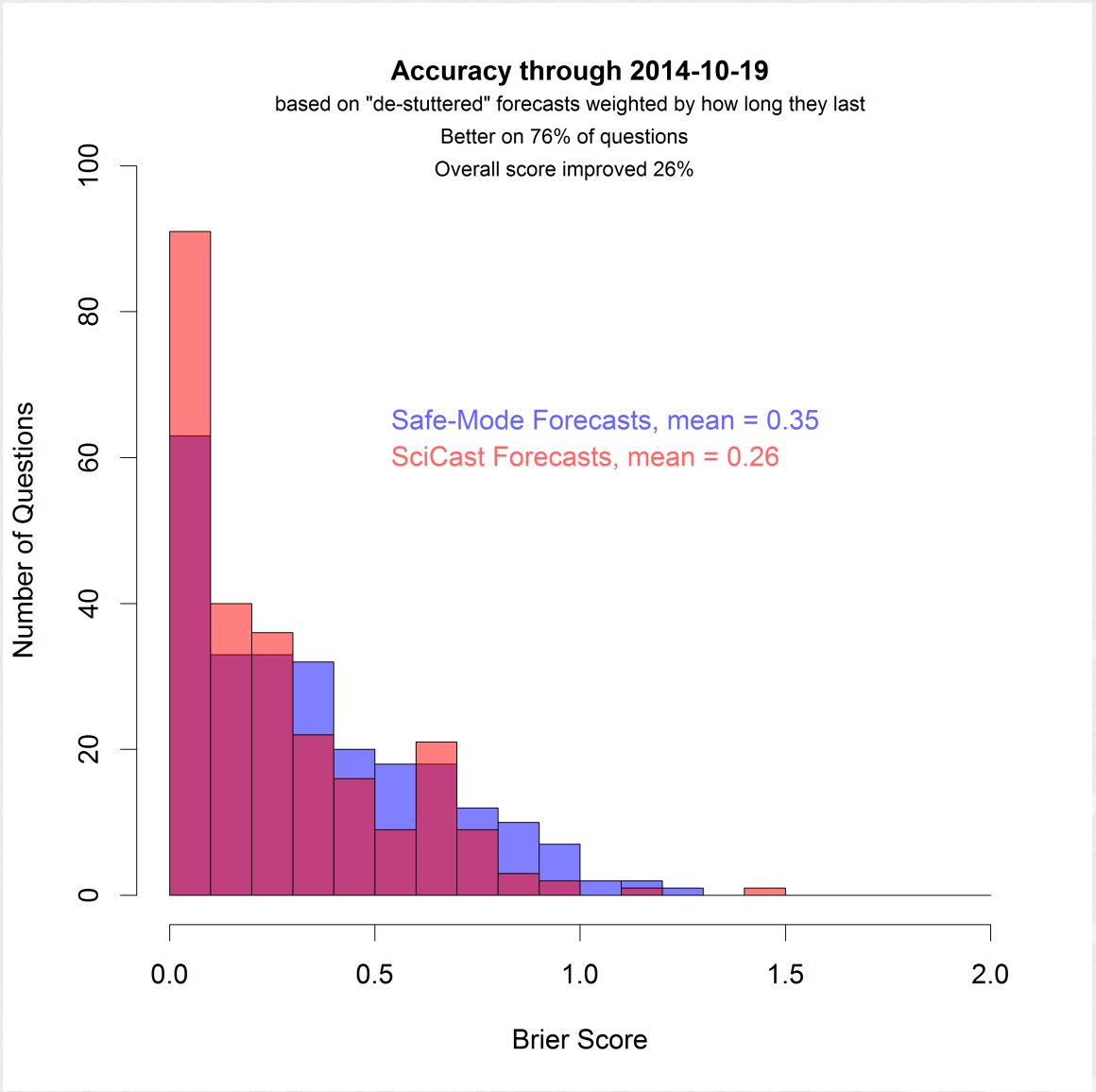




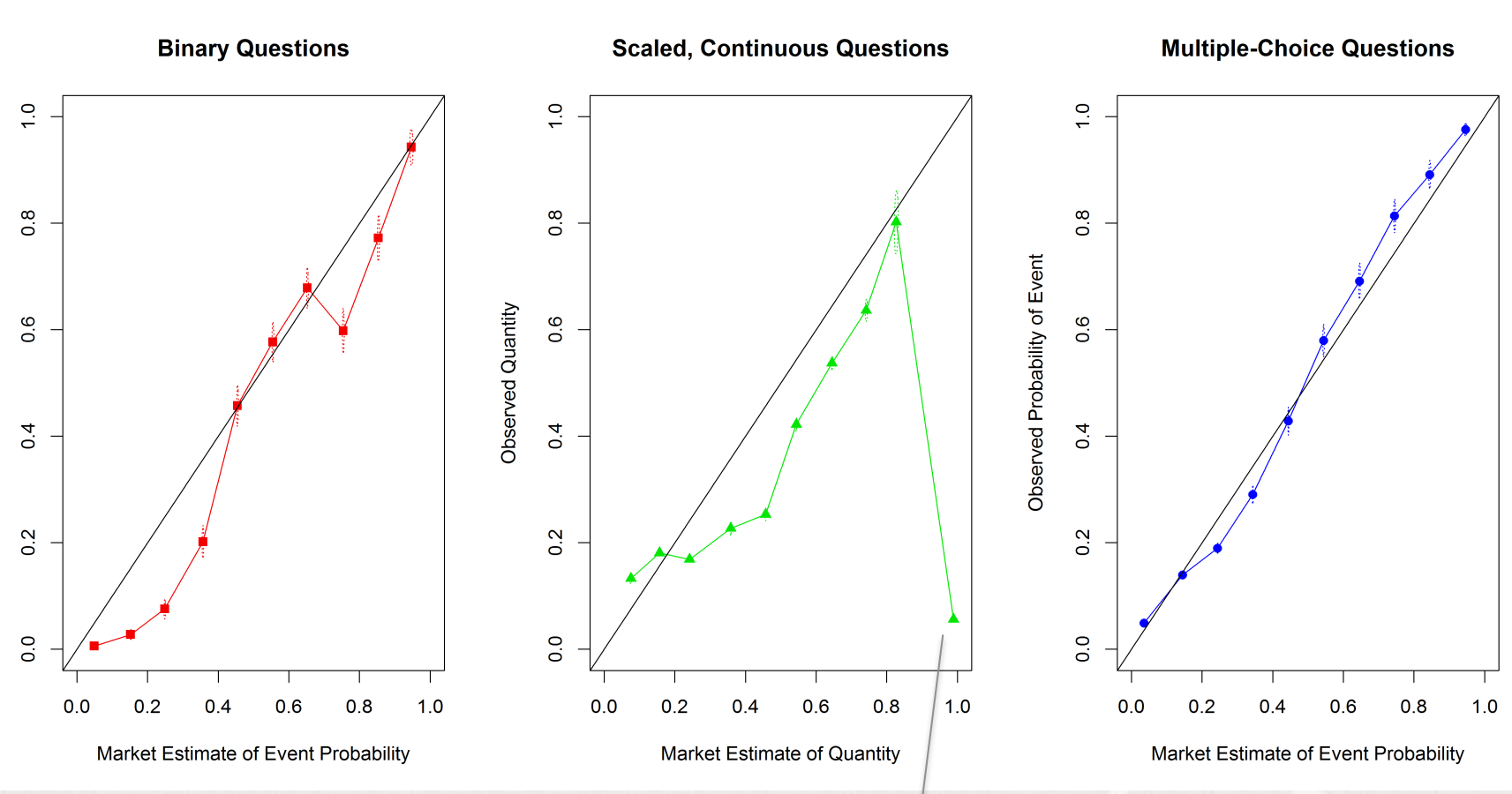
(Crossover is about 67)

DAC is slightly worse on easy cases (No Free Lunch)

SciCast Accuracy



SciCast Calibration



Single forecast: Someone briefly set it to the top of the range, then back.

- Incentivizing accuracy
  - The top 15 participants will win $2250* to spend at Amazon.com
  - The other 135 of the top 150 participants will win $225 to spend at Amazon.com
  - Nov. 7 – Mar. 6
  - http://blog.scicast.org/2014/11/04/scicast-recruitment/

* IRS 1099 will be sent

Conclusions

- SciCast is an open forum for S&T forecasting
  - **Join us!** Register at http://scicast.org
- LMSR based combinatorial prediction market aggregates judgments of many users into market distribution
- User-specific trade-based asset model dramatically increases efficiency of asset management
  - Same structure for assets and probabilities does not scale
  - GS: quick-and-dirty 2-level tree is best when there are few overlaps / small-to-moderate clique size
  - DAC: junction tree constructed from user's trades wins out as overlaps / clique sizes increase