Mathematical Foundations of Human Computation

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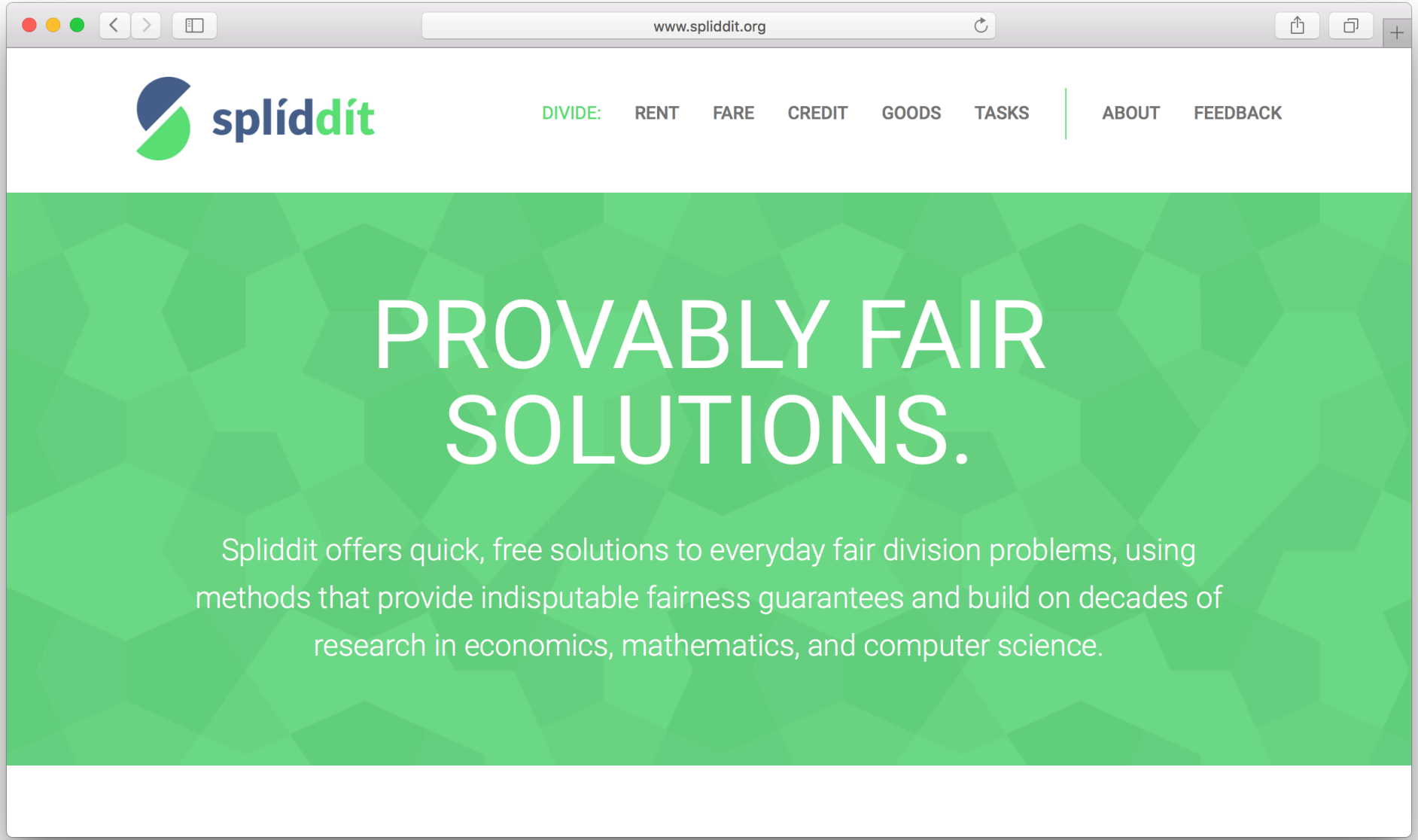
Why mathematical foundations?

Mathematical foundations help…

- Formalize desirable properties (e.g., correctness, optimality, scalability, privacy, fairness)
- Predict impact of design decisions (e.g., would quality improve under performance-based pay?)
- Design systems with provable guarantees (e.g., system does not discriminate based on demographic info, data remains private)
- Perform counterfactual analysis (e.g., what would happen if we increased pay by 30%?)

Warm-Up Example: Fair Division

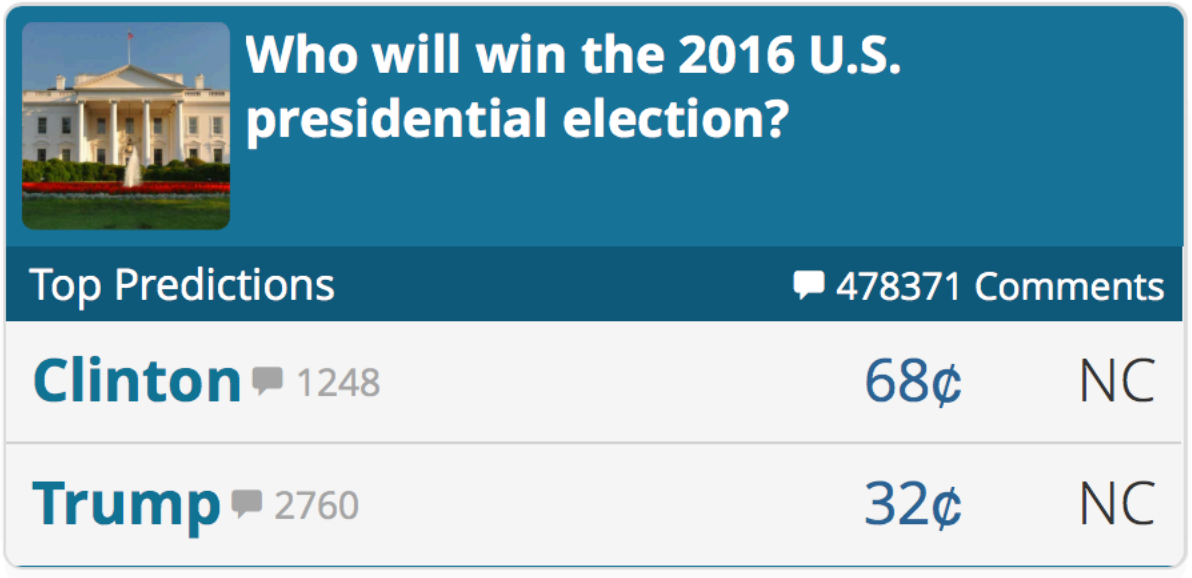


Warm-Up Example: Fair Division

- How should the system interact with roommates to extract the value of each room?
  - Build on economics literature on truthfulness
- What makes a set of prices and allocation fair?
  - Envy-freeness: given the prices for each room, every roommate prefers the room he is assigned
  - Pareto-efficiency: no prices/allocation could make a roommate happier without making another less happy
- How do we achieve fair prices and allocation?

[Gal et al., EC 2016]

Example: Prediction Markets



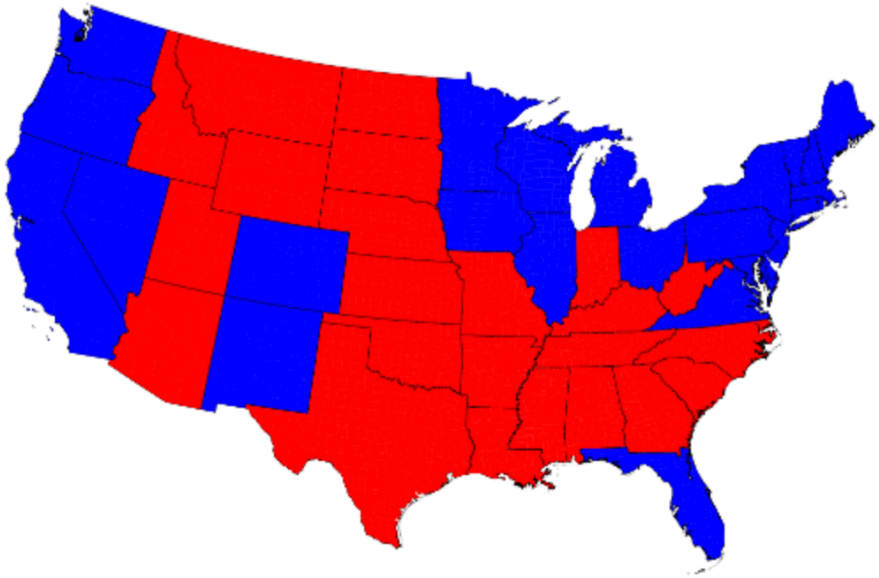
source: PredictIt.org

Payoff is $1 if Clinton wins. If probability of Clinton winning is *x*, I should

- Buy at any price less than $*x*
- Sell at any price greater than $*x*

Market price captures crowd's collective belief

Example: Prediction Markets



Chance of Clinton winning North Carolina?

Chance of Trump winning Ohio or Pennsylvania?

Challenges: liquidity, computational issues, ...

Can we generate coherent prices (and therefore coherent predictions) over large, complex outcome spaces?

[Abernethy et al., ACM TEAC 2013]

Example: Prediction Markets

- What properties should prices satisfy?
  - Information incorporation
  - No arbitrage
- How to find prices satisfying these properties?
  - Algorithms build on tools from convex optimization
  - Sometimes necessary to relax desired properties
- How should we interpret market prices?
  - Trickier; depends on model of trader behavior

[Abernethy et al., ACM TEAC 2013]

Example: Performance-Based Pay

1: Nearly every group of animals has its giants, its species wh
2: their fellows as Goliath of Gath stood head and shoulders a
3: hosts; and while some of these are giants only in comparisi
4: fellows, belonging to families whose members are short of
5: sufficently great to be called giants under any circumstance
6: giants live to-day, some have but recently passed away, an
7: long ages before man trod this earth. The most gigantic of n
8: whales—still survive, and the elphant of to-day suffers but little in
9: comparison with the mammoth of yesterday; the monstrous Dinosaurs, greatest of
10: all reptiles—greatest, in fact, of all animals that have walked the
11: earth—flourished thousands upon thousands of years ago. As for birds, some of
12: the giants among them are still living, some existed long geologic periods ago,
13: and a few have so recently vanished from the scene that th
14: lingers amid the haze of tradition. The best known among
15: most recent in point of time, are the Moas of New Zealand,
16: notice by the Rev. W. Colenso, later on Bishop of New Zea
17: missionaries to whom Science is under obligations. Early
18: Colenso, while on a missonary visit to the East Cape regio
19: natives of Waiapu tales of a monstrous bird, called Moa, h
20: man, that inhabited the mountain-side some eighty miles a
21: the last of his race, was said to be attened by two equally h
22: kept guard while he slept, and on the approach of man wa
23: imediately rushed upon the intruders and trampled them to
24: Maoris had seen this bird, but they had seen and somewhat
25: making parts of their fishing tackle, bones of its extinct relatives, and these
26: bones they declared to be as large as those of an ox.
27:
28: About the same time another missionary, the Rev. Richard Taylor, found a bone
29: ascribed to the Moa, and met with a very similer traditition among the natives of
30: a near-by district, only, as the foot of the rainbow moves away as we move
31: toward it, in his case the bird was said to dwell in quite a diffrent locality
32: from that given by the natives of East Cape. While, however, the Maoris were

Proofread this text, earn $0.50

Earn an extra $0.10 for every typo found

performance-based payments

Example: Performance-Based Pay

- Goals: Use theoretical tools to...
  - Predict the impact of payments on worker quality (a form of counterfactual analysis)
  - Design performance-based payments to optimally trade off cost and benefit (a learning problem)

- Both require a model of worker behavior

[Ho et al., EC 2014]

Example: Performance-Based Pay

- Initial theory derived under standard econ model, worker chooses to produce work of the quality q that maximizes her expected utility:

$$\text{BasePayment} + \text{BonusPayment} \times \Pr(\text{GetBonus} \mid q) - \text{Cost}(q)$$

probability of receiving the bonus

intrinsic cost of performing the work

- Algorithm designed to optimize worker payments adaptively

[Ho et al., EC 2014]

Example: Performance-Based Pay

- Experiments showed a small tweak to this model better explains observed worker behavior:

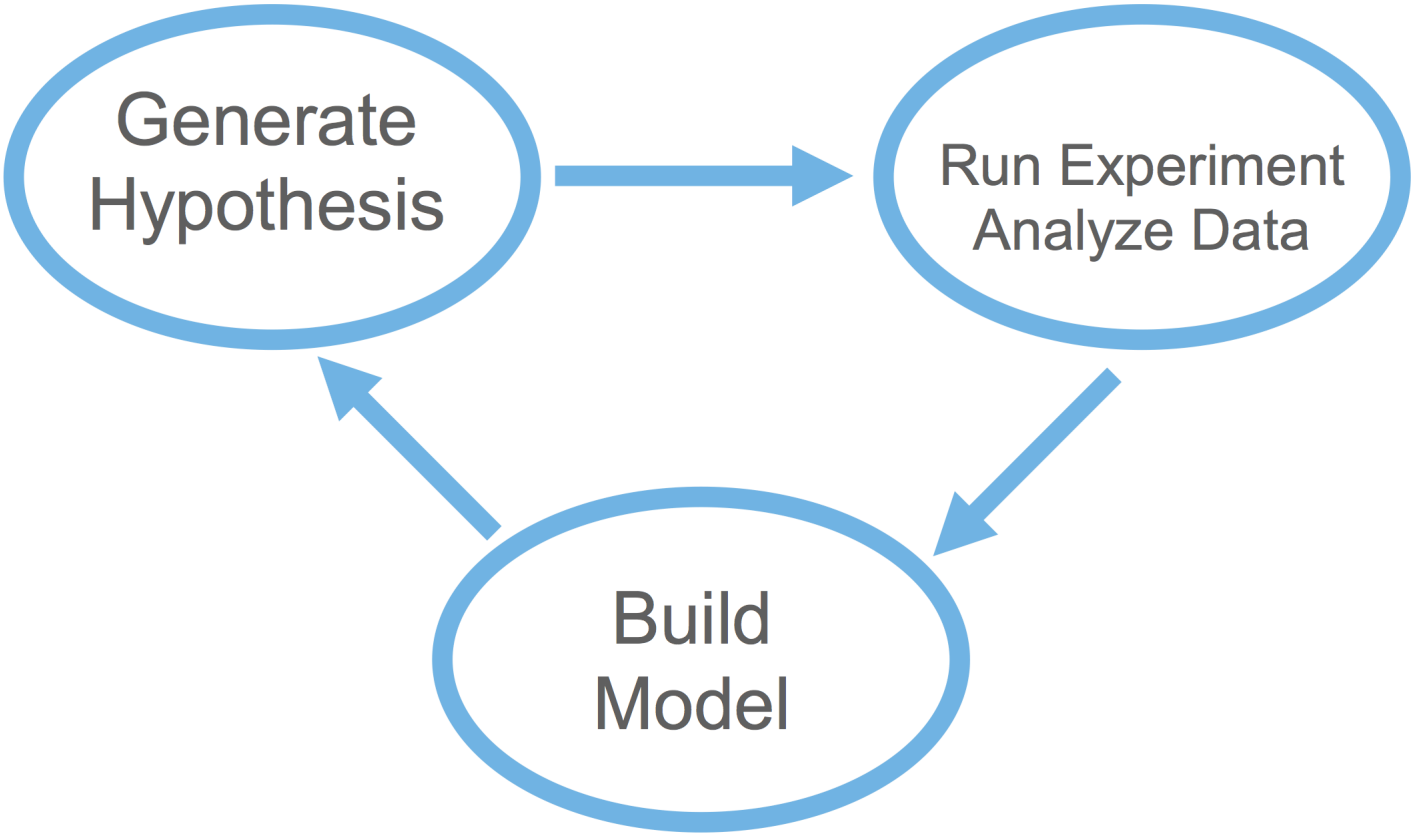
subjective probability of receiving the base

$$\text{BasePayment} \times \Pr(\text{GetBase} \mid q) + \text{BonusPayment} \times \Pr(\text{GetBonus} \mid q) - \text{Cost}(q)$$

subjective probability of receiving the bonus

[Ho et al., WWW 2015]

Challenge 1: How to design models that accurately incorporate human behavior



[source: Sid Suri]

Challenge 2: How to foster dialog between theoretical, experimental, and empirical research & across disciplinary boundaries

Challenge 3: How to get results that generalize beyond inherently mathematical problems

Challenge 4: How to handle issues of transparency, interpretability, and ethical implications

Welcome again!