Australian AI 2015 Tutorial Program
Computational Social Choice

Haris Aziz and Nicholas Mattei
Data61 and UNSW

Social Choice

- Given a collection of agents with preferences over a set of things (houses, cakes, meals, plans, etc.) we must…
  - 1. Pick one or more of them as winner(s) for the entire group

    OR....

  - 2. Assign the items to each of the agents in the group.

Subject to a number of exogenous goals, axioms, metrics, and/or constraints.

Bi-Lateral Trade

Import Ideas

Implement ideas from outside CS when designing, implementing, and deploying systems.

Analyze Results

Analyze computational aspects of procedures found outside CS.

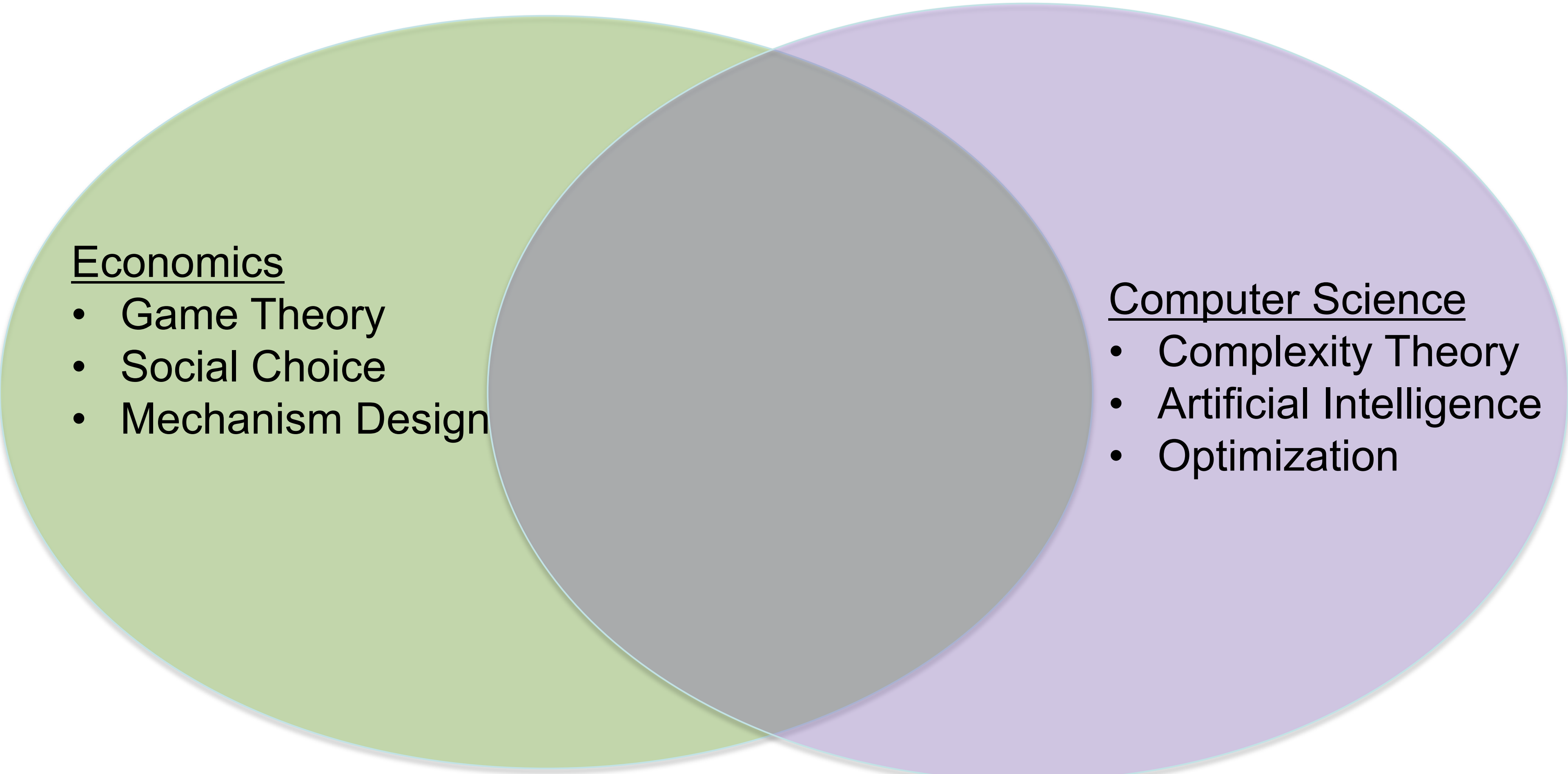
AGT and ComSoc

Economics

- Game Theory
- Social Choice
- Mechanism Design

Overview Article: Vincent Conitzer. Making Decisions Based on the Preferences of Multiple Agents. Communications of the ACM (CACM), 2010

AGT and ComSoc



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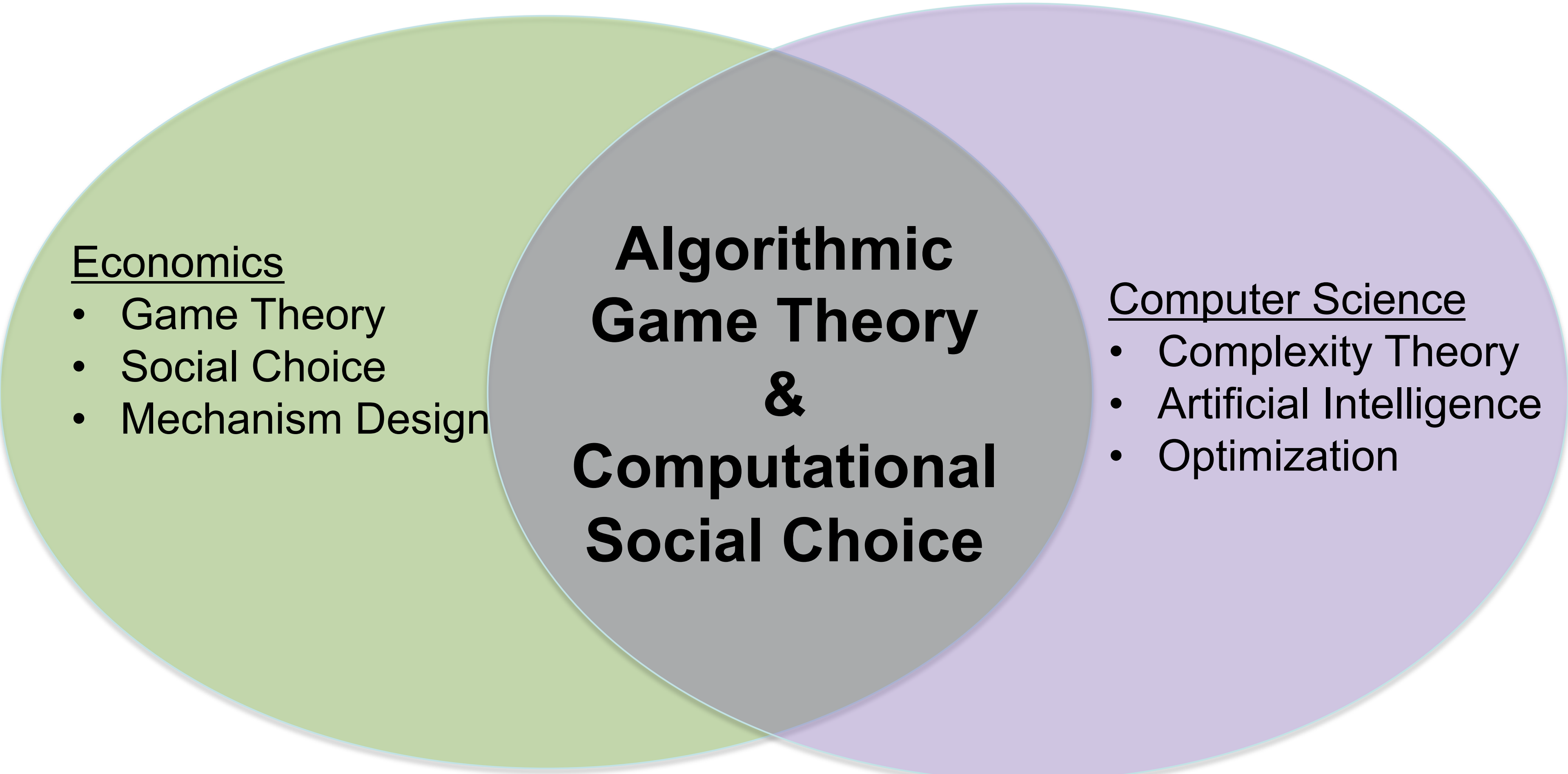

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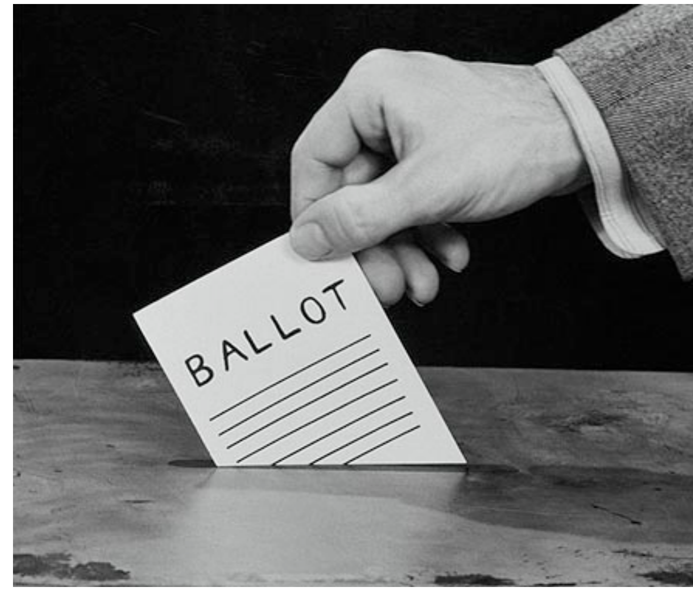
Group Decisions

- Problems arise when groups of agents (humans and/or computers) need to make a collective decision.
- How do we aggregate individual (possibly conflicting) preferences and constraints into a collective decision?

Voting and Ranking Systems

- Voting has been used for thousands of years - many different elections systems which have been developed.
    - Used to select one or more alternatives that a group must share.



- Ranking systems are the social choice setting where the set of agents and the set of choices is the same.

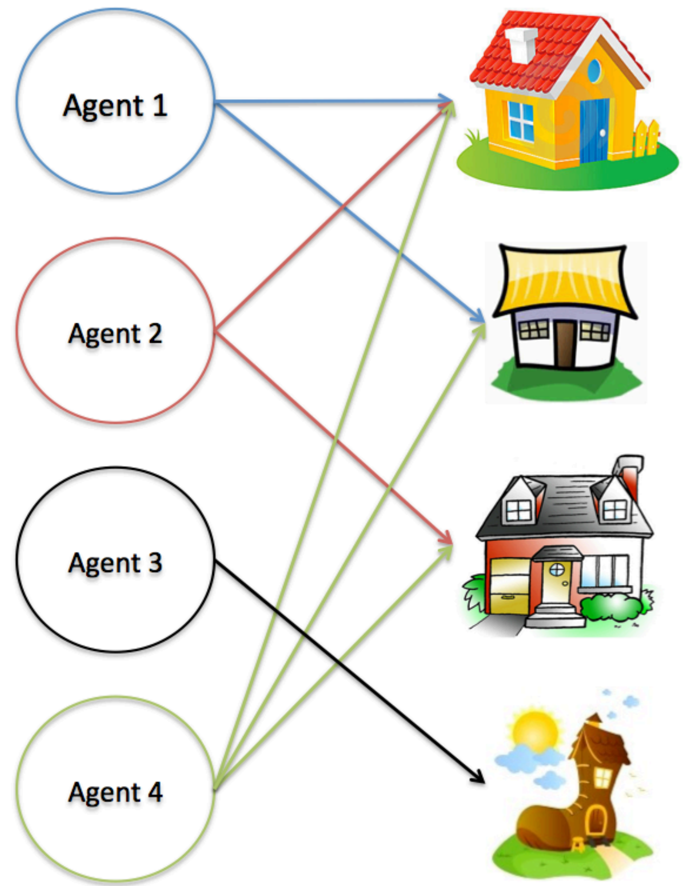
Markets and Mechanisms

- Bidding, Auctions and Markets are other mechanisms used to aggregate the preferences of a collection of agents for an item or sets of items.

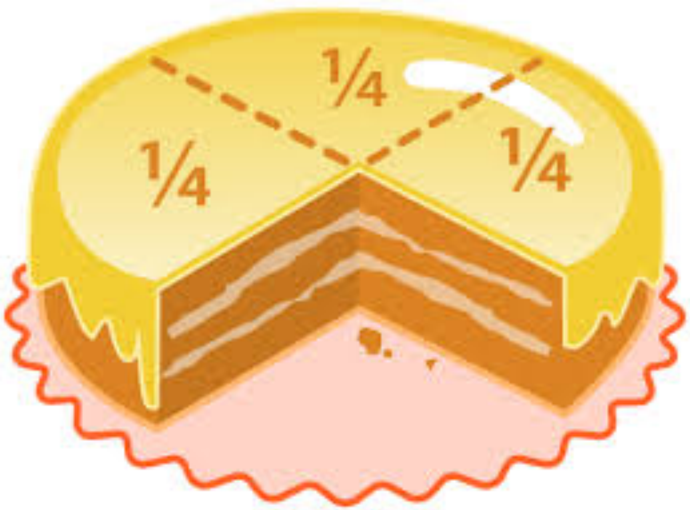
- All these mechanisms usually require a central agent to collect the bids, announce a winner, collect the final price and in some cases, return value to the losing agents.

Matching and Assignment

- Assign items from a finite set to the members of another set.
  - Useful in many applications including allocating seats in schools, kidneys for transplant, runways to airplanes.
- Many axes to consider.
  - Divisible v. Indivisible Goods
  - Centralized v. Decentralized
  - Deterministic v. Random
  - Efficiency v. Fairness



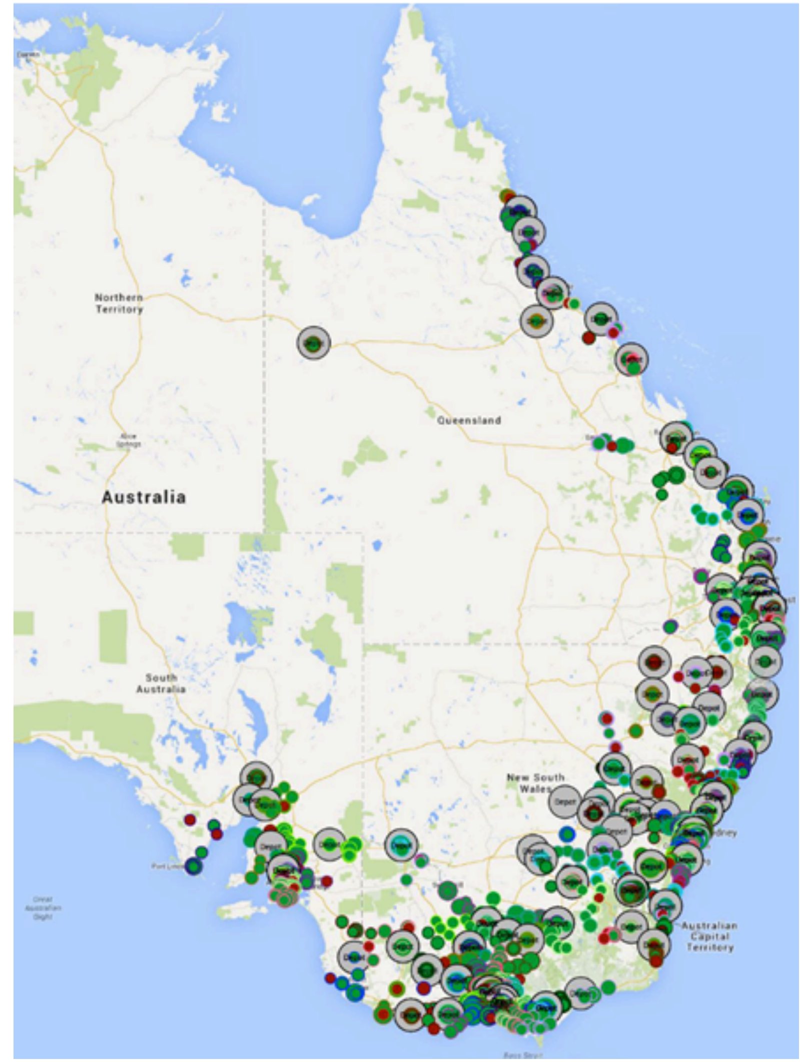
Resource Allocation and Fair Division



- Given a divisible, heterogeneous resource (such as a cake) how do we divide it among agents who may have different constraints, preferences, or complementarities over the portions?
  - Use to allocate land, spectra, water access…
- Many similar considerations:
  - Proportionality, fairness, no disposal, no crumbs…

Coalition Formation

- Agents form teams or groups which improve utility.
  - How and when will these groups form?
  - How do we allocate costs or revenues for these groups?
  - How stable are these groups?
- Part of cooperative game theory and studied in many areas.



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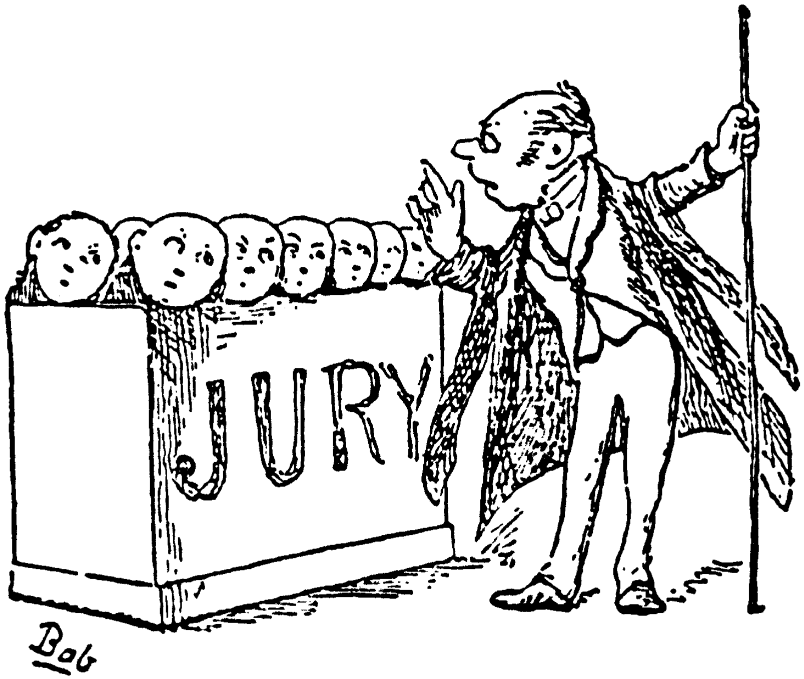
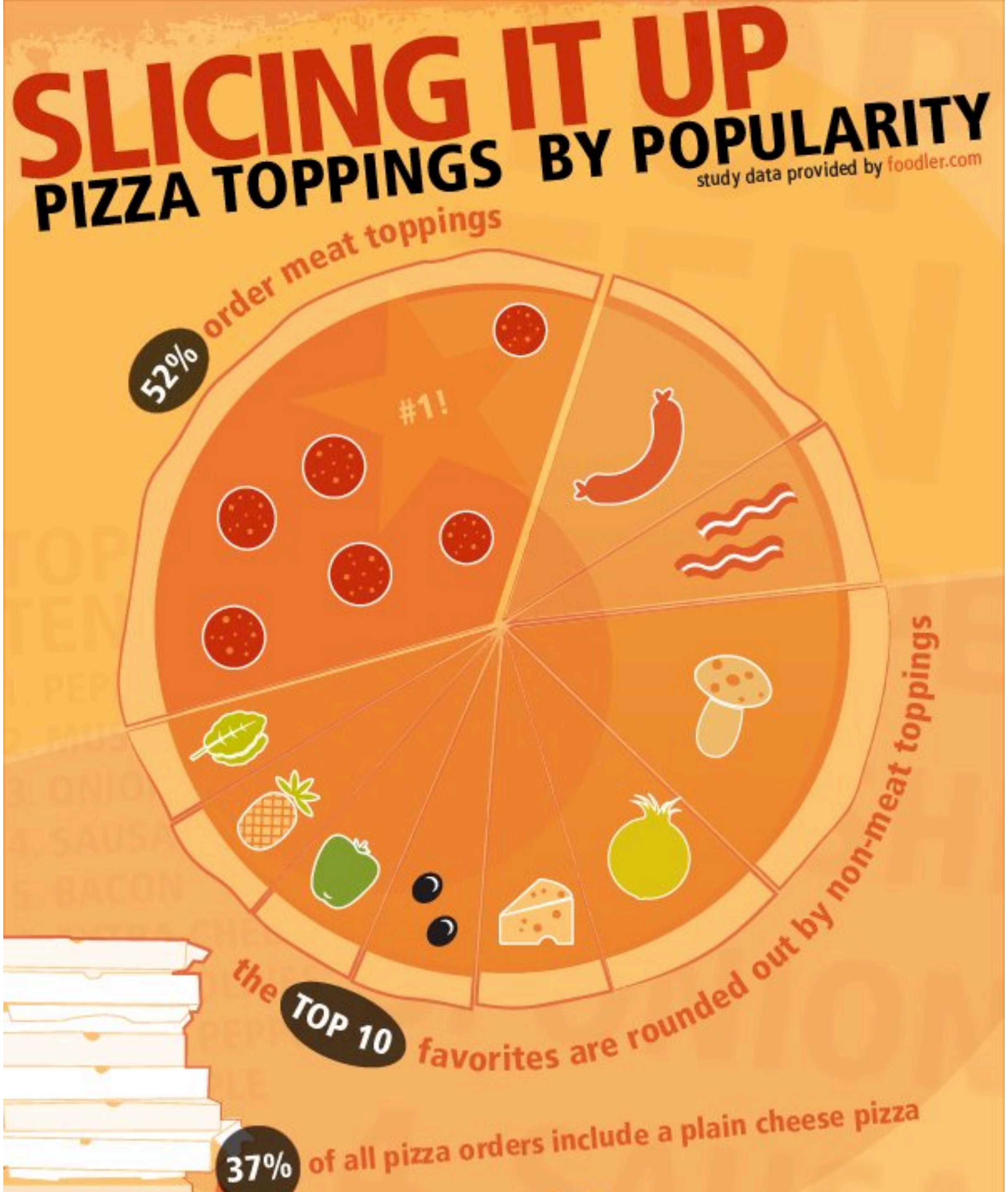
Judgment Aggregation and Belief Merging

- Judgment Aggregation: Groups may need to aggregate judgments on interconnected propositions into a collective judgment.
- Belief Merging: Groups may need to merging a set of individual beliefs or observations into a collective one.
    - Extensively studied in logics and other areas.



Why?

- For collecting and ranking search results, movies, pizzas...
- For selecting leaders in distributed network structures.
- To find optimal allocations of resources.
- To coordinate and control distributed systems.
- To make group judgments, decisions, views of reality…



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Preferences v. Constraints

- In common usage we often conflate constraints and preferences.

- A *constraint* is a requirement.
  - There is a maximum of one meat topping.
  - I cannot eat peanuts.

- A *preference* is a soft (“nicer”) constraint.
  - I *prefer* pizza to pasta.
  - I want anchovies.

So What Are Constraints?

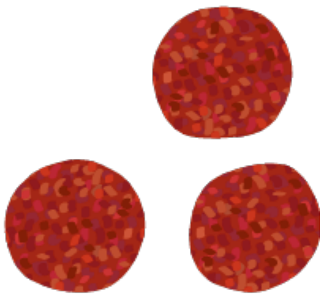
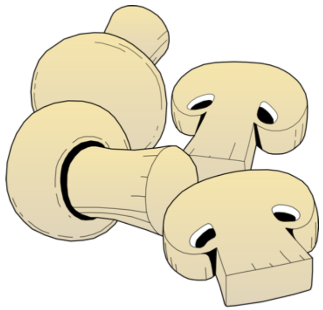
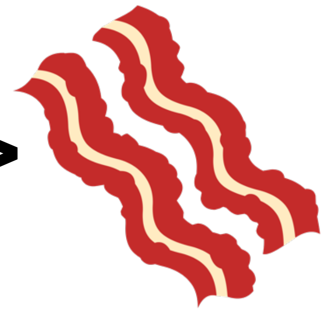
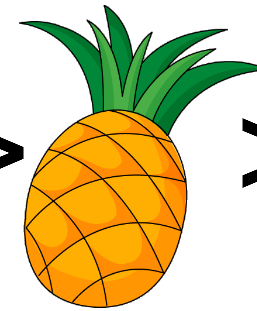
- A constraint is a requirement.
- Constraints limits the feasible space to a set of points where all constraints are satisfied.
- Basic Computational Paradigm:
    - Set of Variables $\{X_1 \ldots X_n\}$ and domains $\{D_1 \ldots D_n\}$.
    - Set of Constraints $C(X_1, X_2)$ - a relation over D_1 X $D_{2.}$
    - Find an assignment to $\{X_1 \ldots X_n\}$ that is consistent.
- Common in many applications:
    - Scheduling, time-tabling, routing, manufacturing…

So What Are Preferences?

- A preference is a relation over the domain.
  - Set of Variables $\{X_1 \ldots X_n\}$ and domains $\{D_1 \ldots D_n\}$.
  - A preference is a relationship over the elements of D_i.
- Refine under constrained problems that admits many solutions.

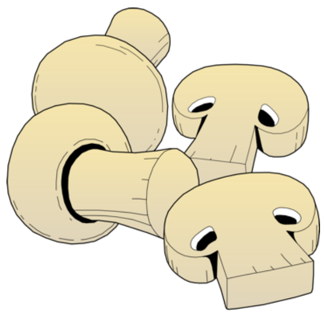
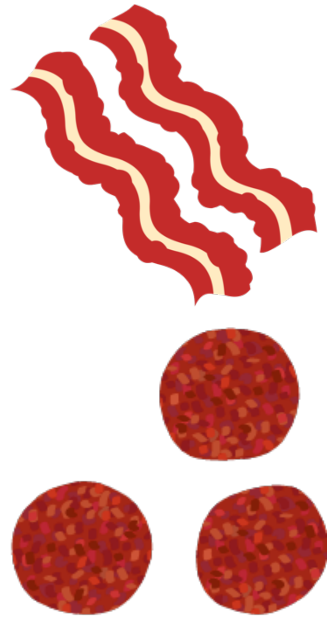
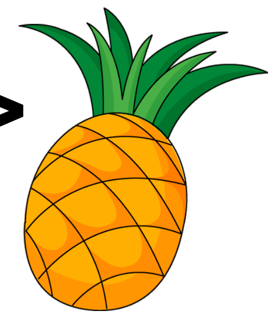
- Positive
  - I like peperoni on my pizza.
- Negative
  - I don't like anchovies.
- Unconditional
  - I prefer extra cheese on my pizza.
- Conditional
  - If we have two pizzas, I prefer a sausage and a bacon pizza, otherwise I prefer an extra cheese pizza.
- Quantitative v. Qualitative
  - My preference is 0.4 for sausage and 0.5 for bacon.
  - Sausage pizzas are better than bacon pizzas.

Complete Strict Orders

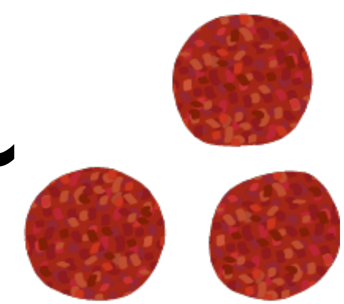
 >  >  >  > 

- Every item appears once in the preference list.
- All pairwise relations are complete, strict, and transitive.

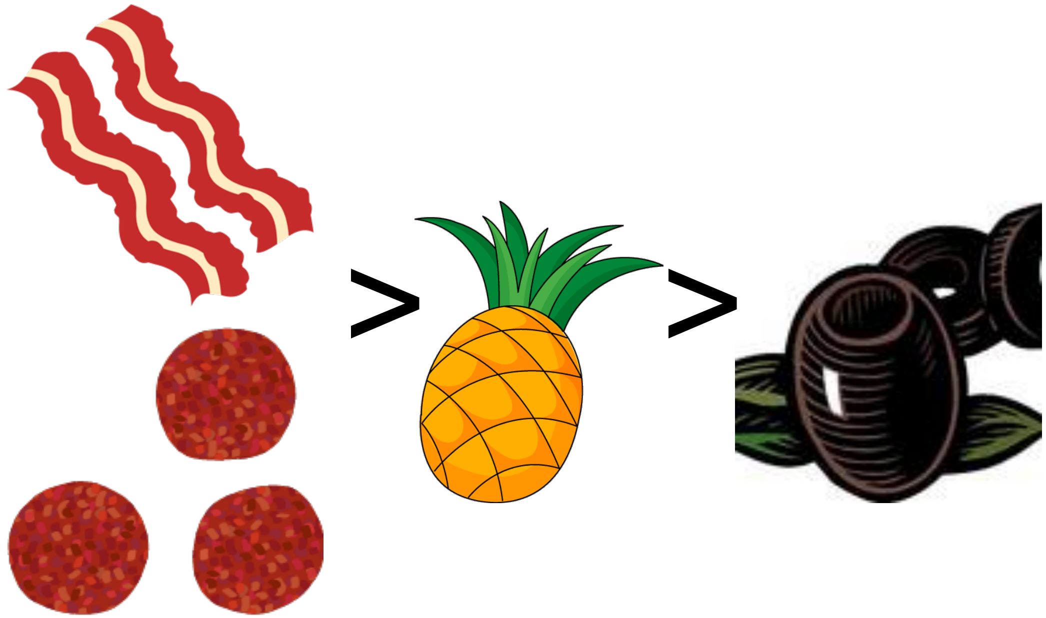
Complete Orders with Indifference

 >  >  > 

- Every item appears once in the preference list.
- Pairwise ***ties*** are present.
- We denote indifference with the ~ operator.

 ~ 

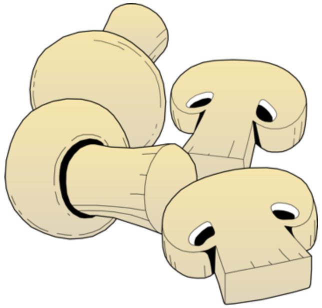
Incomplete Orders with Indifference



- Not every item appears in the preference list.
- Pairwise ties are present.

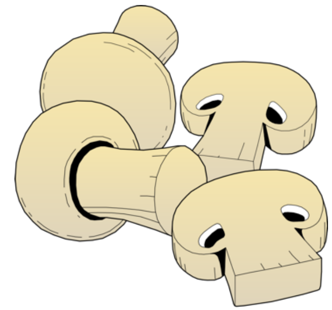
Complex Topping Options

Veg

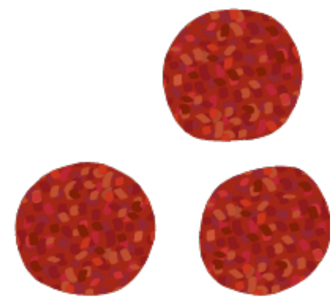


Complex Topping Options

Veg

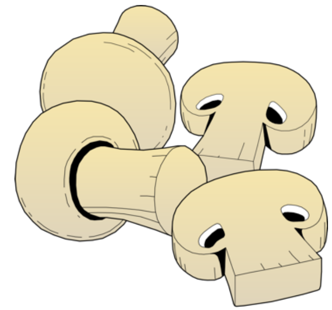


Meat

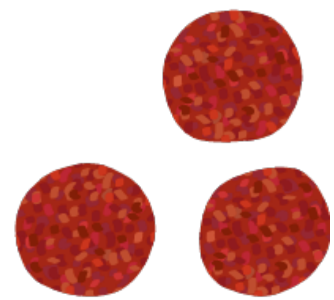


Complex Topping Options

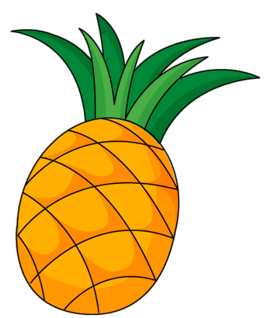
Veg



Meat



Extra



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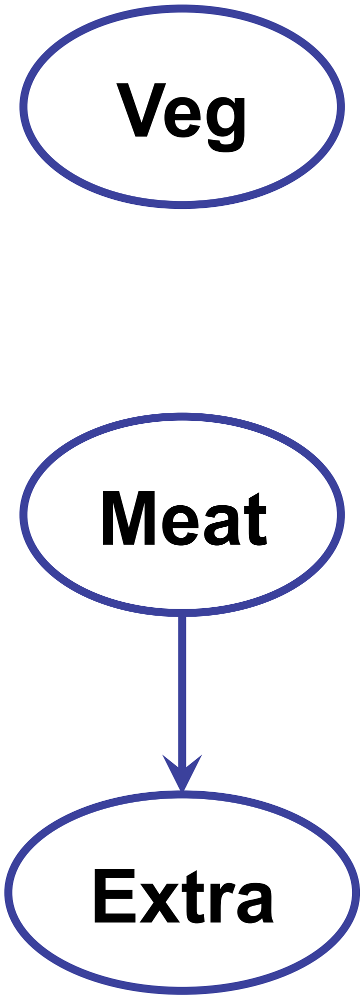

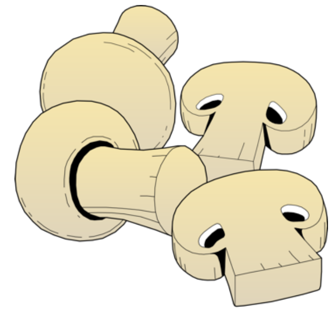

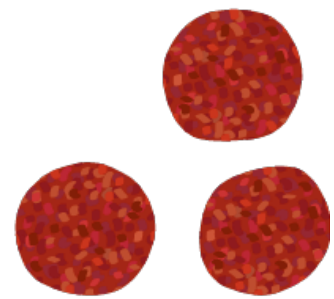

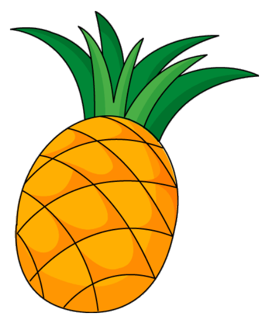

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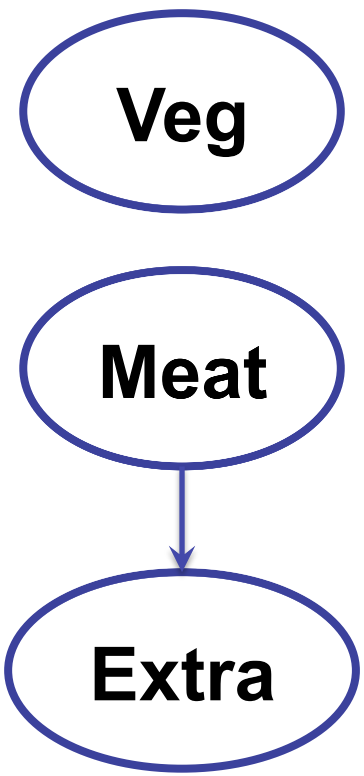
CP-Nets

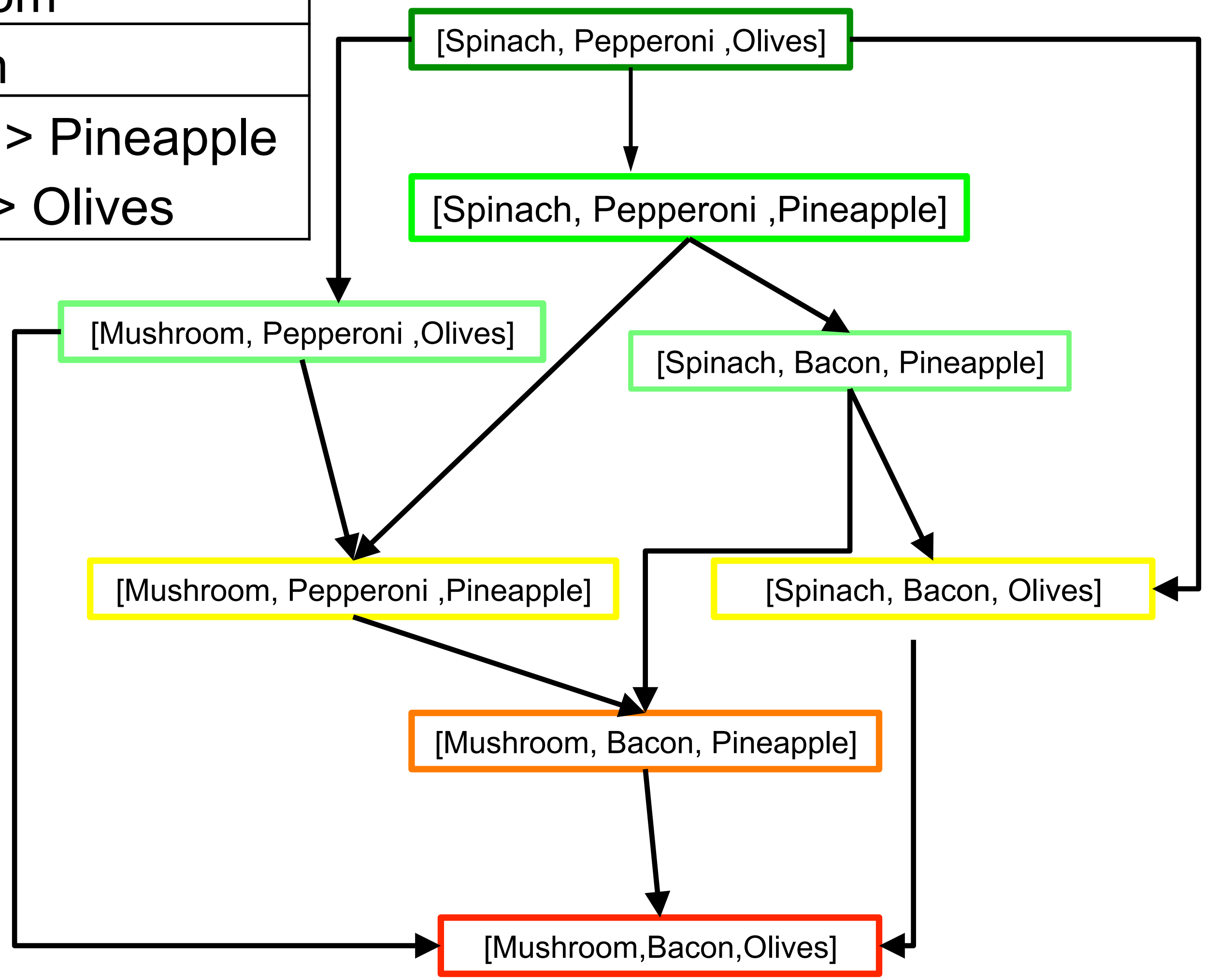
- CP-nets are a graphical model for representing conditional preference relations – sets of cp-statements.
  - “All else being equal, I prefer pineapple to olives if we have bacon pizza.”

- Formally we have:
  - A set of **issues** or **variables** $F = \{X_1, \ldots, X_n\}$ each with finite domain $D_1, \ldots D_n$.
  - A (empty) set of **parents** for each issue $Pa(X_i)$.
  - A preference order over each **complete assignment** to the parents for each issue.

CP-Nets

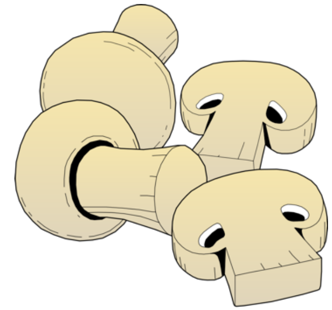
Veg	Spinach > Mushroom
Meat	Pepperoni > Bacon
Extra	Pepperoni: Olives > Pineapple Bacon: Pineapple > Olives





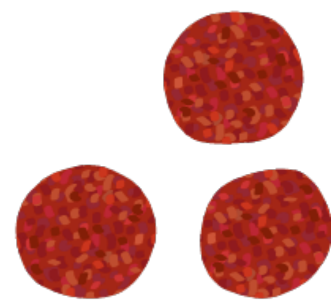
Numerical Preferences (Utility)

= 5.0

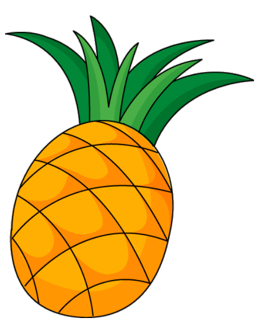


= 0.1

= 0.001



= 0.0



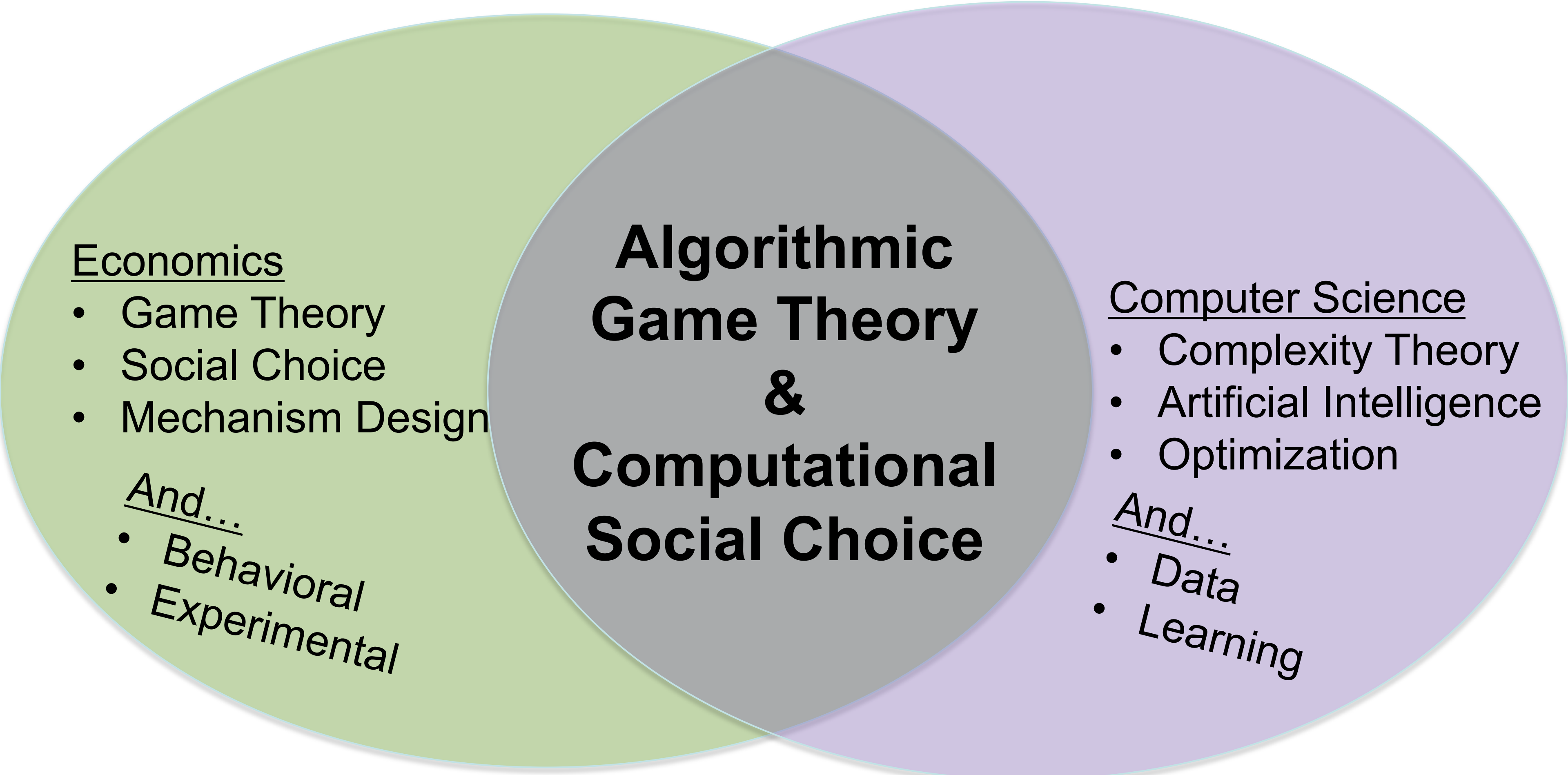
= 10.0

= 22.5764

Numerical Preferences (Utility)

- Utilities can indicate a degree of preference for an object
- Can be from a ranked list of options
  - 1 to 5 stars for movies.
  - +1 and -1 for Like and Dislike.
- Decreases complexity often – but also decreases expressiveness.
- Many issues with combining utilities, scaling, formatting etc. which Haris will touch on later!

AGT and ComSoc



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Challenges

- Variety
  - We need lots of examples from many domains.
- Elicitation
  - How do we collect and ensure quality?
- Modeling
  - What are the correct formalisms?
- Over-fitting
  - Can we be too focused?
- Privacy and Information Silos
  - Some data cannot or will not be shared…

{PrefLib}: A Library for Preferences

Main **About** **Papers** **Data Formats** **Data By Domain** **Data By Type** **Tools**

A reference library of preference data and links assembled by Nicholas Mattei and Toby Walsh. We currently house over 3,000 datasets for use by the community.

We want to provide a comprehensive resource for the multuple research communities that deal with preferences, including computational social choice, recommender systems, data mining, machine learning, and combinatorial optimization, to name just a few.

Please see the about page for information about the site, contacting us, and our citation policy. We rely on the support of the community in order to grow the usefulness of this site. To contribute, please contact Nicholas Mattei at: nicholas**{dot}**mattei@nicta.com.au

$a > b > c > d$

$a > b, c, d > e$

$\frac{1}{2} : a > b > c$

$\frac{1}{4} : c > b > a$

$\frac{1}{4} : b > c > a$

Supported By:

NICTA

www.preflib.org

Sept. 3, 2013:
A big update today brings us over 3000 datasets hosted on the site with a full data archive over 7 GB!

We have also added a Thanks!! section to recognize those individuals who have helped make PrefLib possible.

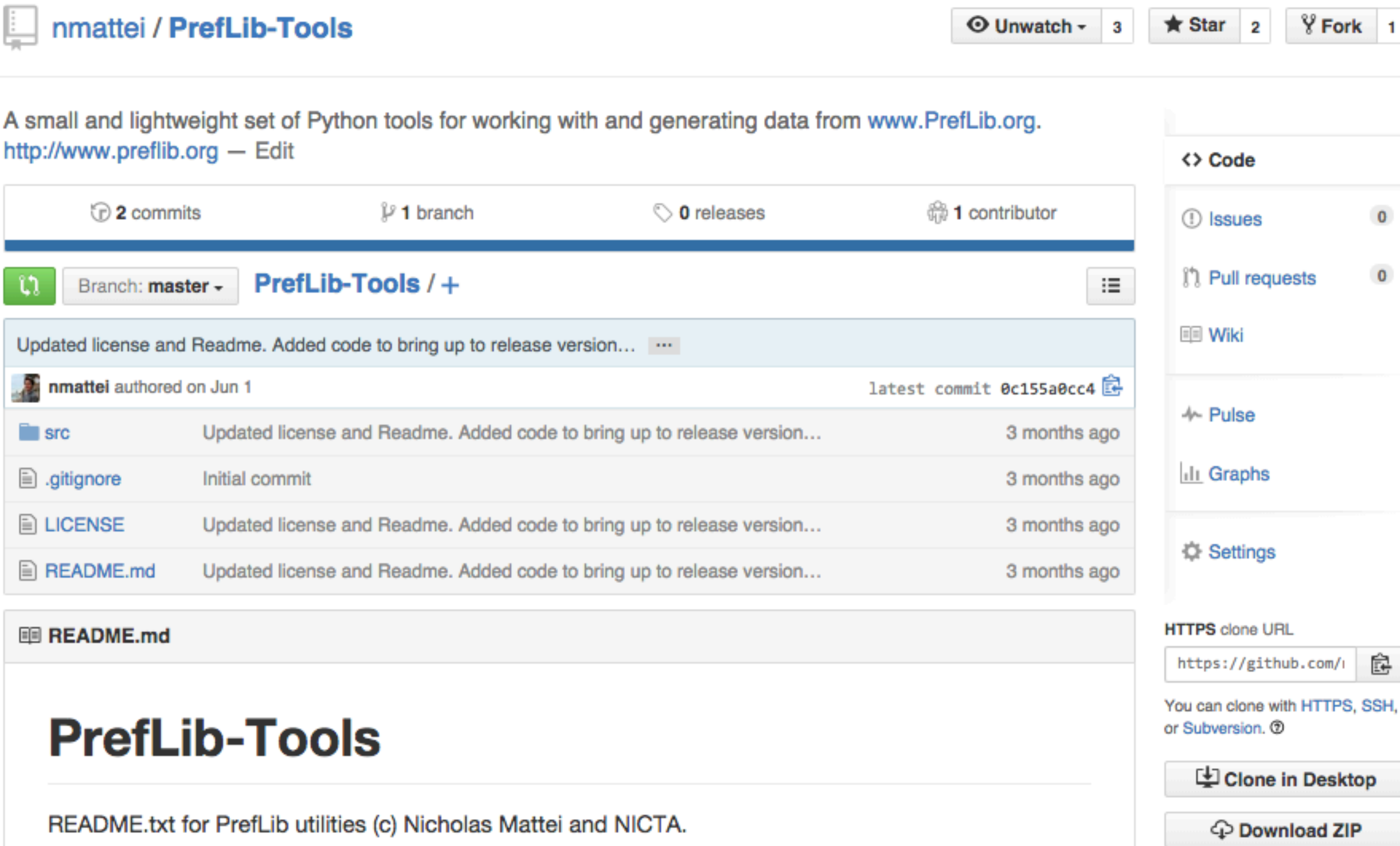
July 1, 2013:
Our paper has been accepted to 2013 Conference on Algorithmic Decision Theory. We have also had several new donated datasets which have been parsed and posted.

We have added a new Papers section to the site with a list of papers that have used PrefLib!

Links

- UC Irvine Machine Learning Repository
- University of Minnesota GroupLens Data Sets
- CSPLib: A Problem Library for Constraints
- Microsoft Learning to Rank Datasets
- SATLib: The Satisfiability Library
- Preference-Learning.org
- Toshihiro Kamishima's Sushi Preference Dataset
- MAX-SAT Evaluations and Datasets

Tools on GitHub



Social Choice

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    OR....

  - 2. Assign the items to each of the agents in the group.

Subject to a number of exogenous goals, axioms, metrics, and/or constraints.

So What Do We *DO* With Preferences?

- We take a multi-agent viewpoint: each preference comes from a different agent and we need to make a group decision.
- We want to select the most preferred alternative(s) according to the preferences of all the agents.

View 1: Vote to compromise among subjective preferences.

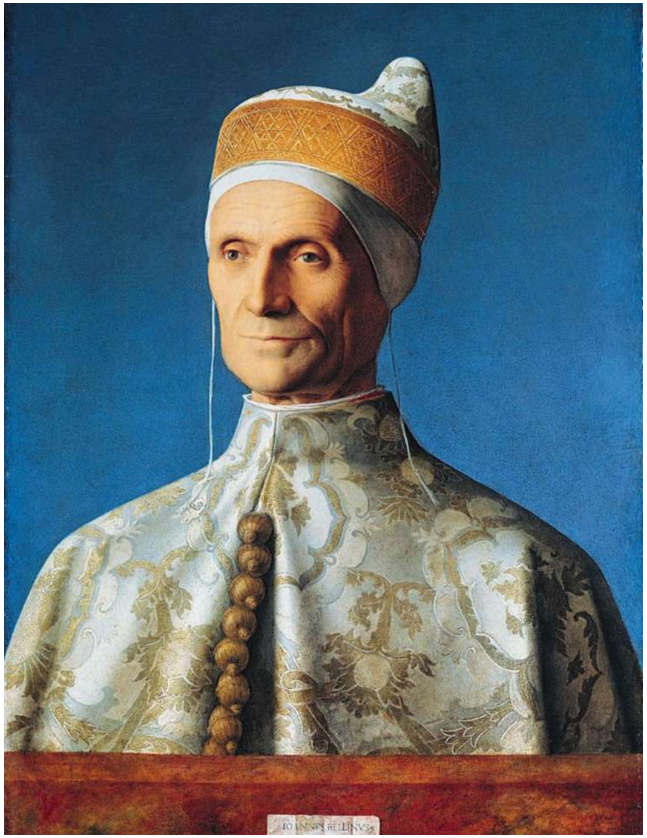
View 2: Vote to reconcile noisy observations to determine truth.

Elections

- An election is:
  - A set of alternatives, or candidates C of size m.
  - A set of voters V of size n.
  - All together, called a profile, P.
- A voting rule R:
  - A **resolute voting rule** returns an element from C.
  - A **voting correspondence** returns a set from C.
  - A **social welfare function** returns an ordering over C.

- Question: Aggregate the set of votes from P over the set of candidates C and return the result according to R

Unreasonable Voting Rules?



- Select random boy off the street to draw lotteries.

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- Round 1: Every member of the Great Council is narrowed to 30 via lottery.
- Round 2: Narrow this to 9 out of 30 by lottery.

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- Round 4: Select 12 out of 40 by lottery.
- Round 5: The 12 elect 25 each requiring 9/12 votes.

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- Round 6: Reduce the 25 to 9 again by lottery.
- Round 7: The 9 elect a college of 45 requiring 7/9 votes.

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- Round 7: The 9 elect a college of 45 requiring 7/9 votes.
- Round 3: The 45 were again reduced to 11 by lottery.
- Round 3: The 11 elect a college of 41 by 9/11 majorities.
- Round 10: The 41, with a majority vote of at least 25/41, elect the Doge of Venice.

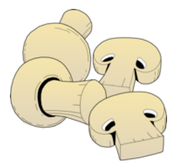
Really?

- 75 Doges were elected over 600 years (between 1172 and 1797).
- Only stopped because Napoleon took over.
- Many interesting and useful properties.

Selecting a Voting Rule

- Start from first principles or ***axioms:***
  - **Anonymity:** the names of the voters do not matter.
  - **Non-dictatorship:** there is no voter who always selects the winner.
  - **Neutrality:** the names of the alternative do not matter.
  - **Condorcet Consistency:** If one alternative is preferred by a majority in ***all*** pairwise comparisons, this alternative should win.
  - **Non-Imposition** or **Universal Domain**: each alternative is the unique winner under at least one profile.

Simple Majority Rule

Candidates	
 **B**acon	 **P**epperoni
 **O**lives	 **M**ushroom

Count	Vote
2	P > B > O > M
3	B > O > M > P
2	O > M > P > B

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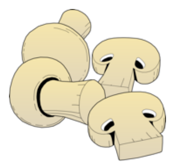
Condorcet's Paradox!

Candidates	
 Bacon	 Pepperoni
 Olives	 Mushroom

Count	Vote
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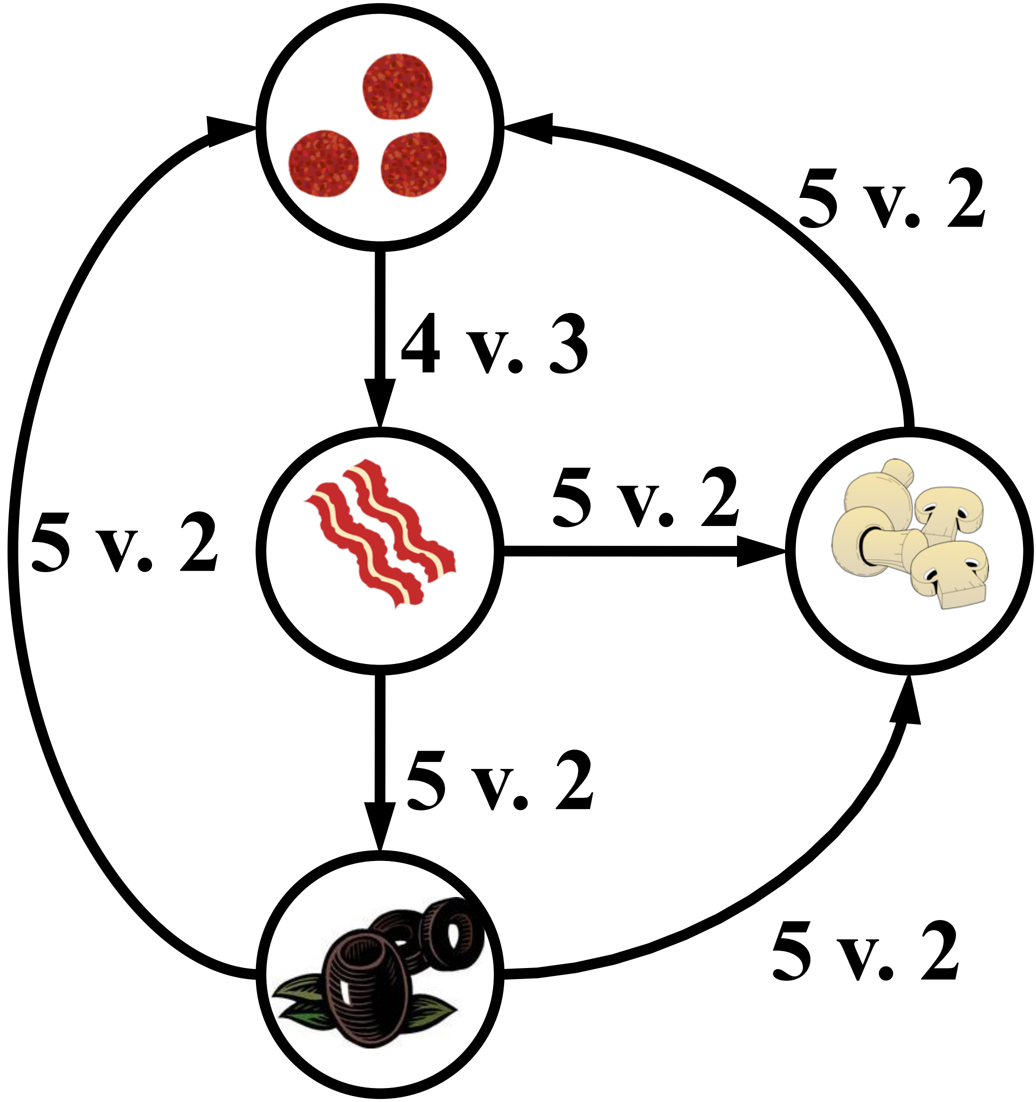
2	O > M > P > B

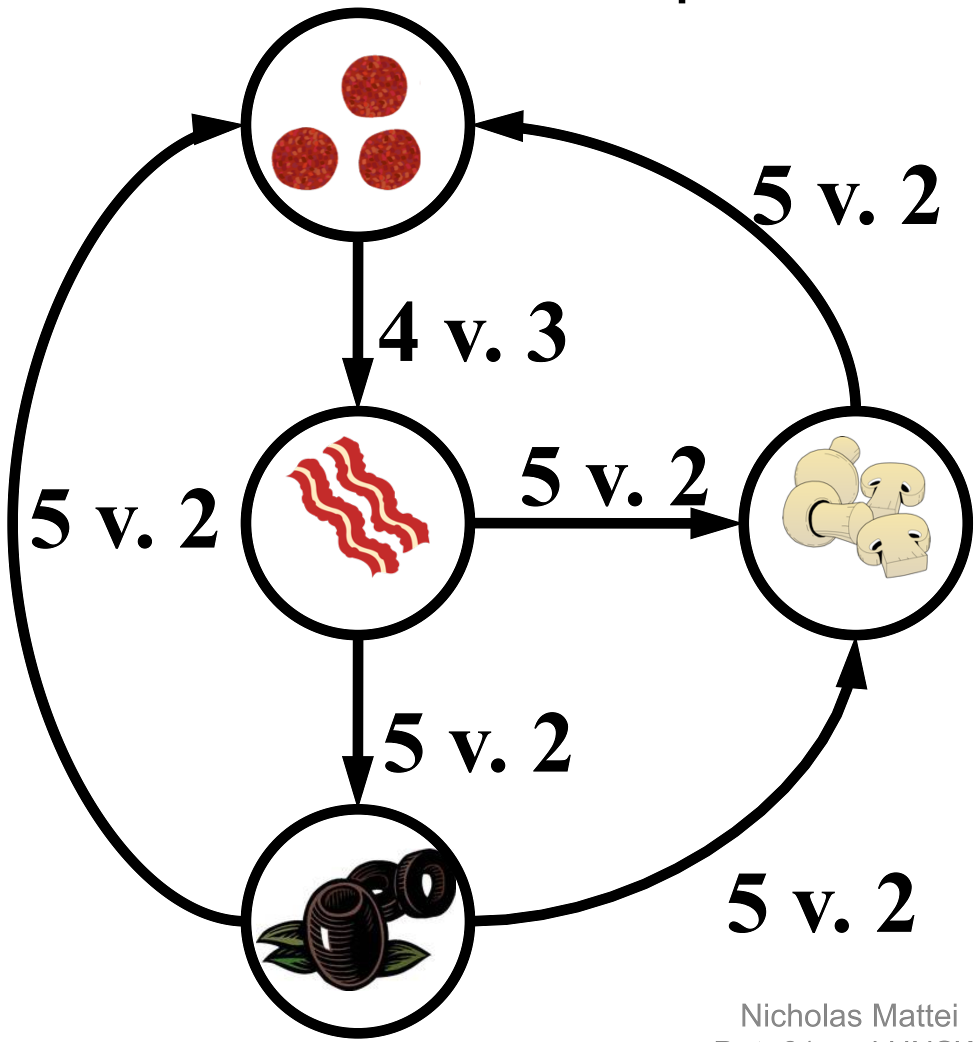


Copeland Scoring

Candidates	
Bacon	Pepperoni
Olives	Mushroom

Count	Vote
2	P > B > O > M
3	B > O > M > P
2	O > M > P > B

- In all pairwise contests, the winner receives a point.



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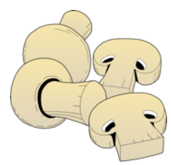
 **O**lives	 **M**ushroom

Count	Vote
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3	B > O > M > P
2	O > M > P > B

- In all pairwise contests, the winner receives a point.

Pair	Result	Winner
P v. B	4 to 3	P
P v. O	2 to 5	O
P v. M	2 to 5	M
B v. O	5 to 2	B
B v. M	5 to 2	B
O v. M	5 to 2	O

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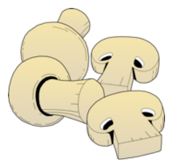
Copeland Scoring

Candidates	
 **B**acon	 **P**epperoni
 **O**lives	 **M**ushroom

Count	Vote
2	P > B > O > M
3	B > O > M > P
2	O > M > P > B

- In all pairwise contests, the winner receives a point.

Pair	Result	Winner
P v. B	4 to 3	P
P v. O	2 to 5	O
P v. M	2 to 5	M
B v. O	5 to 2	B
B v. M	5 to 2	B
O v. M	5 to 2	O

Result
O and B tie with 2 each.

Scoring Rules

- A **family** of voting rules where we award points for placement in the preference list
- **Plurality:** First place gets a point (S = [1, 0, 0 … 0]).
- **Veto:** All but last gets a point (S = [1, 1, 1, …, 0]).

Plurality	
B	3
O	2
P	2
M	0

Count	Vote
2	P > B > O > M
3	B > O > M > P
2	O > M > P > B

Scoring Rules

- A family of voting rules where we award points for placement in the preference list
- **Plurality:** First place gets a point (S = [1, 0, 0 … 0]).
- **Veto:** All but last gets a point (S = [1, 1, 1, …, 0]).

Plurality	
B	3
O	2
P	2
M	0

Veto	
O	7
B	5
M	5
P	4

Count	Vote
2	P > B > O > M
3	B > O > M > P
2	O > M > P > B

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Scoring Rules

- **Borda:** A candidate receives more points for being placed higher in the preference list (S = [m – 1, m – 2, … 0]).

Count	Vote
2	P > B > O > M
3	B > O > M > P
2	O > M > P > B

Scoring Rules

- **Borda:** A candidate receives more points for being placed higher in the preference list (S = [m – 1, m – 2, … 0]).

Count	Vote
2	P > B > O > M
3	B > O > M > P
2	O > M > P > B

Borda	
O	2*1 + 3*2 + 2*3 = 14
B	2*2 + 3*3 + 0 = 13
P	2*3 + 0 + 2*1 = 8
M	0 + 3*1 + 2*2 = 7

Plurality with Runoff

- **Round 1:** Plurality Score.

Count	Vote
10	P > B > O > M
7	M > P > B > O
6	O > M > P > B
3	B > O > M > P

Plurality	
P	10
M	7
O	6
B	3

Plurality with Runoff

- **Round 1:** Plurality Score.

Count	Vote
10	P > B > O > M
7	M > P > B > O
6	O > M > P > B
3	B > O > M > P

Plurality	
P	10
M	7
O	6
B	3

- **Round 2:** Select the most preferred remaining.

Count	Vote
10	P > M
7	M > P
6	M > P
3	M > P

Run-Off	
M	16
P	10

Single Transferable Vote (STV)

- Also known as Instant Run-off Voting and used in Australia, Ireland, and places in the US.
- We have *m-1* rounds where we eliminate the alternative with lowest plurality score.
- Winner is the last one left.

Count	Vote
10	P > B > O > M
7	M > P > B > O
6	O > M > P > B
3	B > O > M > P

Round 1	
P	10
M	7
O	6
B	3

Single Transferable Vote (STV)

- Also known as Instant Run-off Voting and used in Australia, Ireland, and places in the US.
- We have *m-1* rounds where we eliminate the alternative with lowest plurality score.
- Winner is the last one left.

Count	Vote
10	P > O > M
7	M > P > O
6	O > M > P
3	O > M > P

Round 2	
P	10
O	9
M	7
B	--

Single Transferable Vote (STV)

- Also known as Instant Run-off Voting and used in Australia, Ireland, and places in the US.
- We have *m-1* rounds where we eliminate the alternative with lowest plurality score.
- Winner is the last one left.

Count	Vote
10	P > O
7	P > O
6	O > P
3	O > P

Round 3	
P	17
O	9
M	--
B	--

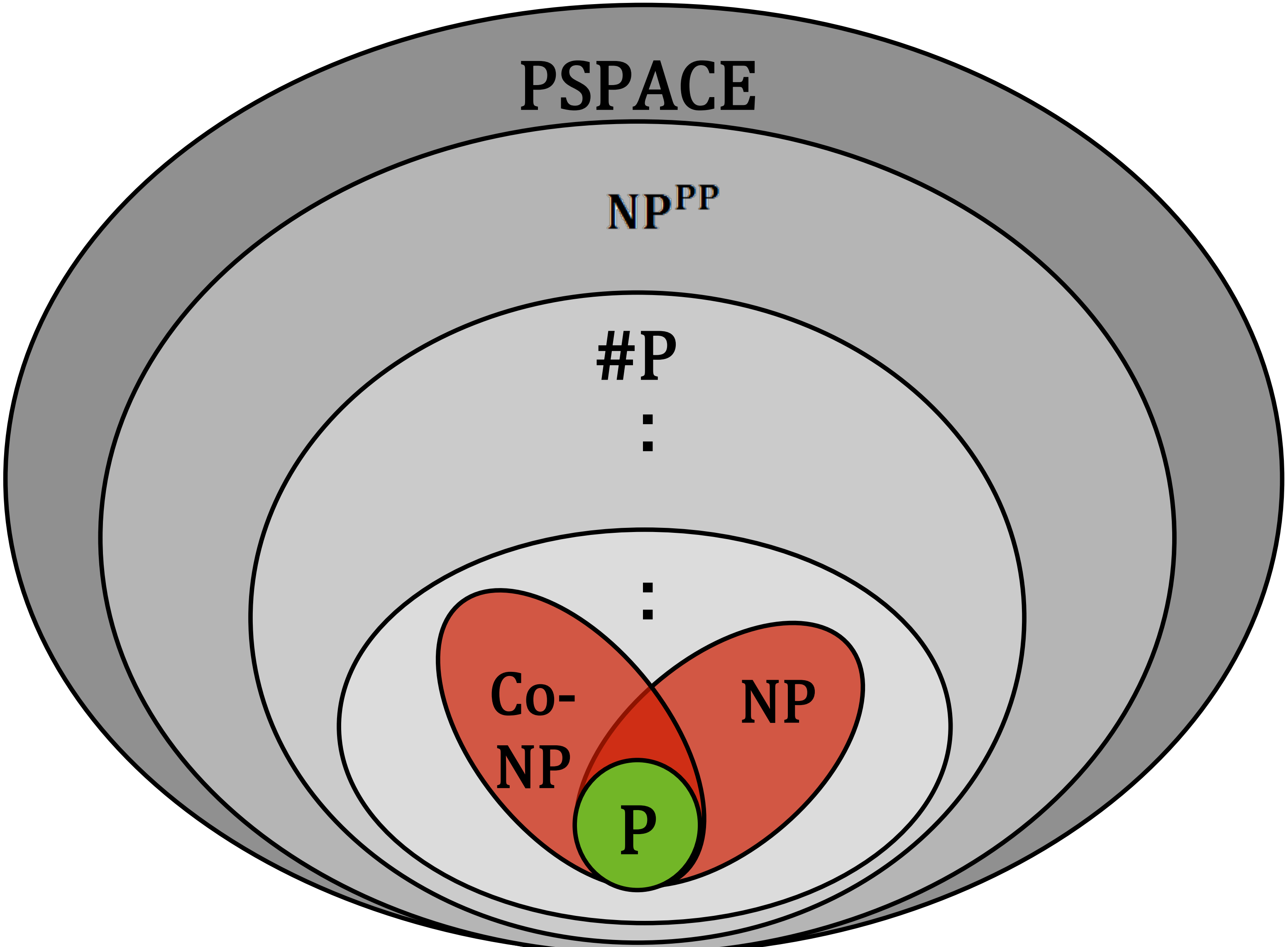
More Complicated Rules

- **Dodgson's Voting:** Select the winner which has the closest swap distance to being a Condorcet Winner.

- **Kemeny-Young:** Select the ordering which minimizes the sum of Kendall-Tau (Bubble Sort) distances to the input profile.

- However, these rules are intractable!!

Finding Winners Should Be EASY!



Bi-Lateral Trade

Import Ideas

Implement ideas from outside CS when designing, implementing, and deploying systems.

Analyze Results

Analyze computational aspects of procedures found outside CS.

The No-Show Paradox

- With Plurality with Run-off it can be better to abstain..

Count	Vote
25	P > M > O
46	O > P > M
24	M > O > P

Plurality	
O	46
P	25
Winner	
Olives!	

The No-Show Paradox

- With Plurality with Run-off it can be better to abstain..

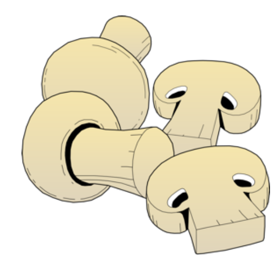
Count	Vote
25	P > M > O
46	O > P > M
24	M > O > P

Plurality	
O	46
P	25
Winner	
Olives!	

- Removing 2 voters....

Count	Vote
23	P > M > O
46	O > P > M
24	M > O > P

Plurality	
O	46
M	24
Winner	
Mushroom!	



Participation and Reinforcement

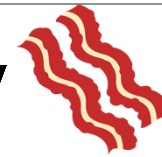
- **Participation:** Given a voter, his addition to a profile P results in the same or a more preferred result.
  - **We never have an incentive to abstain.**

- **Reinforcement (Consistency):** Given 2 profiles P_1 and P_2 over the same set of candidates C and rule R if we have $R(P_1) \cap R(P_2) \neq \emptyset$ then $R(P_1 \cup P_2) = R(P_1) \cap R(P_2)$.
  - **If**  **is elected in two disjoint profiles..**

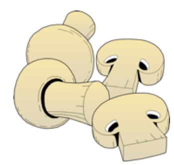
    Bacon

    combining them together shouldn't change this.

Axioms about Strong Preferences

- **Unanimous:** If *all* voters say 
  Bacon
  is the best

  then we select 
  Bacon

- **(Weak) Pareto Condition:** If all voters in the profile prefer 
  Bacon
  to 
  Mush.
  then we never

  select 
  Mush.

Monotonicity

- A current *winner* should not be made a *loser* by increasing support.

- If  Bacon is a winner given a vote *v*, then  Bacon

  must **remain a winner** in all other votes

  v' obtained from *v* where  Bacon is ranked higher.

Mmmmm….  Bacon

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Picking on Plurality with Run-off..

Count	Vote
27	P > M > O
42	O > P > M
24	M > O > P

Plurality	
O	42
P	27
Winner	
Olives!	

It’s Non-Monotonic!

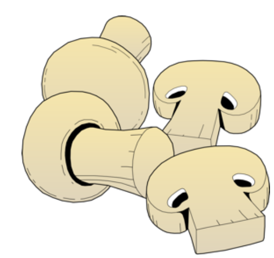
Count	Vote
27	P > M > O
42	O > P > M
24	M > O > P

Plurality	
O	42
P	27
Winner	
Olives!	

- By switching 4 votes **TO** olives..

Count	Vote
23	**P > M > O**
46	**O > P > M**
24	M > O > P

Plurality	
O	50
M	24
Winner	
Mushroom!	



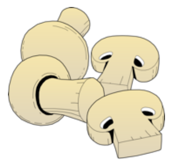
Independence of Irrelevant Alternatives

- Another (very strong) axiom about how preferences can change when adding new votes.

- **IIA:** whenever **B** is a winner and **M** is not and we modify *P* such that the relative ranking of **B and M** does not change in *P* then **M** cannot win.

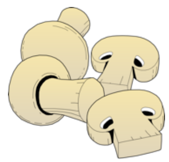
  - 
    Bacon *remains a winner despite any possible changes to irrelevant alternatives.*

Using Axioms…

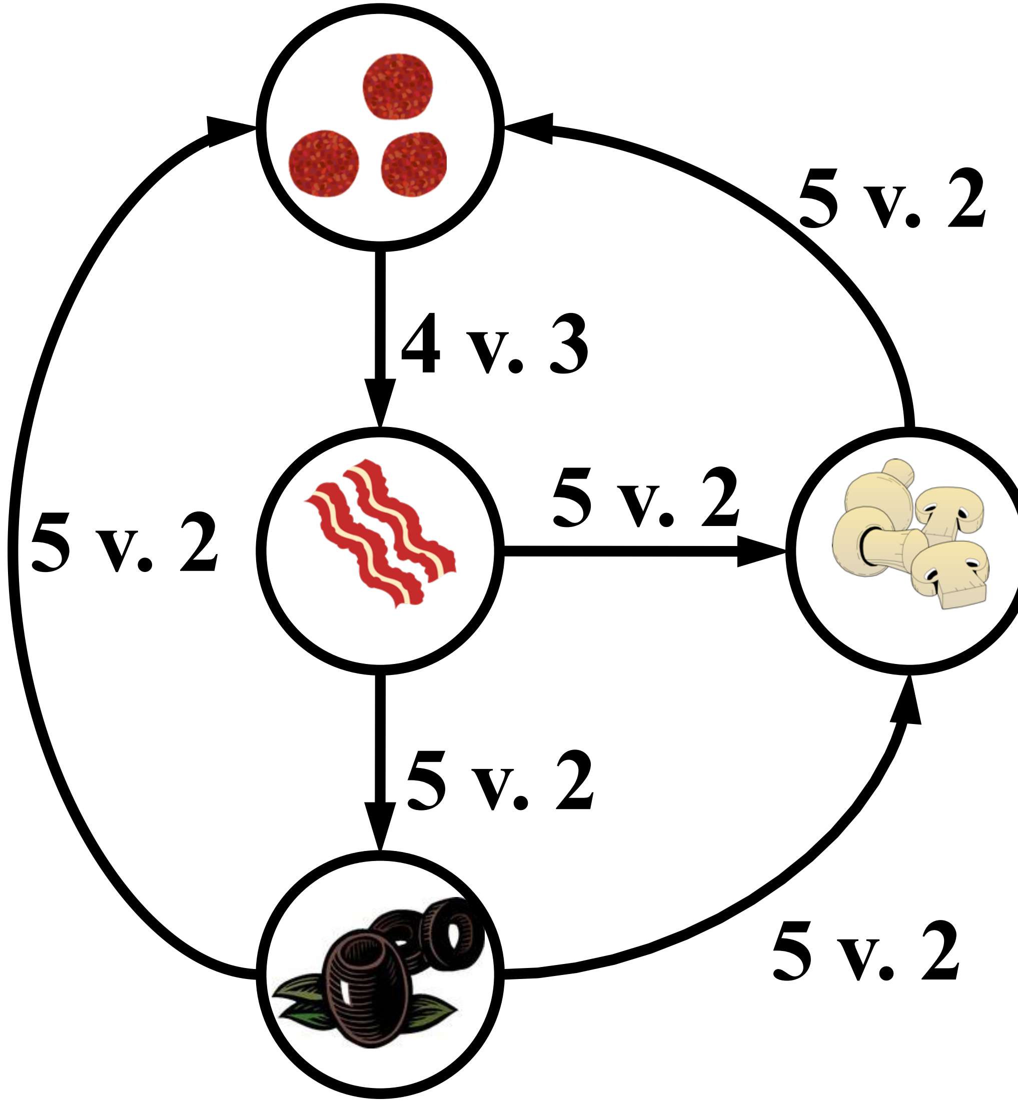
Candidates	
 **B**acon	 **P**epperoni
 **O**lives	 **M**ushroom

Count	Vote
2	P > B > O > M
3	B > O > M > P
2	O > M > P > B

Condorcet's Paradox!

Candidates	
 **Bacon**	 **Pepperoni**
 **Olives**	 **Mushroom**

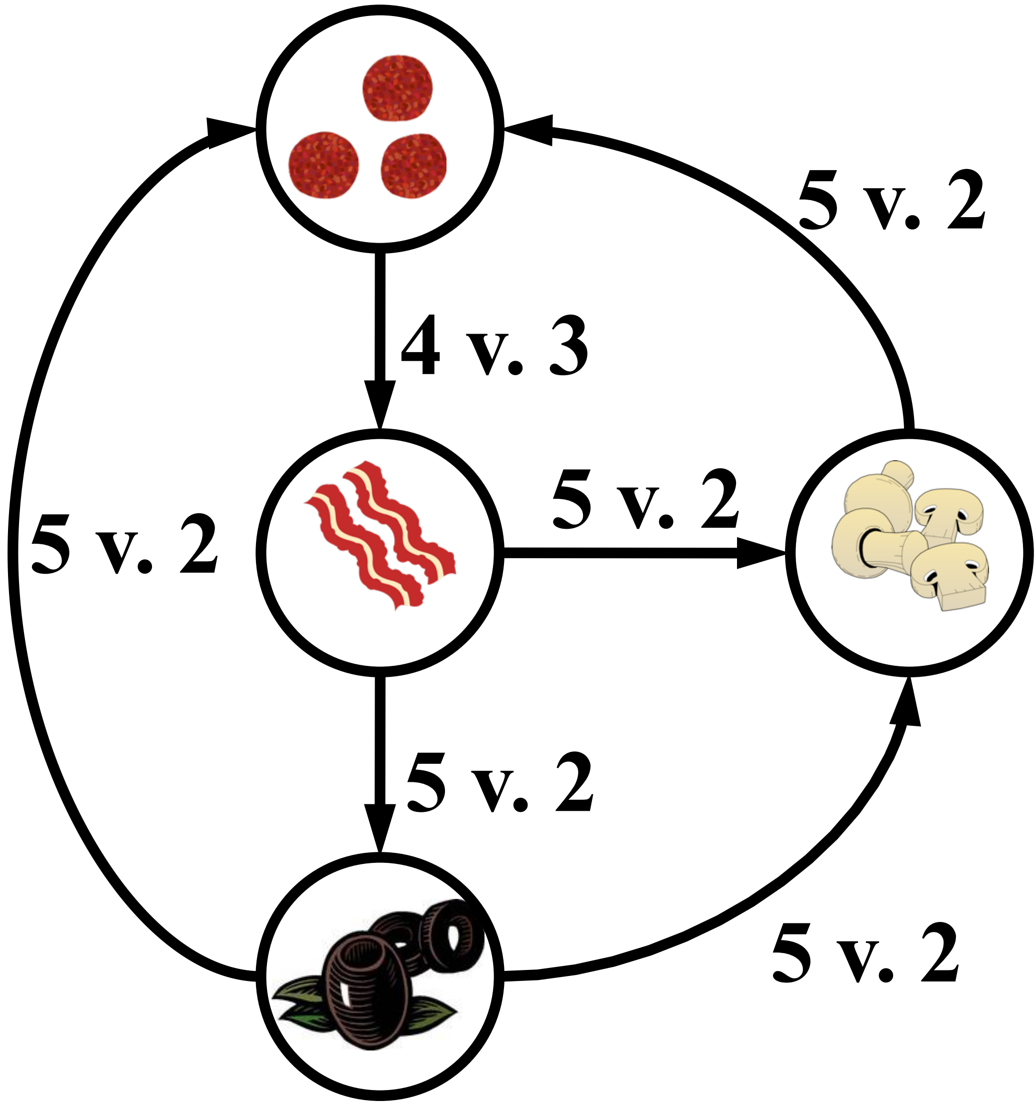
Count	Vote
2	P > B > O > M
3	B > O > M > P
2	O > M > P > B



Condorcet's Paradox!

- This result can be expanded to prove the following fact…
- [**Fishburn 74**]: There exists no positional scoring rule that is Condorcet Consistent!

Count	Vote
2	P > B > O > M
3	B > O > M > P
2	O > M > P > B



Positive Facts...

- Using the axioms we have discussed we can come up with some positive results!

AP

- [**May 52**] If a voting rule is resolute, anonymous, neutral, monotone (positively responsive) and has only two candidates, then it must be the **majority rule**!

So maybe we got that right…

Mostly Bad News Though…

- **Arrow's Theorem [Arrow 51]:** If there are more than three alternatives then we cannot devise a voting rule that satisfies weak Pareto optimality, non-dictatorship, and independence of irrelevant alternatives (IIA)!

K. J. Arrow 1951. *Social Choice and Individual Values*. John Wiley and Sons.

And Worse!

- **[Muller and Satterthwaite 77]:** If there are at least 3 candidates then no voting rule simultaneously satisfies universal domain, monotonicity, and is non-dictatorial!

Other Pitfalls of Voting Systems

- **Gibbard – Satterthwaite:** Any resolute voting procedure for at least 3 candidates that has universal domain and is strategy-proof is dictatorial.

Dictatorships are starting to look good….

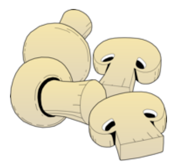
- A. Gibbard 1973. Manipulation of voting schemes. *Econometrica 41*.
- M. Satterthwaite 1975. Strategy-proofness and Arrow's conditions: Existence and correspondence theorems for voting procedures and social welfare functions. *J. Econ. Theory 10*.

Manipulation and Voting

- 3 primary ways to look at affecting an aggregation procedure:
    - Manipulation
    - Bribery
    - Control

- Given a preferred candidate, can we make it a winner?

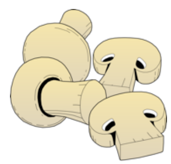
Coalitional Manipulation

Candidates	
 **B**acon	 **P**epperoni
 **O**lives	 **M**ushroom

Count	Vote
49	B > O > P > M
20	O > P > B > M
20	O > B > P > M
11	P > O > B > M

- Can an agent or group of agents misrepresent their preferences in such a ways as to obtain a better result?
- We generally make worst case assumptions:
  - Manipulator(s) know all.
  - Tie-breaking favors them…

Coalitional Manipulation

Candidates	
 **B**acon	 **P**epperoni
 **O**lives	 **M**ushroom

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20	O > P > B > M
20	O > B > P > M
11	P > O > B > M

- Can an agent or group of agents misrepresent their preferences in such a ways as to obtain a better result?

Bacon

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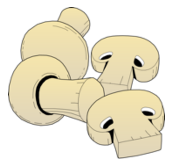
Coalitional Manipulation

Candidates	
 **B**acon	 **P**epperoni
 **O**lives	 **M**ushroom

Count	Vote
49	B > O > P > M
20	O > P > B > M
20	O > B > P > M
11	**O > P > B > M**

- Can an agent or group of agents misrepresent their preferences in such a ways as to obtain a better result?

Olive!

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Computer Science To The Rescue!

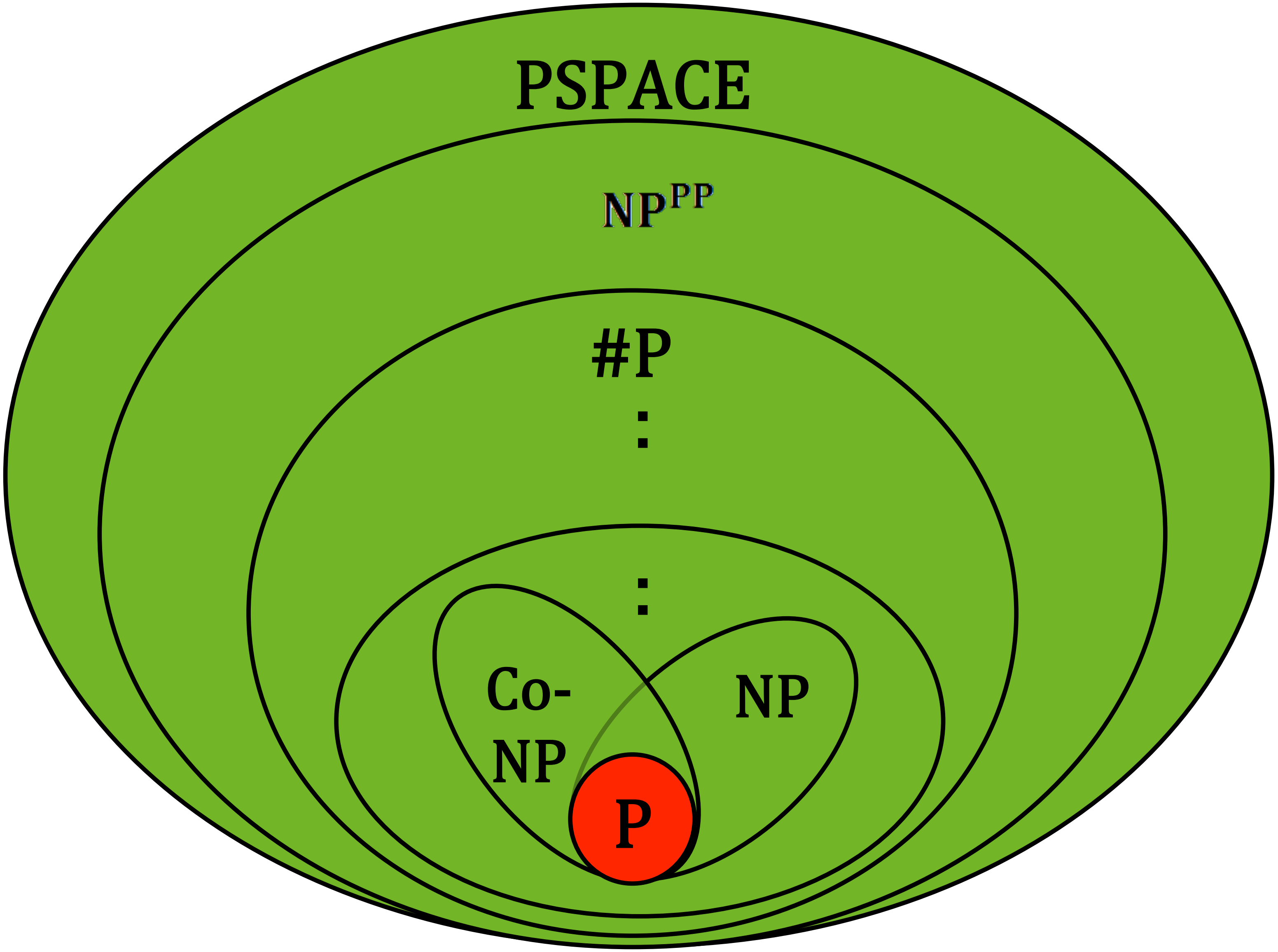
- An idea by Bartholdi, Tovey, and Trick on how to protect elections: **COMPLEXITY!**

- Like cryptography, if a manipulation is NP-hard to compute then maybe elections will not be manipulated.

- Founded a line of research that is still highly active in the ComSoc community.

- J. Bartholdi, III, C. Tovey, and M. Trick 1989. The computational difficulty of manipulating an election. *Social Choice and Welfare, 6(3)*.

Good is Bad!

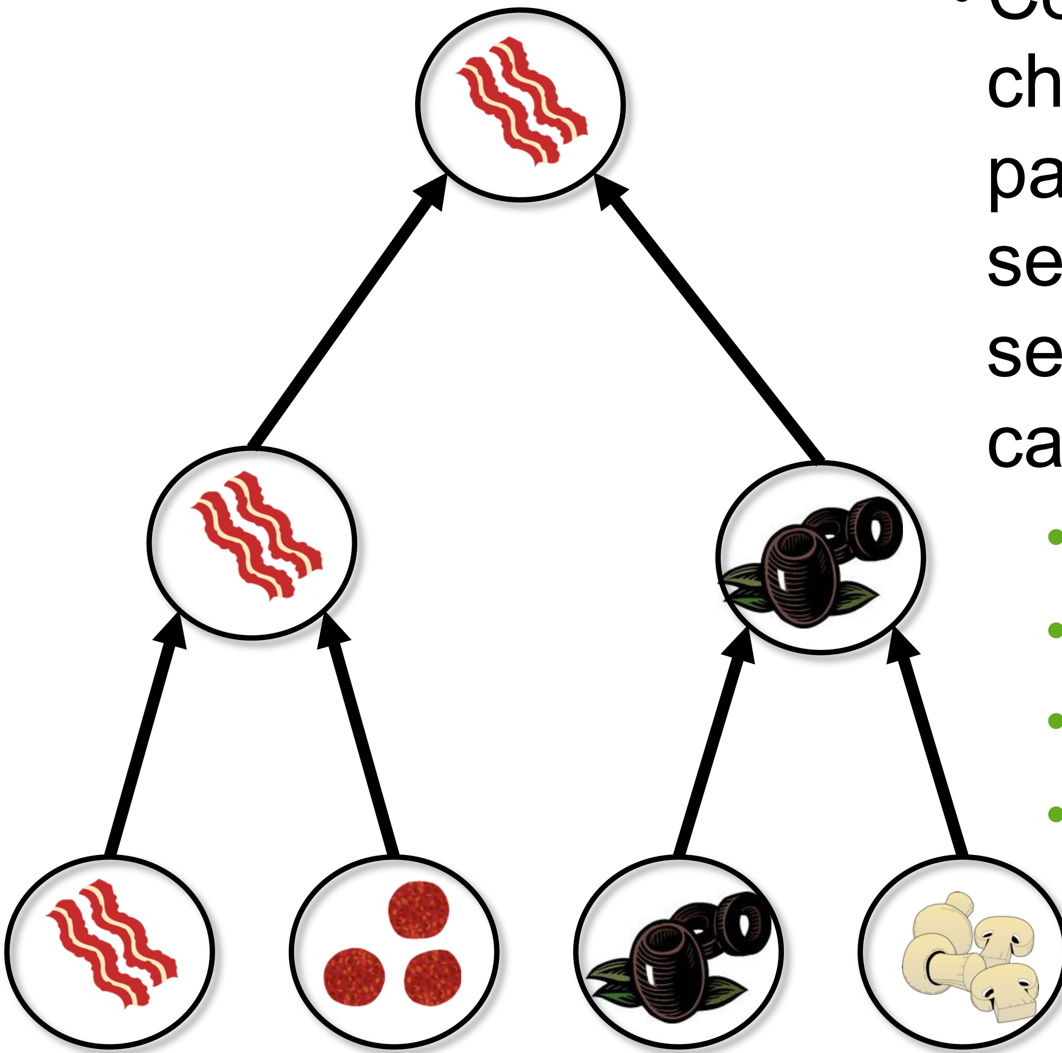


Coalitional Manipulation Results!

Voting Rule	One Manipulator	At Least 2
Copeland	Polynomial	NP-Complete
STV	Polynomial	NP-Complete
Veto	Polynomial	Polynomial
Plurality with Runoff	Polynomial	Polynomial
Cup	Polynomial	Polynomial
Borda	Polynomial	NP-Complete
Maximin	Polynomial	NP-Complete
Ranked Pairs	NP-Complete	NP-Complete
Bucklin	Polynomial	Polynomial
Nanson's Rule	NP-Complete	NP-Complete
Baldwin's Rule	NP-Complete	NP-Complete

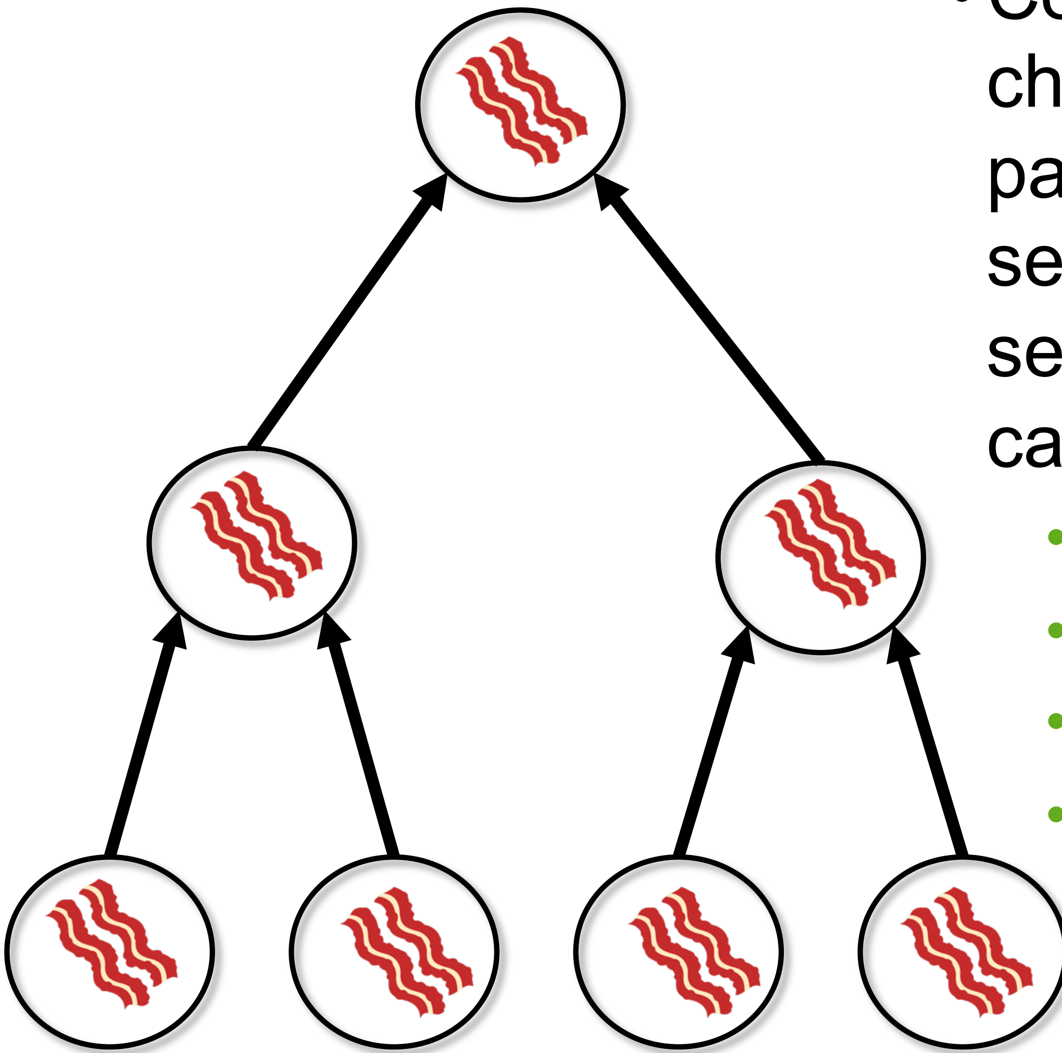
– Many of these appeared in top AI venues (AAAI, IJCAI)
– Thanks to Lirong Xia for the table!

Control Problems



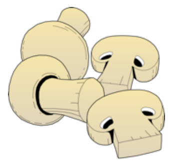
- Control involves changing some parameter of the setting in order to select a more preferred candidate.
  - Change the voting tree
  - Add candidates
  - Replace candidates
  - Add/Delete/Replace voters…

Control Problems (with constraints!)



- Control involves changing some parameter of the setting in order to select a more preferred candidate.
  - Change the voting tree
  - Add candidates
  - Replace candidates
  - Add/Delete/Replace voters…

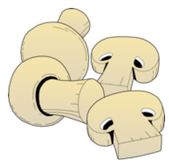
Bribery

Candidates	
 Bacon	 Pepperoni
 Olives	 Mushroom

Count	Vote
49	B > O > P > M
20	O > P > B > M
20	O > B > P > M
11	P > O > B > M

- Can we expend some resource in order to make a particular candidate a winner.
  - Money
  - Time
  - Pollsters
- Usually subject to hard constraints or can only affect probability of changing someone's mind..

Bribery

Candidates	
 **B**acon	 **P**epperoni
 **O**lives	 **M**ushroom

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49	B > O > P > M
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20	O > B > P > M
11	P > O > B > M

- Can we expend some resource in order to make a particular candidate a winner.

Bacon

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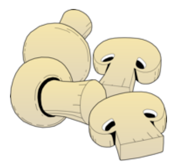
Bribery

Candidates	
 **B**acon	 **P**epperoni
 **O**lives	 **M**ushroom

Count	Vote
49	B > O > P > M
20	O > P > B > M
20	O > B > P > M
11	**O > P > B > M**

- Can we expend some resource in order to make a particular candidate a winner.

Olive!

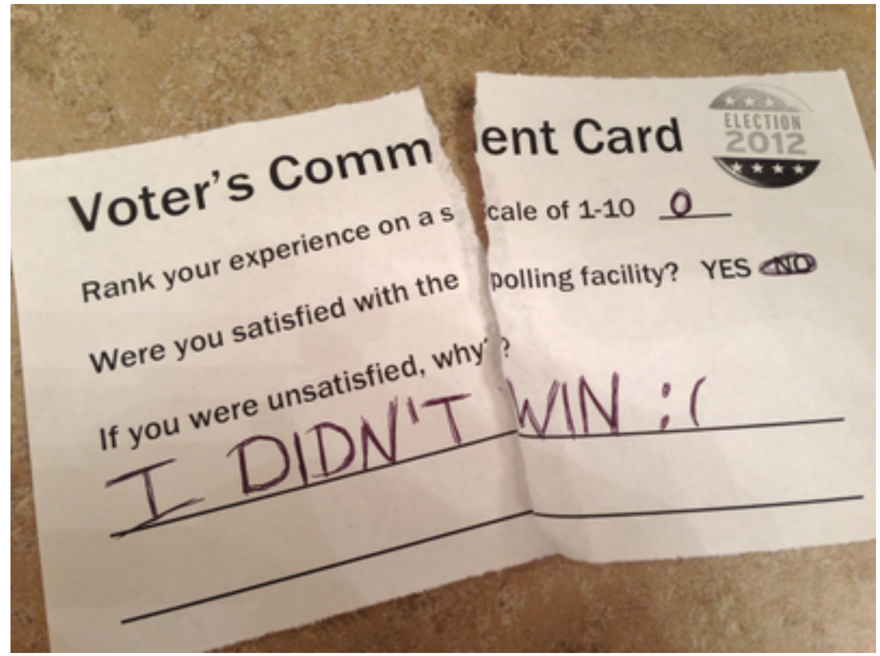
Bi-Lateral Trade

Analyze Results		Import Ideas
Analyze computational aspects of procedures found outside CS.	⟷	Implement ideas from outside CS when designing, implementing, and deploying systems.

- Your handout has more resources and links to more reading on individual algorithms and complexity results.
- Current research directions include designing new mechanisms that are hard to manipulate, new elicitation schemes that limit opportunities for full information, and understanding the preference profile restrictions that may make bad behaviors hard.
- For more those with more interest in combinatorics there is lots of research in sequential or multi-issue decision making including selecting committees (under constraints) or using CP-nets instead of linear orders as input.

Thanks!

- Questions



- Comments

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