CS 886: Multiagent Systems

Fall 2016

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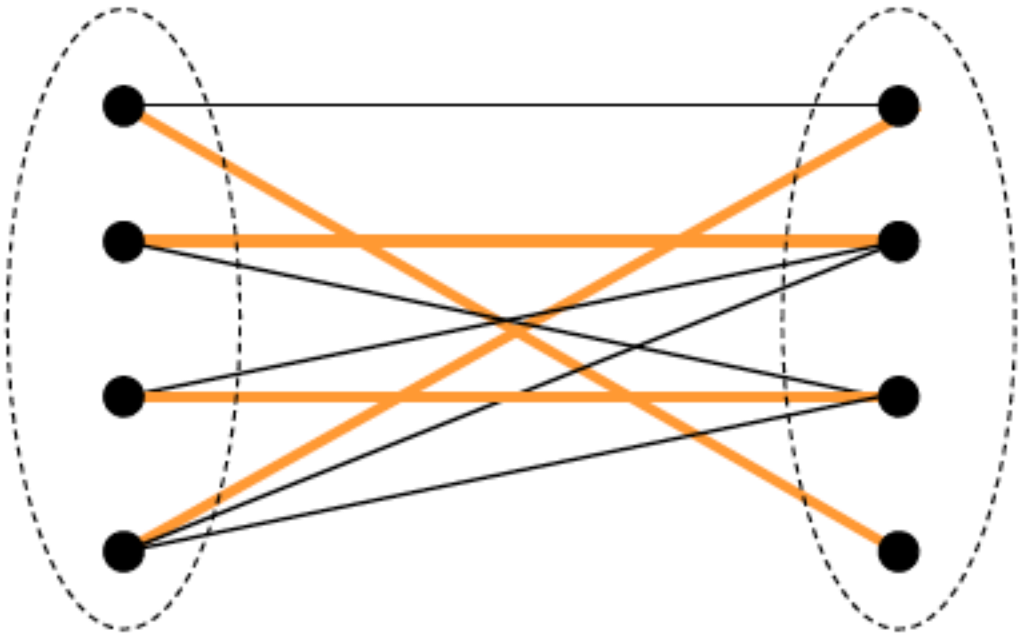
Multiagent Systems

- We will study the mathematical and computational foundations of multiagent systems, with a focus on the analysis of systems where agents can not be guaranteed to behave cooperatively (self-interested multiagent systems)

- Topics include
  - Computational Social Choice
  - Mechanism Design
  - Game-theoretic Analysis
  - Applications

Let’s make this a little more concrete…

Bipartite Matching Problem



A Perfect Match

Figure from Shahab Bahrami

Matching Mechanisms

Agents may have preferences over whom they are matched

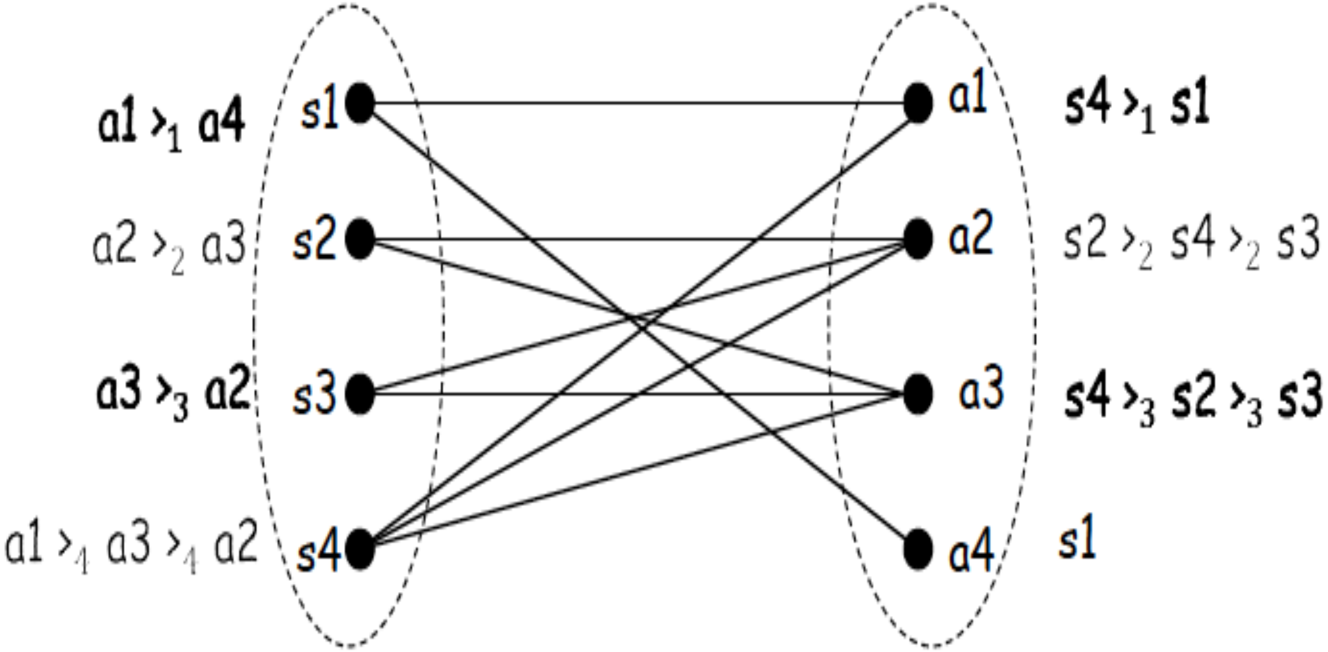
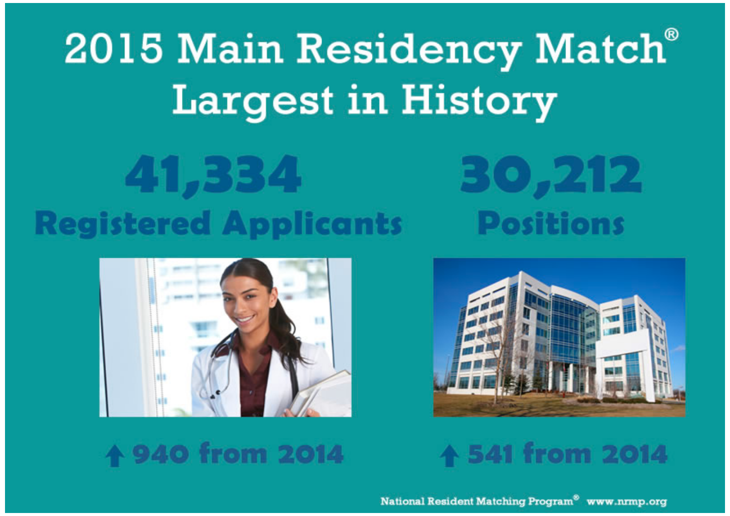


Figure from Shahab Bahrami

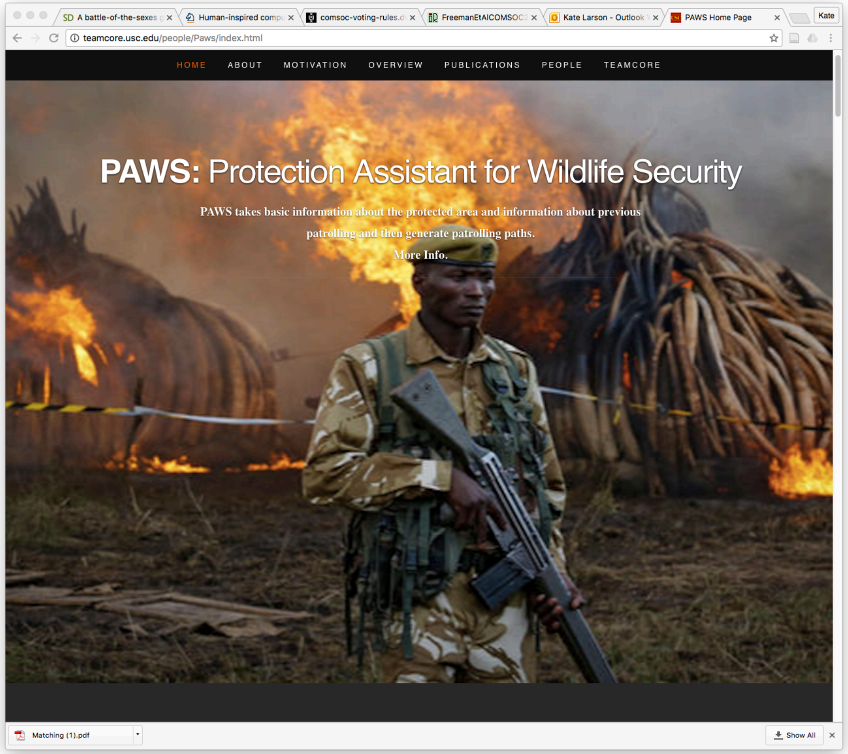
- What is a "good" matching?
- Can we compute "good matchings"?
- How much information do agents need to reveal to find matchings?
- Will they reveal correct information? Can they?



Other Examples and Applications

- How do you make a decision for a group? (Voting)
  - What is the best voting rule?
  - What is the computational cost of different voting rules?
  - Are some rules more subject to manipulation than others?
  - What information should voters provide? What if they can not?

- How do you decide how to deploy resources against poachers?



From Teamcore@usc

This Course

- Introduction to social choice, game theory and mechanism design
- We will study
  - Computational issues arising in these areas
  - How these ideas are used in computer science

- Course structure
  - Background lectures for the first few weeks
  - Research papers

Logistics

- Tues/Thurs 11:30-12:50 in DC2568

- Seminar course covering recent research papers
  - Several lectures introducing relevant background information

- Marking Scheme
  - Presentations: 20%
  - Participation: 20%
  - Course Project: 60%

- Any questions?
  - Kate Larson klarson@uwaterloo.ca
  - www.cs.uwaterloo.ca/~klarson/teaching/F16-886

Prerequisites: No Formal Prerequisites

- Students should be comfortable with formal mathematical proofs
- Some familiarity with probability
- Ideally students will have an AI course but I will try to cover relevant background material
- **I will quickly cover the basic social choice and game theory**

Presentations

- Every student is responsible for presenting a research paper in class
  - Short survey + a critique of the work
  - Everyone in class will provide feedback on the presentation
  - Marks given on coverage of material + organization + presentation

Class Participation

- You must participate!

- Before each class (before 10:30 am) you must submit a review of at least one of the papers being discussed that day
  - What is the main contribution?
  - Is it important? Why?
  - What assumptions did the paper make?
  - What applications might arise from the results?
  - How can is be extended?
  - What was unclear?
  - …?

Project

- The goal of the project is to develop a deep understanding of a topic related to the course
- The topic is open
  - Theoretical, experimental, in-depth literature review, …
  - Can be related to your own research
  - If you have trouble coming up with a topic, come talk to me
- Proposal due October 21
  - 1-2 page discussion of topic of interest and preliminary literature review
- Final project due December 16
  - Projects will also be presented in class at the end of the semester

Introduction to Social Choice

- Social choice is a mathematical theory which studies how to aggregate individual preferences

- **Voting Model**
  - Set of **voters** N={1,...,n}
  - Set of **alternatives** A, |A|=m
  - Each voter has a **ranking** over the alternatives (**preferences**)
  - **Preference profile** is a collection of voters' rankings

1	2	3
a	b	c
b	a	a
c	c	b

Voting Rules

- A voting rule is a function from preference profiles to alternatives that specifies the winner of the election

- **Plurality**
  - Each voter assigns one point to their most preferred alternative
  - Alternative with the most points wins
    - Common voting rule, used in many political elections (including Canada)

1	2	3
a	b	b
b	a	c
c	c	a

Alt.	Points
a	1
b	**2**
c	0

Voting Rules

- **Borda Rule**
  - Each voter awards m-k points to its k^{th} ranked alternative
  - Alternative with the most points wins
  - Used for elections to the national assembly of Slovenia
  - Quite similar to the rule used in the Eurovision song context

1	2	3
a	b	c
b	a	a
c	c	b

Alt.	Points
a	**2+1+1=4**
b	1+2+0=3
c	0+0+2=2

Voting Rules

- **Scoring Rules (Positional Rules)**
  - Defined by a vector $(s_1,\ldots,s_m)$
  - Add up scores for each alternative
  - Plurality (1,0,…,0)
  - Borda (m-1,m-2,…,0)
  - Veto (1,1,…,1,0)

1	2	3
a	b	c
b	a	a
c	c	b

Alt.	Points
a	**1+1+1=3**
b	1+1+0=2
c	0+0+1=1

We can also have multi-stage voting rules

- *x* beats *y* in **a pairwise election** of the majority of voters prefer *x* to *y*
- **Plurality with runoff**
  - Round 1: Eliminate all alternatives except the two with the highest plurality scores
  - Round 2: Pairwise election between these two alternatives
- **Single Transferable Vote (STV)**
  - m-1 rounds
  - In each round, alternative with the lowest plurality score is eliminated
  - Last remaining alternative is the winner
  - Used in Ireland, Australia, New Zealand, Malta

How do we choose which voting rule to use?

- We are usually interested in using rules with “good” properties

- **Majority consistency**
  - If a majority of voters rank alternative x first, then x should be the winner

Condorcet Principle and Condorcet Winners

- If an alternative is preferred to all other alternatives, then it should be chosen

10 voters	6 voters	5 voters
c	b	a
b	a	b
a	c	c

- **Condorcet Winner**: An alternative that beats every other alternatives in pairways elections

Pairwise Election	Winner
a vs b	b
a vs c	a
b vs c	b

Condorcet Paradox

- A Condorcet winner might not exist

1	2	3
a	b	c
b	c	a
c	a	b

- **Condorcet consistency**: Select a Condorcet winner if one exists

Even More Voting Rules!

- **Copeland**
  - Alternative's score is the number of alternatives it beats in pairwise elections
- **Maximin**
  - Score of alternative x is $\min_y |\{i \in N \text{ such that } x \succ_i y\}|$
- **Dodgson's Rule**
  - Define a distance function between profiles: number of swaps between adjacent candidates
  - Dodgson Score of x: minimum distance from a profile where x is a Condorcet winner
  - Select alternative with lowest Dodgson Score

Interesting Example

33 voters	16 voters	3 voters	8 voters	18 voters	22 voters
a	b	c	c	d	e
b	d	d	e	e	c
c	c	b	b	c	b
d	e	a	d	b	d
e	a	e	a	a	a

- Plurality: *a*
- Borda: *b*
- Condorcet Winner: *c*
- STV: *d*
- Plurality with runoff: *e*

Revisiting Voting Rule Properties

- A voting rule should produce an ordered list of alternatives (**social welfare function**)

- A voting rule should work with any set of preferences (**universality**)

- If all voters rank alternative *x* above *y* then our voting rule should rank *x* above *y* (**Pareto condition**)

Revisiting Voting Rule Properties

- If alternative *x* is socially preferred to *y*, then this should not change when a voter changes their ranking of alternative *z* (**independence of irrelevant alternatives (IIA)**)

- There should not be a voter *i* such that the outcome of the voting rule always coincides with *i*'s ranking, irrespective of the preferences of the other voters (**no dictators**)

Arrow’s Theorem (1951)

If there are at least three alternatives, then any universal social welfare function that satisfies the Pareto condition and is IIA must be a dictatorship.