Algorithmic Game Theory

Professor Amy Greenwald

CSCI 1440/2440

Algorithmic Game Theory

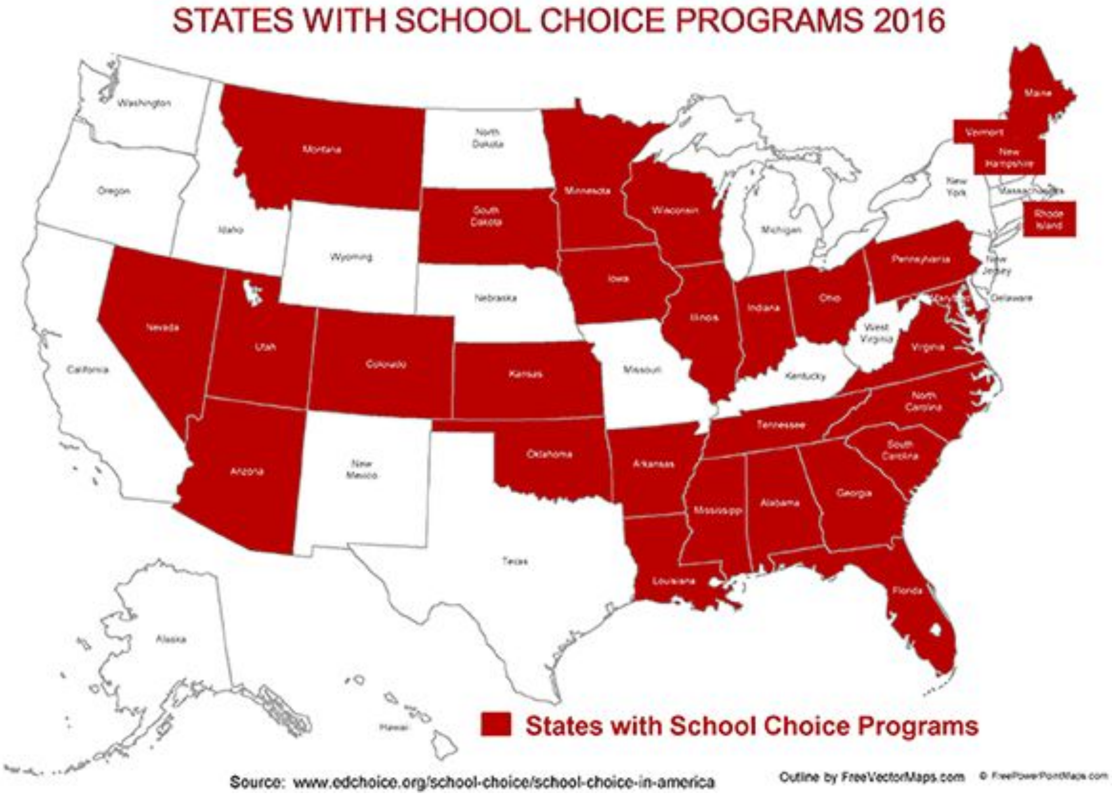
- Game theory is used to model multiagent interactions (multiagent systems)
  - Participants (agents, players, etc.) have partially competing & partially cooperative interests
  - Economics: agents are people, nations, etc.
  - AI: softbots, robots, LLMs, etc.

- Q: How do agents play games?
- If we assume agents behave rationally, then A: equilibrium (stable outcome)
  - Computational game theory: algorithms that solve for equilibrium in games
  - Game-theoretic machine learning: learning algorithms that converge to equilibrium in games
- Heuristic: Agents play their part of an equilibrium strategy
  - Successful examples in complete- and incomplete-information zero-sum games: AlphaGo, poker agents, etc.

Mechanism Design (Inverse Game Theory)

- Given assumptions about how agents play games (e.g., rationality), the goal is to design games that achieve a desired objective: i.e., whose equilibria satisfy certain properties
- Typical approach: design games that are straightforward to play: e.g., games with unique equilibria
- In practice: this goal is difficult to achieve
- Why? Because the agents' preferences are unknown, and must be elicited

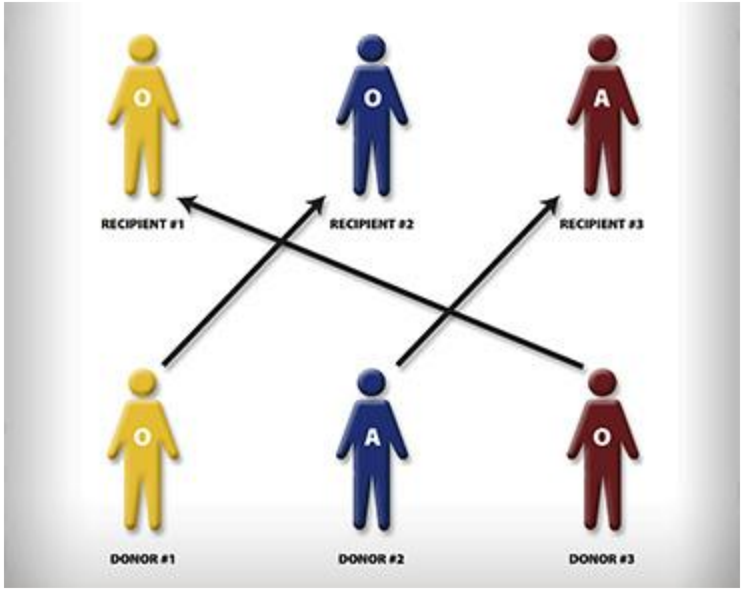
School Choice



School Choice

- Milton Friedman (Nobel laureate)
- Students: rank (a subset of) schools
- Schools: “rank” students (neighborhood, siblings, etc.)
- Objective: make students happy, make schools diverse, etc.
- Matching algorithm
  - Stable marriage
  - Gale & Shapley 1962
- Are these mechanisms truthful?

Kidney Exchanges



Kidney Exchanges

- Al Roth (Nobel laureate)
- An exchange announces a matching algorithm to find compatible kidneys for people whose donor’s kidney is incompatible with theirs
- Hospitals report incompatible donor-recipient pairs (e.g., blood type mismatch)
- Objective: to facilitate as many trades as possible
- Matching algorithm
  - Stable marriage
  - Gale & Shapley
- Are these mechanisms truthful?

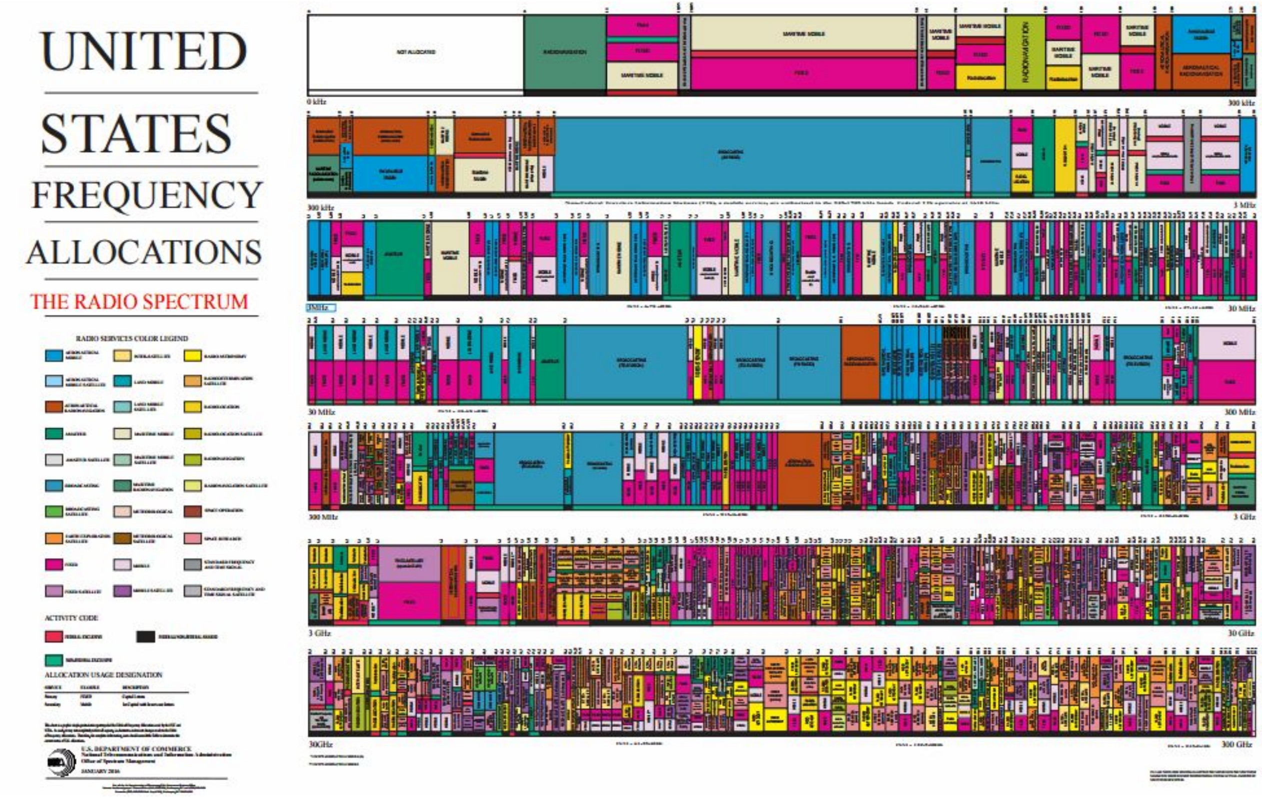
Auctions

Auctions

- William Vickrey (Nobel laureate)
- An auction for some goods is announced
- Bidders report their willingness to pay for the goods
- Bidders’ values for the goods are their private information
- Utilities are the difference between the value to bidders of what is allocated to them and what they pay
- An “optimal” auction is one that extracts maximal total payments (i.e., revenue) from the participants
- Another common objective (especially in government auctions) is to maximize welfare

from Theory to Practice

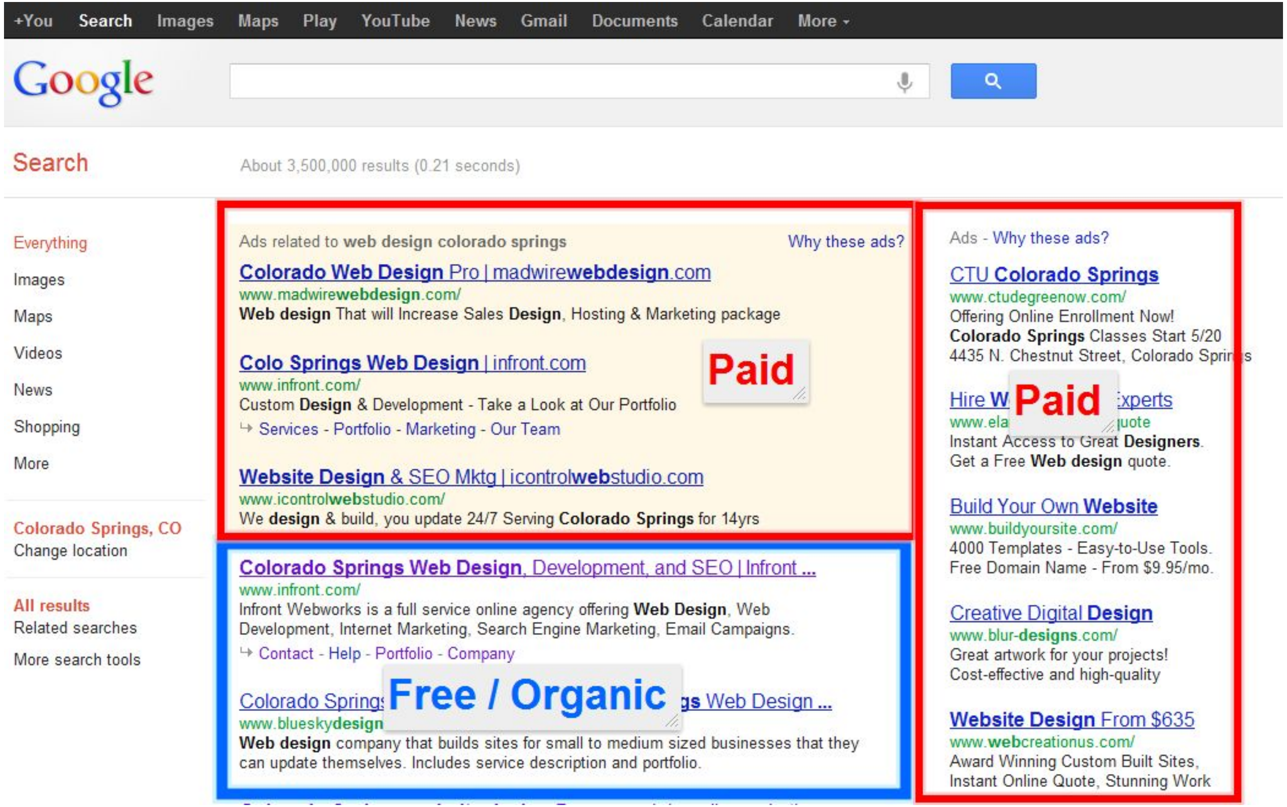
Spectrum Auctions



Spectrum Auctions

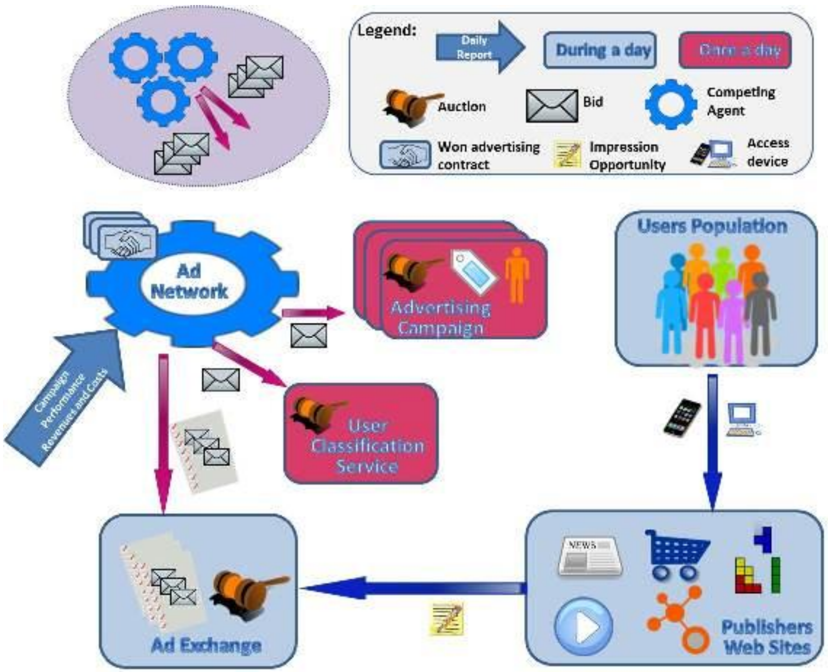
- All wireless communication signals travel over the air via radio frequency: a.k.a. spectrum
- No two radio or TV stations transmit data over the same spectrum at the same time in the same area, because doing so would cause interference!
  - Ditto for wireless communication: wireless operators also cannot transmit wireless signals over the same frequency at the same time in the same area
- Combinatorial resource allocation problem, because providers have preferences over sets of goods (e.g., MA, RI, and CT; or CT, NY, and NJ)
- Combinatorial auctions
  - 1990 New Zealand: simultaneous second-price auctions
  - 1999 Germany: simultaneous first-price auctions

Computational Advertising: Sponsored Search Auctions



Computational Advertising: Ad Exchanges

Trading Agent Competition



Automated Agents Negotiation Competition

- Automated Negotiation League
- Supply Chain Management League
- Human-Agent Negotiation Pilot

My thesis, 1999

Environment

- Shopbots and pricebots were causing a paradigm shift in Ecommerce
- But their widespread deployment posed technical and societal challenges

Key Observation

- Shopbots and pricebots are economic agents, and can thus be modeled as boundedly rational decision makers in an online economy

Key Questions

- Can we use machine learning to build better shopbots and pricebots?
- Can we use game theory to explain dynamic interactions among bots?

My hypothesis, 2023

Environment

- Foundation models (like LLMs) are causing a major paradigm shift in AI
- But their widespread deployment pose technical and societal challenges

Analogous Observation

- Foundation models are loss minimizers, and can thus be modeled as boundedly rational decision makers in an online ecosystem

Key Questions

- We are already using machine learning to build foundation models
- Can we use game theory to build *strategic* foundation models?
- Can we use game theory to explain dynamic interactions among SFMs?

Game plan

1. Build strategic foundation models by incorporating GT modeling and tools

Examples:

- GANs (generative adversarial networks) as zero-sum games
- RLHF as a general-sum Stackelberg game

2. Advance game theory and algorithmic game theory using strategic FMs
3. Assess the societal impact of strategic FMs using game theory