CSC2556 Spring'18 Algorithms for Collective Decision Making

Nisarg Shah

Introduction

- People
  - Instructor: Nisarg Shah (/~nisarg, nisarg@cs)
  - TA: Sepehr Abbasi Zadeh (/~sepehr, sepehr@cs)
- Meet
  - Lectures: Wed, 1p-3p, BA 2135
  - Office hour: SF 2301C, any time, but please email me first
- Info
  - Course Page: `www.cs.toronto.edu/~nisarg/teaching/2556s18/`
  - Discussion Board: `piazza.com/utoronto.ca/winter2018/csc2556`

What is this course about?

- Collective decision making by groups of agents

- Most traditional computer science problems have a "single-agent perspective"
  - Consider the popular *traveling salesman problem*, in which a single agent is trying to decide the optimal route.
  - What happens there are multiple agents with different costs, and thus different individually optimal routes?
- More naturally in other settings such as allocating resources to processes in an operating system

What is this course about?

- "How do we strike a good balance between the preferences of different agents?"
  - Fairness
  - Welfare
  - …
- "How will these agents behave? What are their incentives?"
  - What if agents lie about their preferences, so the final outcome chosen is more preferable to them?

How will we answer these?

- We will study a number of settings that differ in key considerations:
  - Are the agents allowed to form legally binding contracts?
    - Entering in contracts allows agents to hedge uncertainties.
  - Is it possible to make monetary transfers to (or between) agents?
    - Maybe we make a decision that is less preferable to an agent, but pay the agent to compensate.
  - Are the agents dividing resources/costs or are they making a common decision?
  - …

Logistics

Textbooks

- Handbook of Computational Social Choice
  - Felix Brandt, Vincent Conitzer, Ulle Endriss, Jérôme Lang, and Ariel D. Procaccia.
- Algorithmic Game Theory
  - Noam Nisan, Tom Roughgarden, Eva Tardos and Vijay Vazirani.
- Networks, Crowds and Markets
  - David Easley and Jon Kleinberg

Grading Policy

- One homework: 30%
- Final project: 60%
- Class participation: 10%

Policies

- Collaboration
  - Individual homeworks.
  - Free to discuss with classmates or read online material.
  - Must write solutions in your own words (easier if you do not take any pictures/notes from the discussions)
    - Plagiarism will be dealt with seriously.

- Citation
  - For each question, must cite the peer (write the name) or the online sources (provide links) referred, if any.
  - Failing to do this is also plagiarism!

Other Policies

- "No Garbage" Policy
  - Borrowed from: Prof. Allan Borodin (citation!)

  1. Partial marks for viable approaches
  2. Zero marks if the answer makes no sense
  3. 20% marks if you admit to not knowing how to solve

- 20% > 0% !!

Course Project

- How? In groups of 1-2
  - If you want to find a partner, start early!

- What?
  - Empirical: Quantitative analysis of algorithms presented in class (or your own) using simulations or real data
  - Theoretical: Prove new observations about the algorithms
  - Ideal: A bit of both

Course Project

- I'll mention some open problems as we go along.
- You can also create new problems by combining two of the settings we study:
  - "How do I apply fairness considerations in game theory?"
- The topics naturally encourage interdisciplinary work
  - You can apply these ideas in your own research interest.
  - "How do we allocate CPU and RAM fairly between processes in an operating system?"

Course Project

- (Finding a partner, if you prefer)
- Thinking about a project idea
- Submission 1: Project proposal
  - 1-2 pages
  - Project idea, prior work, goal outline
- Submission 2: Final project report
  - 4-5 pages (appendix allowed)
  - Focus on quality academic writing
- Class presentations

Introductions

Introductions

- Places
  - Bachelors, IIT Bombay → PhD, Carnegie Mellon → Postdoc, Harvard → Asst. Prof., U of T
- Research
  - Voting, fair division, game theory, mechanism design, applications to machine learning
- What about you?

Social Choice vs Mechanism Design

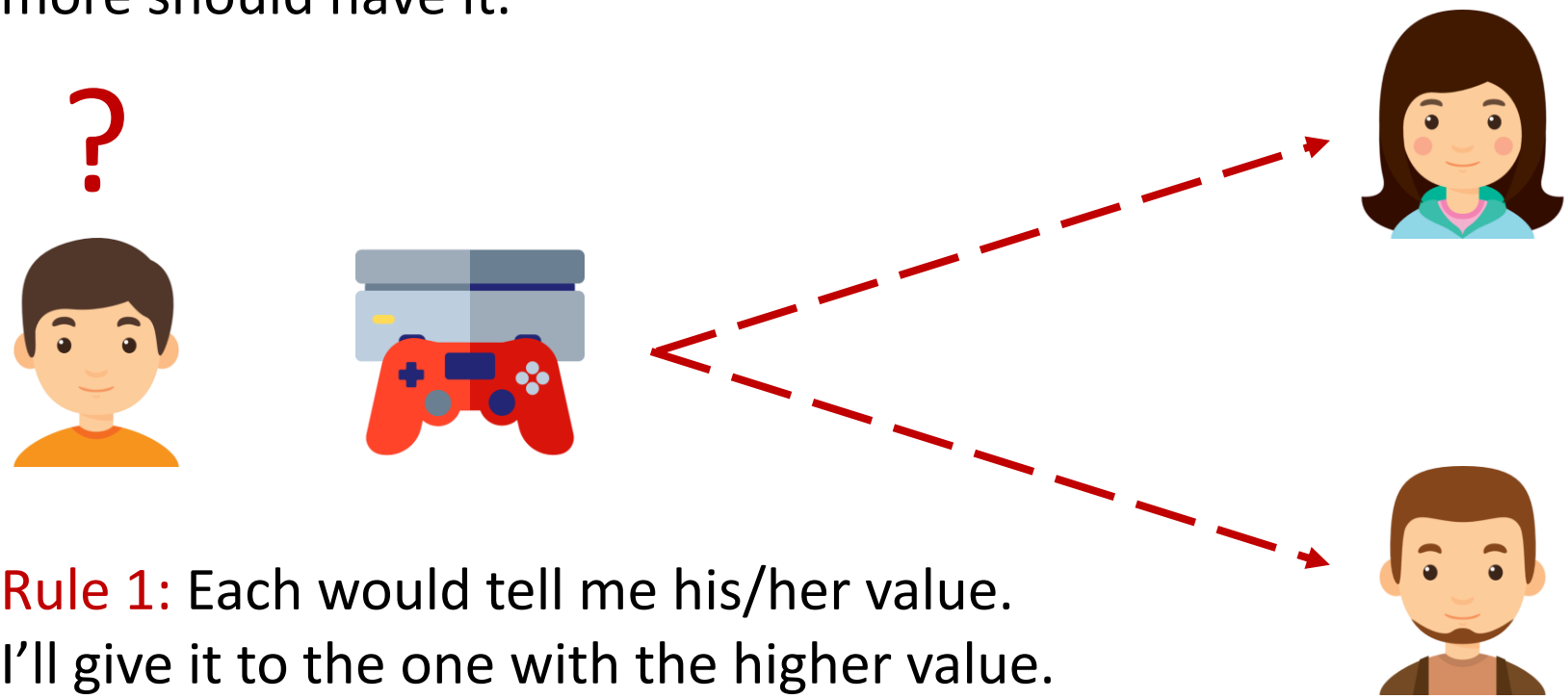
- Social choice: Given the preferences of the agents, which collective decision is the most desirable?
  - Fairness, welfare, ethics, resource utilization, …
- Mechanism design: Agents have private information, which they may lie about.
  - How to design the "rules of the game" such that selfish agent behavior results in desirable outcomes.
  - We call this "implementing" the social choice rule.

Mechanism Design

- With money
  - Principal can “charge” the agents (require payments)
  - Helps significantly
  - Example: auctions
- Without money
  - Monetary transfers are not allowed
  - Incentives must be balanced otherwise
  - Often impossible without sacrificing the objective a little
  - Example: elections, kidney exchange

Example: Auction

Objective: The one who really needs it more should have it.

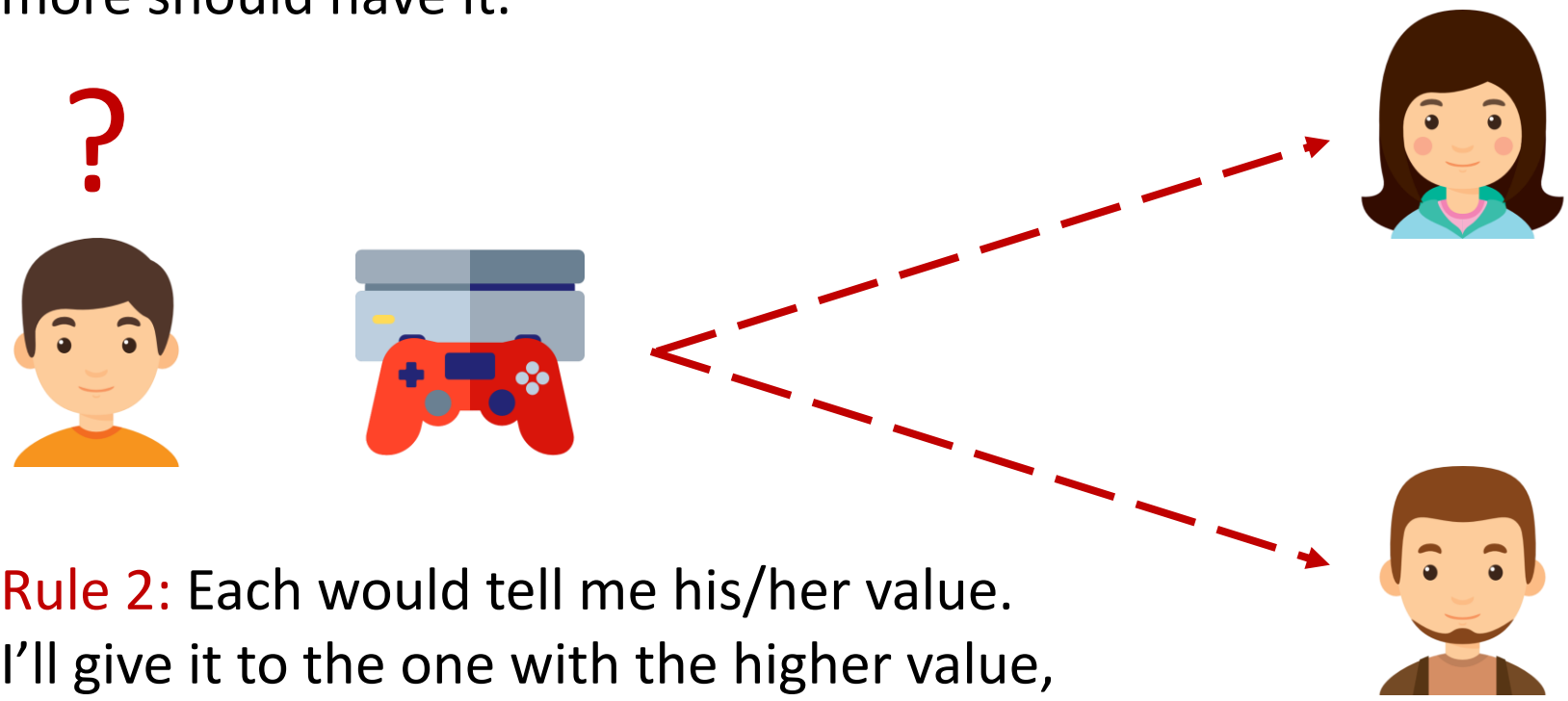


Rule 1: Each would tell me his/her value.
I'll give it to the one with the higher value.

Image Courtesy: Freepik

Example: Auction

Objective: The one who really needs it more should have it.

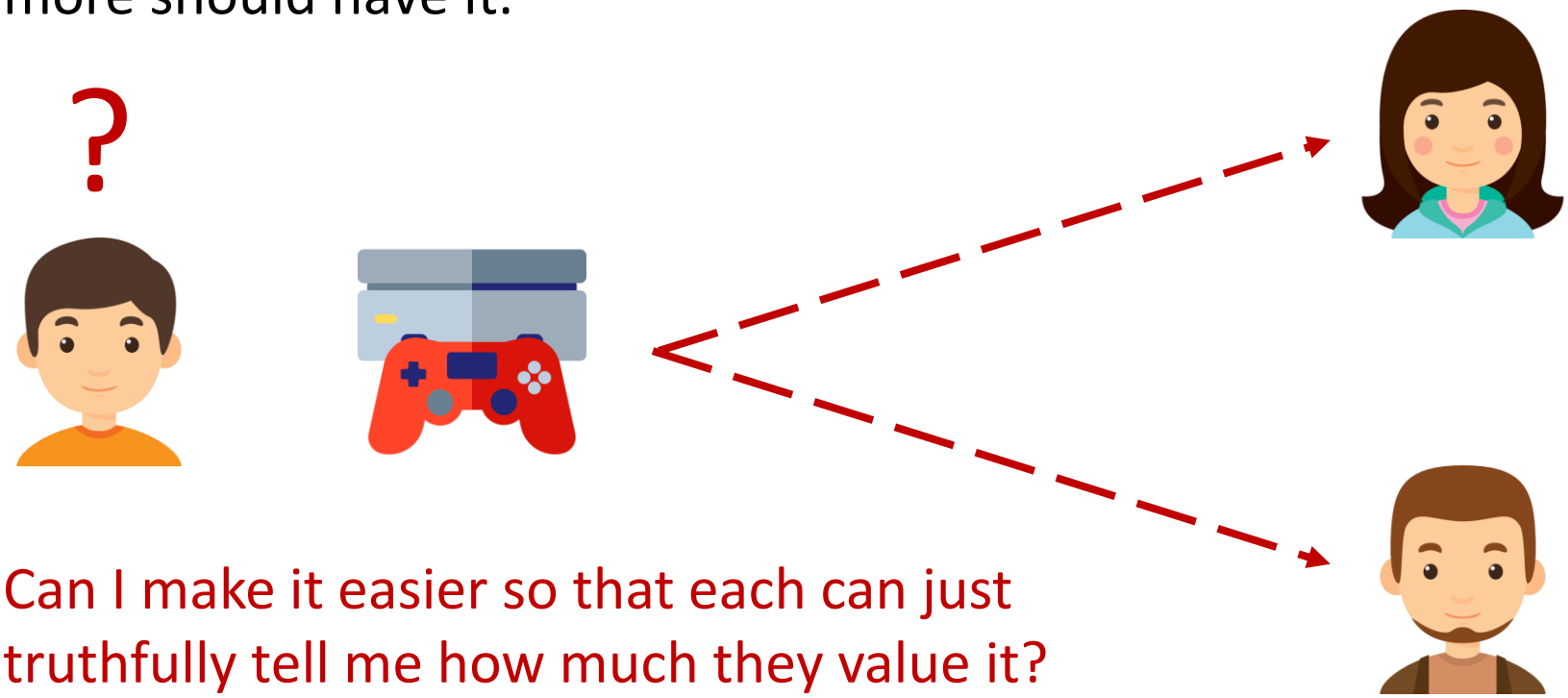


Rule 2: Each would tell me his/her value. I'll give it to the one with the higher value, but they have to pay me that value.

Image Courtesy: Freepik

Example: Auction

Objective: The one who really needs it more should have it.



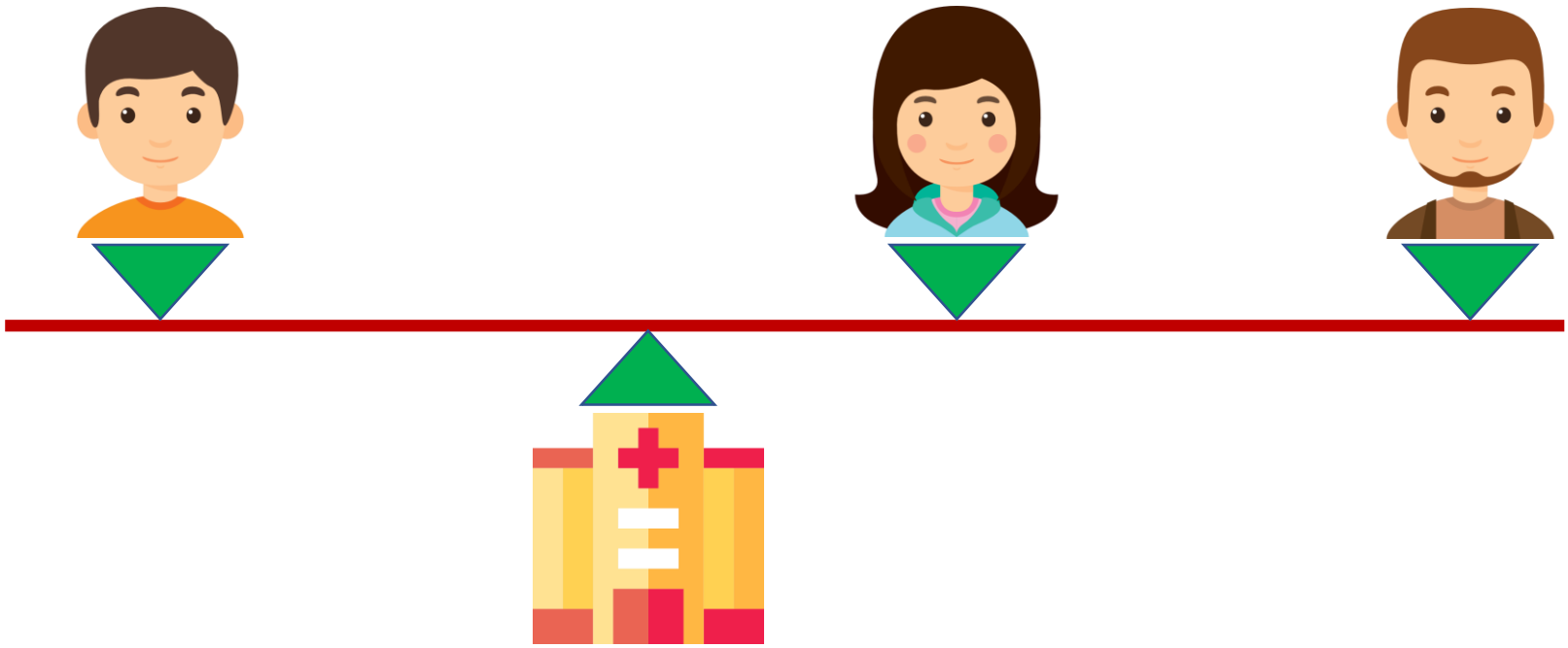
Can I make it easier so that each can just truthfully tell me how much they value it?

Image Courtesy: Freepik

Real-World Applications

- Auctions form a significant part of mechanism design with money
- Auctions are ubiquitous in the real world!
  - A significant source of revenue for many large organizations (including Facebook and Google)
  - Often run billions of tiny auctions everyday
  - Need the algorithms to be fast

Example: Facility Location



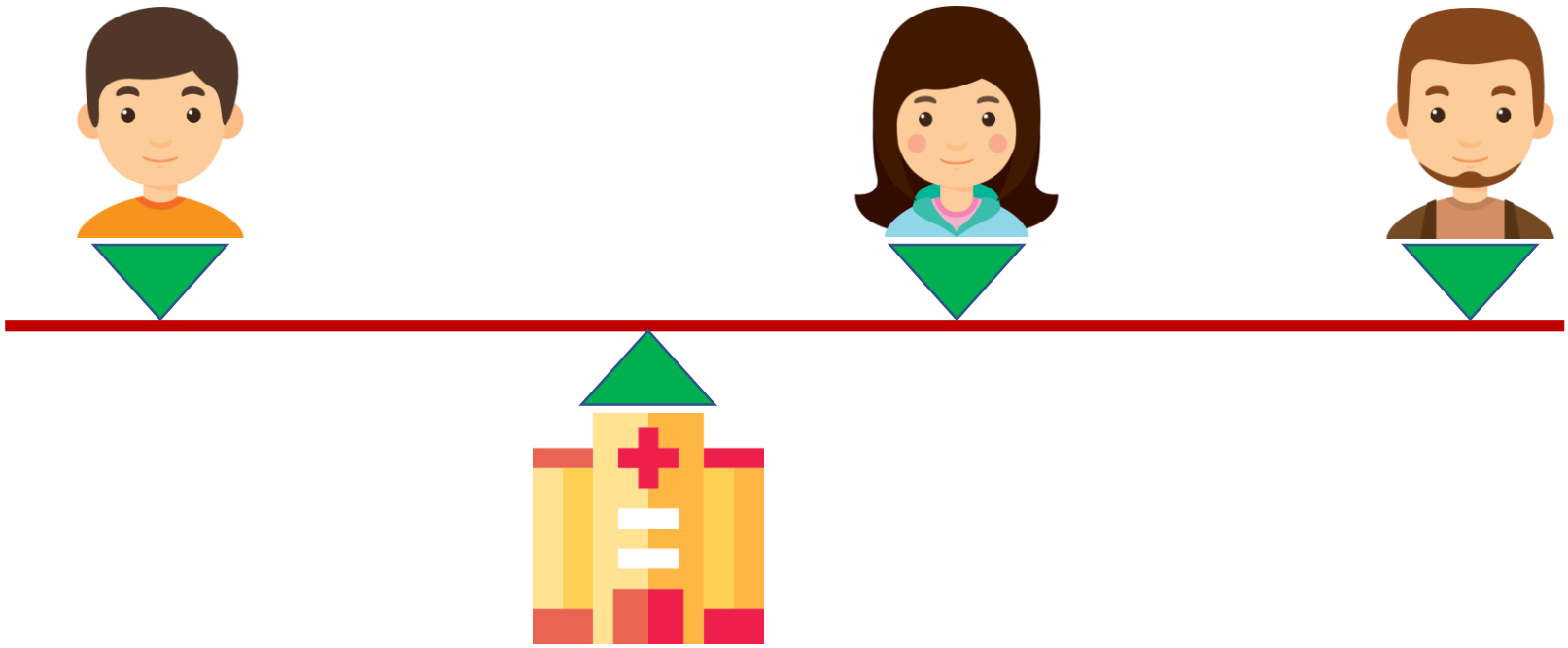
Cost to each agent: Distance from the hospital

Objective: Minimize the sum of costs

Constraint: No money

Image Courtesy: Freepik

Example: Facility Location

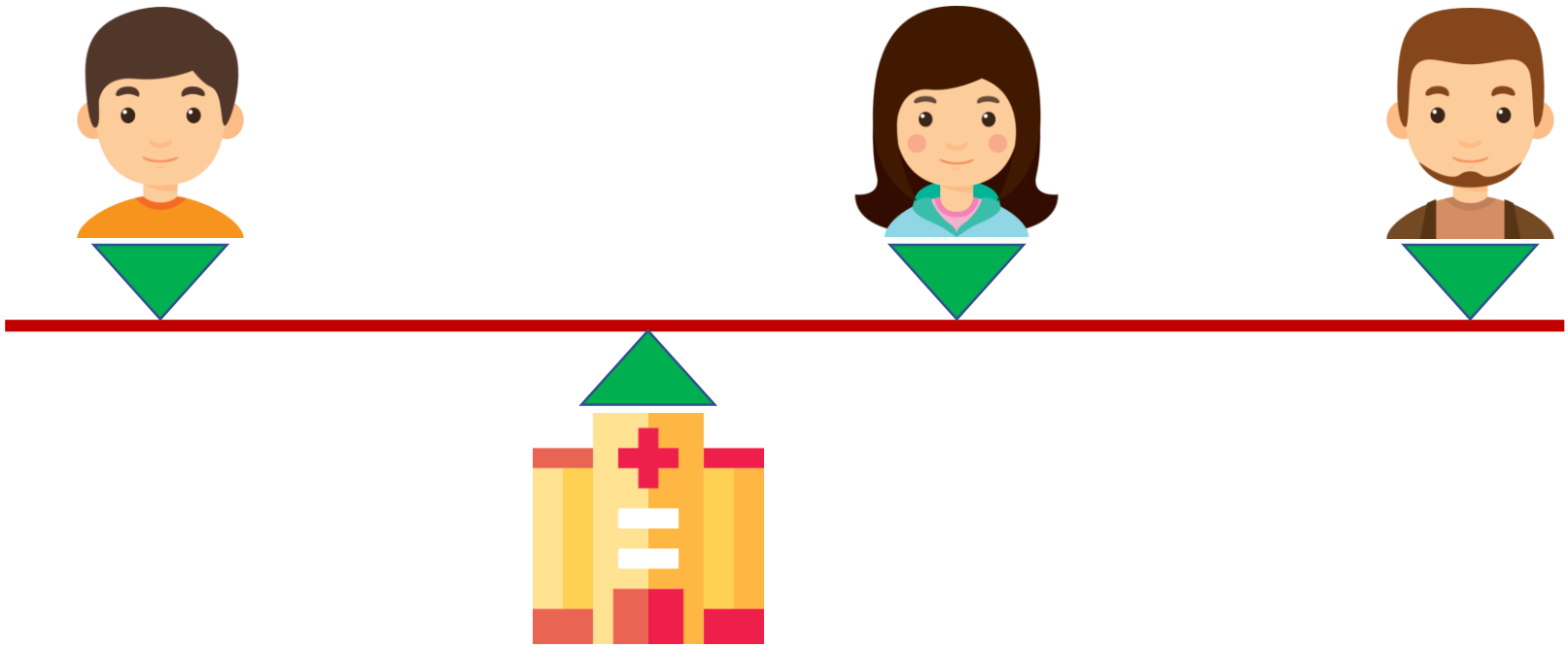


Q: What is the optimal hospital location?

Q: If we decide to choose the optimal location, will the agents really tell us where they live?

Image Courtesy: Freepik

Example: Facility Location



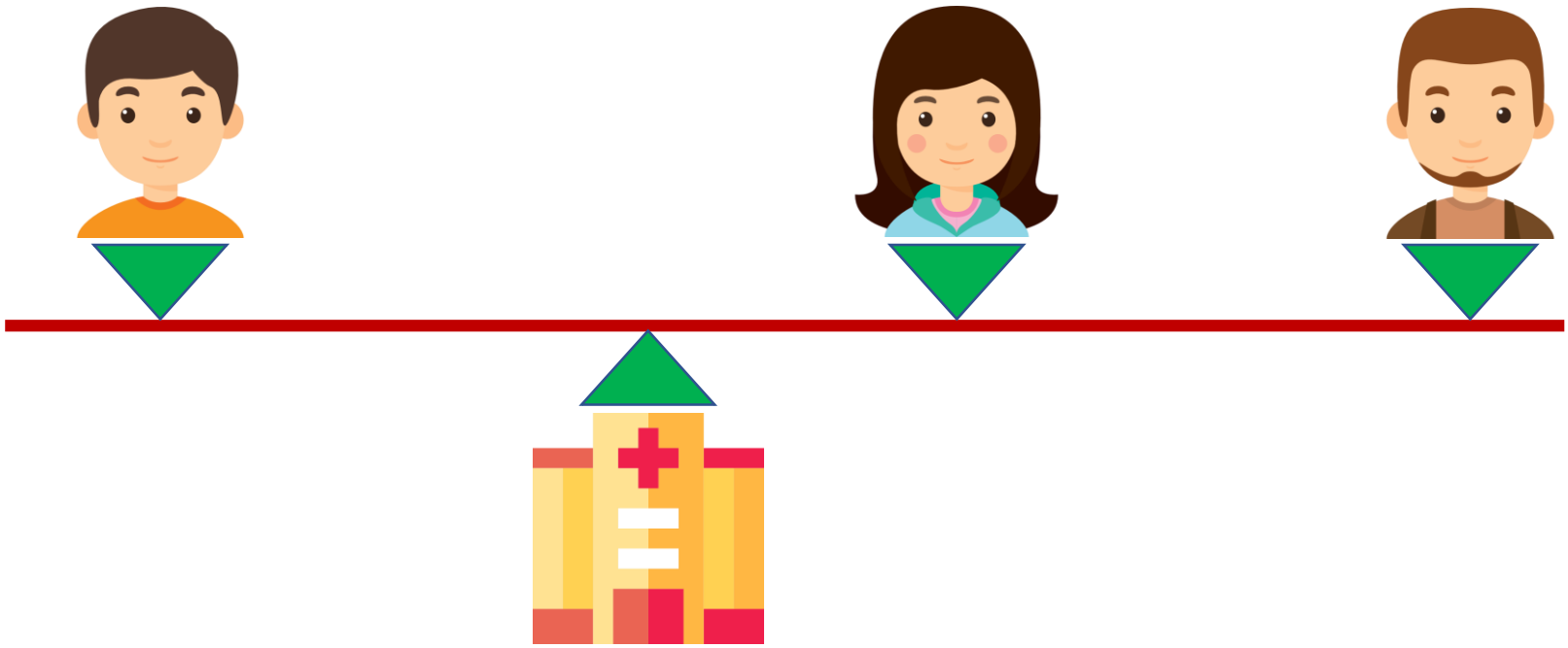
Cost to each agent: Distance from the hospital

Objective: Minimize the maximum cost

Constraint: No money

Image Courtesy: Freepik

Example: Facility Location



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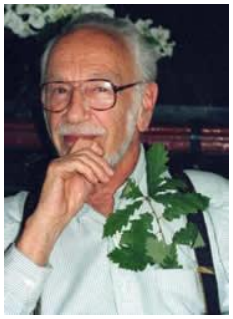
Real-World Applications


Roth


Gale


Shapley

National Resident Matching Program (NRMP)

School Choice (New York, Boston)

Fair Division

Voting

Voting Theory

Social Choice Theory

- Mathematical theory for aggregating individual preferences into collective decisions

Voting Theory

- Originated in ancient Greece
- Formal foundations
- 18th Century (Condorcet and Borda)
- 19th Century: Charles Dodgson (a.k.a. Lewis Carroll)
- 20th Century: Nobel prizes to Arrow and Sen

Voting Theory

- We want to select a collective decision based on (possibly different) individual preferences
  - Presidential election, restaurant/movie selection for group activity, committee selection, facility location, …
- Resource allocation is a special case:
  - You can think of all possible allocations as the different "outcomes"
    - A very restricted case due to lots of ties
    - An agent is indifferent among all allocations in which the resources *she* gets are the same
  - We want to study the general case

Voting Framework

- Set of voters $N = \{1, \ldots, n\}$
- Set of alternatives A, $|A| = m$
- Voter i has a preference ranking $\succ_i$ over the alternatives
- Preference profile $\vec{\succ}$ is the collection of all voters' rankings

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

Voting Framework

- Social choice function f
  - Takes as input a preference profile $\vec{\succ}$
  - Returns an alternative $a \in A$
- Social welfare function f
  - Takes as input a preference profile $\vec{\succ}$
  - Returns a societal preference $\succ^*$
- For now, voting rule = social choice function

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

Voting Rules

- Plurality
  - Each voter awards one point to her top alternative
  - Alternative with the most point wins
  - Most frequently used voting rule
  - Almost all political elections use plurality

- Problem?

1	2	3	4	5
a	a	a	b	b
b	b	b	c	c
c	c	c	d	d
d	d	d	e	e
e	e	e	a	a

Winner
a

Voting Rules

- Borda Count
  - Each voter awards $m - k$ points to alternative at rank k
  - Alternative with the most points wins
  - Proposed in the 18th century by chevalier de Borda
  - Used for elections to the national assembly of Slovenia

1	2	3
a (2)	c (2)	b (2)
b (1)	a (1)	a (1)
c (0)	b (0)	c (0)

Total
a: 2+1+1 = 4
b: 1+0+2 = 3
c: 0+2+0 = 2

Winner
a

Current uses [edit]

Political uses [edit]

The Borda count is used for certain political elections in at least three countries, Slovenia and the tiny Micronesian nations of Kiribati and Nauru. In Slovenia, the Borda count is used to elect two of the ninety members of the National Assembly: one member represents a constituency of ethnic Italians, the other a constituency of the Hungarian minority. As noted above, members of the Parliament of Nauru are elected based on a variant of the Borda count that involves two departures from the normal practice: (1) multi-seat constituencies, of either two or four seats, and (2) a point-allocation formula that involves increasingly small fractions of points for each ranking, rather than whole points. In Kiribati, the president (or *Beretitenti*) is elected by the plurality system, but a variant of the Borda count is used to select either three or four candidates to stand in the election. The constituency consists of members of the legislature (*Maneaba*). Voters in the legislature rank only four candidates, with all other candidates receiving zero points. Since at least 1991, tactical voting has been an important feature of the nominating process.

The Republic of Nauru became independent from Australia in 1968. Before independence, and for three years afterwards, Nauru used instant-runoff voting, importing the system from Australia, but since 1971, a variant of the Borda count has been used.

The modified Borda count has been used by the Green Party of Ireland to elect its chairperson.[6][7]

The Borda count has been used for non-governmental purposes at certain peace conferences in Northern Ireland, where it has been used to help achieve consensus between participants including members of Sinn Féin, the Ulster Unionists, and the political wing of the UDA.

Other uses [edit]

The Borda count is used in elections by some educational institutions in the United States.

- University of Michigan
  - Central Student Government
  - Student Government of the College of Literature, Science and the Arts (LSASG)
- University of Missouri: officers of the Graduate-Professional Council
- University of California Los Angeles: officers of the Graduate Student Association
- Harvard University: officers of the Civil Liberties Union
- Southern Illinois University at Carbondale: officers of the Faculty Senate,
- Arizona State University: officers of the Department of Mathematics and Statistics assembly.
- Wheaton College, Massachusetts: faculty members of committees.
- College of William and Mary: members of the faculty personnel committee of the School of Business Administration (tie-breaker).

The Borda count is used in elections by some professional and technical societies.

- International Society for Cryobiology: Board of Governors.
- Tempo sustainable design network: management committee.
- U.S. Wheat and Barley Scab Initiative: members of Research Area Committees.
- X.Org Foundation: Board of Directors.

The OpenGL Architecture Review Board uses the Borda count as one of the feature-selection methods.

The Borda count is used to determine winners for Toastmasters International speech contests. Judges offer a ranking of their top three speakers, awarding them three points, two points, and one point, respectively. All unranked candidates receive zero points.

The modified Borda count is used to elect the President for the United States member committee of AIESEC.

The Borda count, and points-based systems similar to it, are often used to determine awards in competitions.

The Borda count is a popular method for granting sports awards in the United States. Uses include:

- MLB Most Valuable Player Award (baseball)
- Heisman Trophy (college football)[8]
- Ranking of NCAA college teams

The Eurovision Song Contest uses a positional voting method similar to the Borda count, with a different distribution of points: only the top ten entries are considered in each ballot, the favorite entry receiving 12 points, the second-placed entry receiving 10 points, and the other eight entries getting points from 8 to 1. Although designed to favor a clear winner, it has produced very close races and even a tie.

The People's Remix Competition uses a Borda variant where each voter ranks only the top three contestants.

The Borda count is used for wine trophy judging by the Australian Society of Viticulture and Oenology, and by the RoboCup autonomous robot soccer competition at the Center for Computing Technologies, in the University of Bremen in Germany.

The Finnish Associations Act lists three different modifications of the Borda count for holding a proportional election. All the modifications use fractions, as in Nauru. A Finnish association may choose to use other methods of election, as well.[9]

Borda count in real life

Voting Rules

- Positional Scoring Rules
  - Defined by a score vector $\vec{s} = (s_1, \dots, s_m)$
  - Each voter gives s_k points to alternative at rank k

- A family containing many important rules
  - Plurality = $(1,0, \dots, 0)$
  - Borda = $(m-1, m-2, \dots, 0)$
  - k-approval = $(1, \dots, 1,0, \dots, 0)$ ← top k get 1 point each
  - Veto = $(0, \dots, 0,1)$
  - …

Voting Rules

- Plurality with runoff
  - First round: two alternatives with the highest plurality scores survive
  - Second round: between these two alternatives, select the one that majority of voters prefer

- Similar to the French presidential election system
  - Problem: vote division
  - Happened in the 2002 French presidential election

Voting Rules

- Single Transferable Vote (STV)
  - $m - 1$ rounds
  - In each round, the alternative with the least plurality votes is eliminated
  - Alternative left standing is the winner
  - Used in Ireland, Malta, Australia, New Zealand, …

- STV has been strongly advocated for due to various reasons

STV Example

2 voters	2 voters	1 voter
a	b	c
b	a	d
c	d	b
d	c	a

2 voters	2 voters	1 voter
a	b	c
b	a	b
c	c	a

2 voters	2 voters	1 voter
a	b	b
b	a	a

2 voters	2 voters	1 voter
b	b	b

Voting Rules

- Kemeny's Rule
  - Social welfare function (selects a ranking)
  - Let $n_{a \succ b}$ be the number of voters who prefer a to b
  - Select a ranking σ of alternatives = for every pair (a, b) where $a \succ_\sigma b$, we make $n_{b \succ a}$ voters unhappy
  - Total unhappiness $K(\sigma) = \sum_{(a,b): a \succ_\sigma b} n_{b \succ a}$
  - Select the ranking σ^* with minimum total unhappiness
- Social choice function
  - Choose the top alternative in the Kemeny ranking

Condorcet Winner

- Definition: Alternative x beats y in a pairwise election if a strict majority of voters prefer x to y
  - We say that the majority preference prefers x to y
- Condorcet winner beats every other alternative in pairwise election
- Condorcet paradox: when the majority preference is cyclic

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

Majority Preference

$a \succ b$

$b \succ c$

$c \succ a$

Condorcet Consistency

- Condorcet winner is unique, if one exists
- A voting rule is Condorcet consistent if it always selects the Condorcet winner if one exists
- Among rules we just saw:
  - *NOT* Condorcet consistent: all positional scoring rules (plurality, Borda, …), plurality with runoff, STV
  - Condorcet consistent: Kemeny (WHY?)

Majority Consistency

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

- Question: What is the relation between majority consistency and Condorcet consistency?

  1. Majority consistency ⇒ Condorcet consistency
  2. Condorcet consistency ⇒ Majority consistency
  3. Equivalent
  4. Incomparable

Condorcet Consistency

- Copeland
  - Score(x) = # alternatives x beats in pairwise elections
  - Select x^* with the maximum score
  - Condorcet consistent (WHY?)

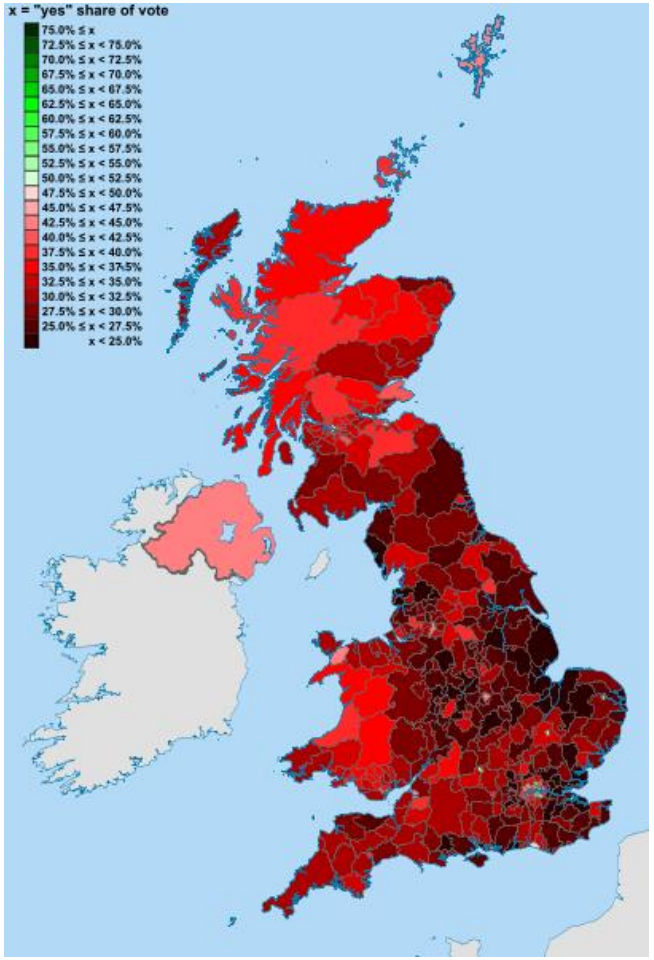
- Maximin
  - Score(x) = $\min_y n_{x \succ y}$
  - Select x^* with the maximum score
  - Also Condorcet consistent (WHY?)

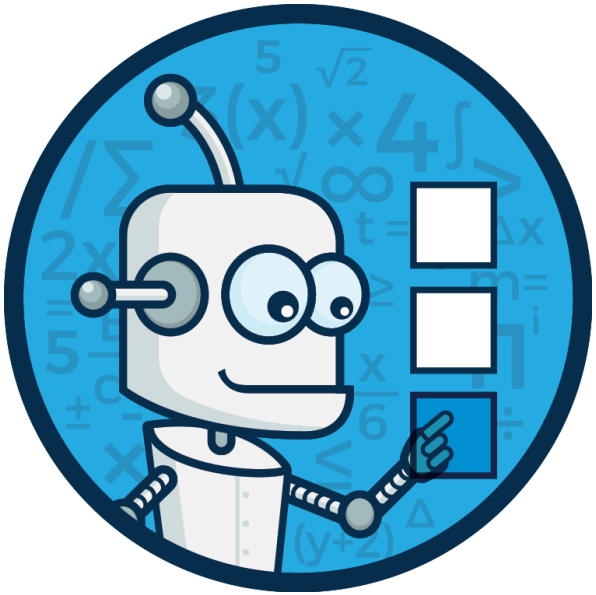
Which rule to use?

- We just introduced infinitely many rules
  - (Recall positional scoring rules…)
- How do we know which is the "right" rule to use?
  - Various approaches
  - Axiomatic, statistical, utilitarian, …
- How do we ensure good incentives without using money?
  - Bad luck! [Gibbard-Satterthwaite, next lecture]

Is Social Choice Practical?

- UK referendum: Choose between plurality and STV for electing MPs
- Academics agreed STV is better...
- ...but STV seen as beneficial to the hated Nick Clegg
- Hard to change political elections!





ROBOVOTE

Voting:
For the People, By the People

- Voting can be useful in day-to-day activities
- On such a platform, easy to deploy the rules that we believe are the best