Course overview and logistics

CS639: Algorithmic Game Theory & Learning

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Spring 2026

January 20, 2026

Game theory

A mathematical framework for modelling interactions between multiple **strategic and selfish** agents (players).
- Agents view the interaction as a *"game".*
- Each agent is trying to *"win the game".*

- Agents could be partially competitive and partially cooperative.

- Agents: people, organizations, countries, robots.

Example 1: Prisoner's dilemma

Two robbers are caught after committing a robbery together. They are each given the option to ***betray their partner*** or ***remain loyal***.

		Prisoner B	
		Betray	**Remain loyal**
Prisoner A	**Betray**	A serves 3 years, B serves 3 years	A goes free, B serves 5 years
	Remain loyal	A serves 5 years, B goes free	A serves 1 years, B serves 1 years

Prisoner's dilemma in the real world

1. Individually, countries find it beneficial to develop nuclear weapons.

    - But the mutually better outcome is if no country had nuclear weapons.

2. Competing firms lower prices to attract customers.

    - But best if they collectively keep prices high.

    - **Counter-examples:** OPEC, Cable/wireless companies in the US.

Example 2: Tragedy of the commons

A common resource can be used by some agents.

- Each agent benefits by using the resource.
- It is collectively better for all agents to use less of the resource.
- However, it is better for each individual agent to use more. This leads to socially less desirable outcomes.

Tragedy of the commons in the real world

1. Individual fishermen compete to catch as much fish as possible.
   - But over-fishing will deplete the fish population over time.
2. Individually, plastic consumption is convenient and does not affect the environment significantly.
   - But collectively, plastic consumption is not sustainable.

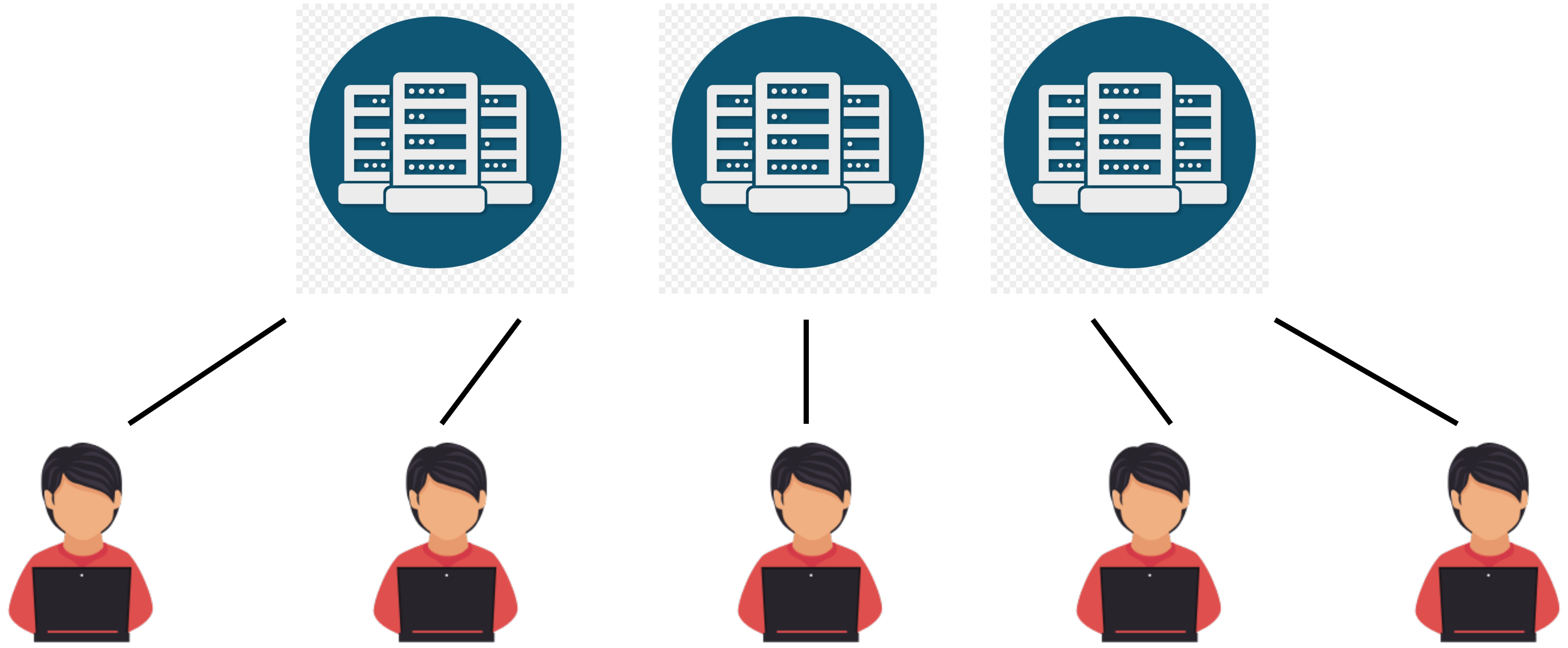
Counter-measures via regulations: Restrictions on overfishing, Pay for single-use plastic bags.

Mechanism design

The design of games, i.e social interactions, to obtain desirable social outcomes when agents are acting in self-interest.

- “Inverse” game theory
- Ideally, there would be an “obvious” strategy that leads to the desired outcome. (Not always possible)

Example 1: Resource allocation in clusters

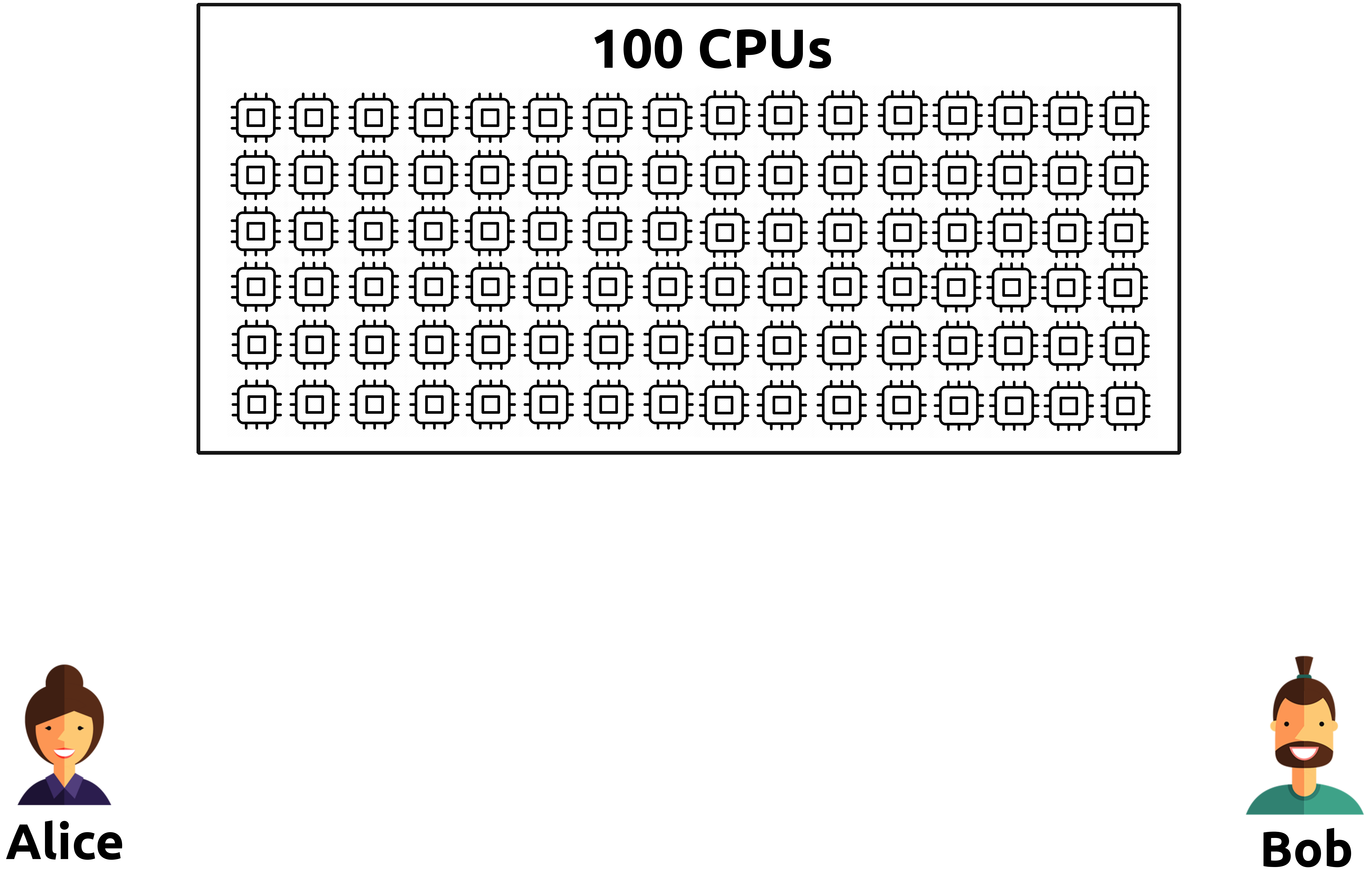


Several users are sharing a compute cluster. How do you allocate the resources among them?

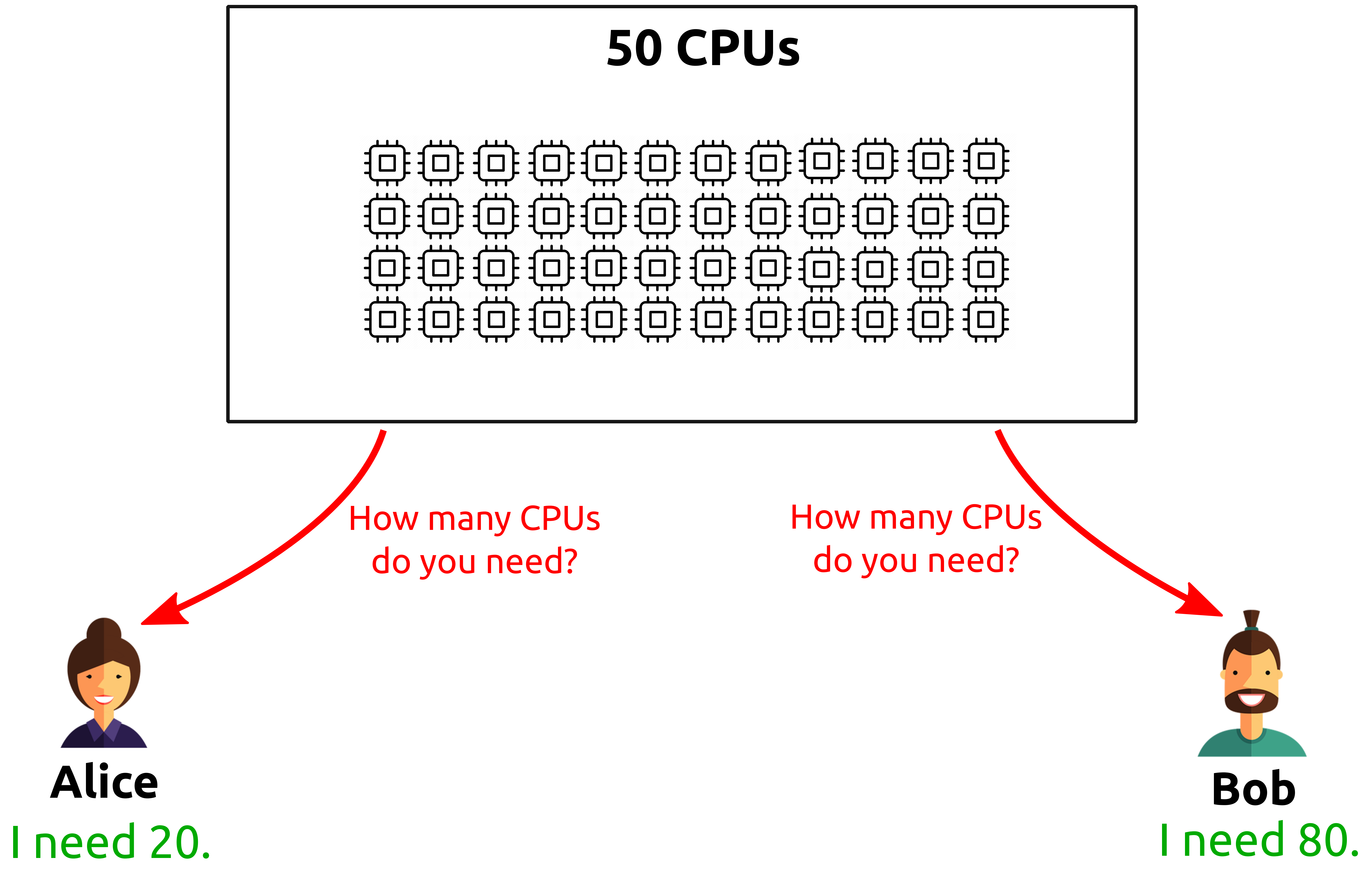
- Users are *competing* for the *finite* amount of resources. Usually demand exceeds supply.
- Users want to "win this game", i.e try to get more resources for themselves. *E.g "if I ask more, I will get more".*
- Users wish to be treated fairly.

If managed poorly, this is an example of the tragedy of the commons.

Fair resource allocation in clusters



Fair resource allocation under scarcity

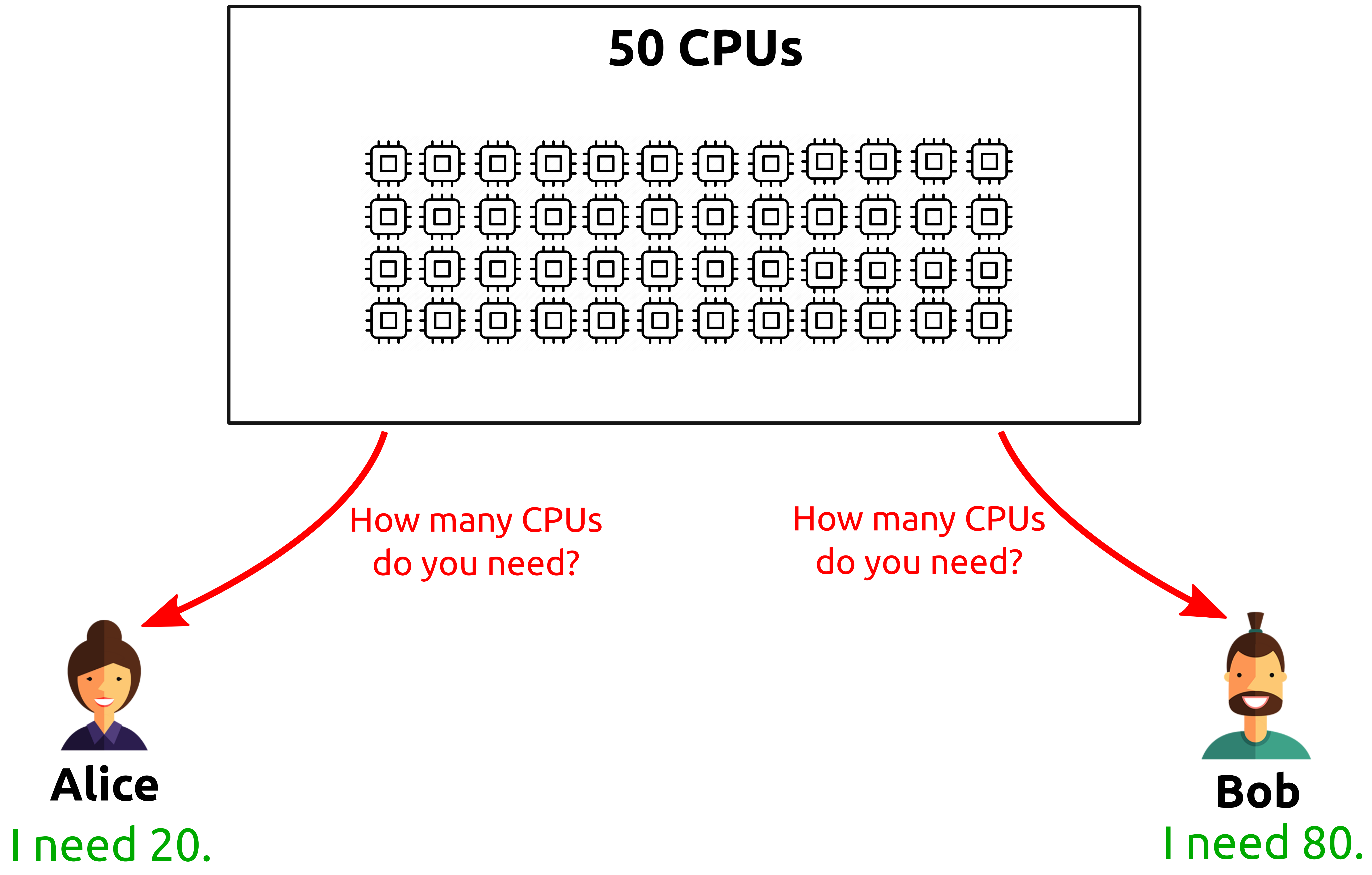


Cluster manager:
Let me try allocating proportionally

Issue 1:
Alice: this is not fair! My fair share is 25 CPUs.

Issue 2:
Bob: If I request more than 80, I will get more than 40.
Alice: I also need to request more.

Are there better solutions?



The Max-min fairness *mechanism*

- we will study this in detail later in class

100 CPUs, 4 Users	**Carol**	**Dave**	**Eve**	**Frank**
Demands	50	26	10	80
Rnd 1: fair share	25	25	25	25
Allocation			10	
Rnd 2: fair share	30	30	-	30
Allocation		26	-	
Rnd 3: fair share	32	-	-	32
Allocation	32	-	-	32

The Max-min fairness *mechanism*

Properties of this mechanism:

1. No incentives for agents to ask for more.

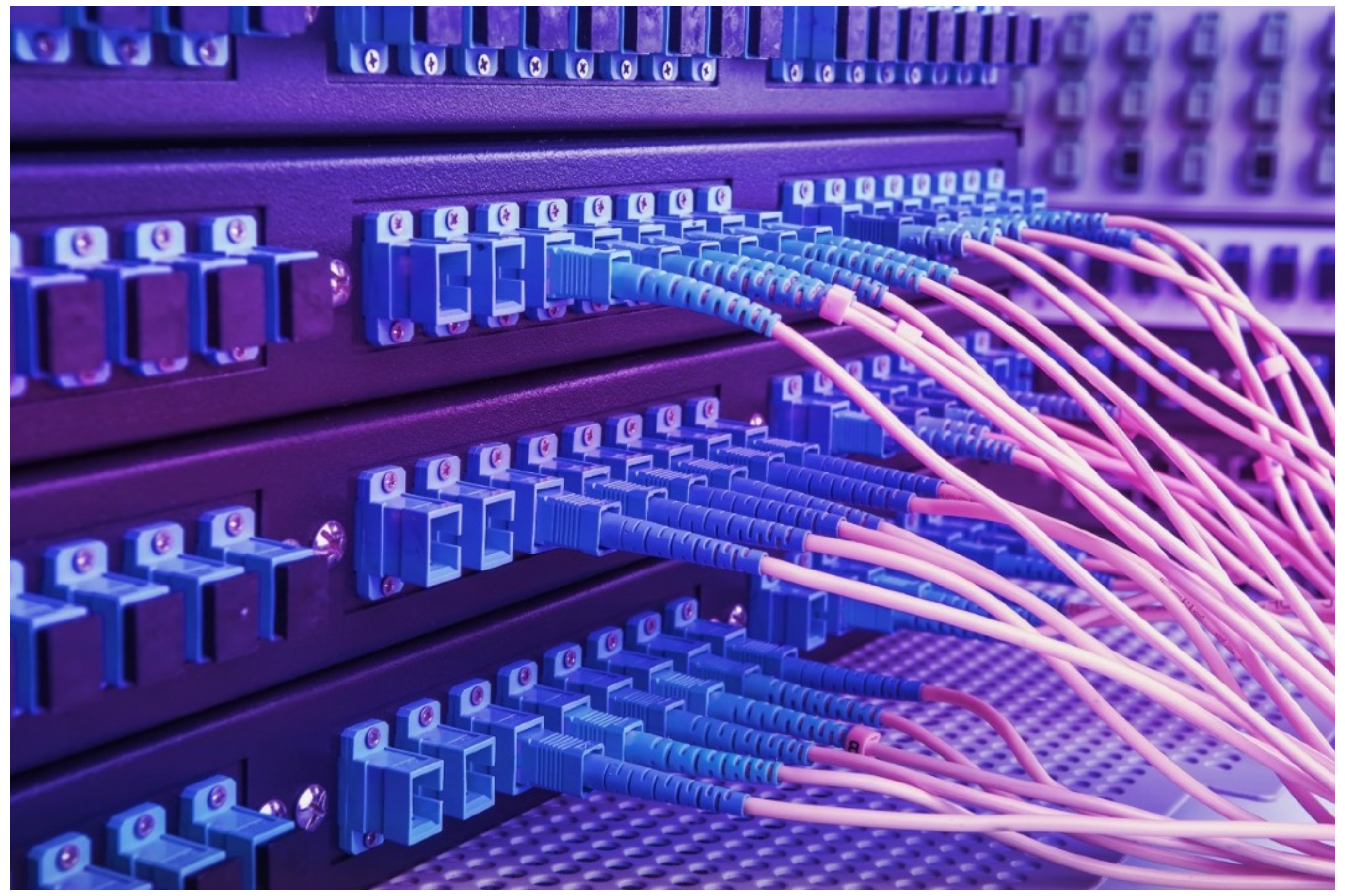
2. Fair *(a user will either fully satisfy her demand or receive at least her fair share)*

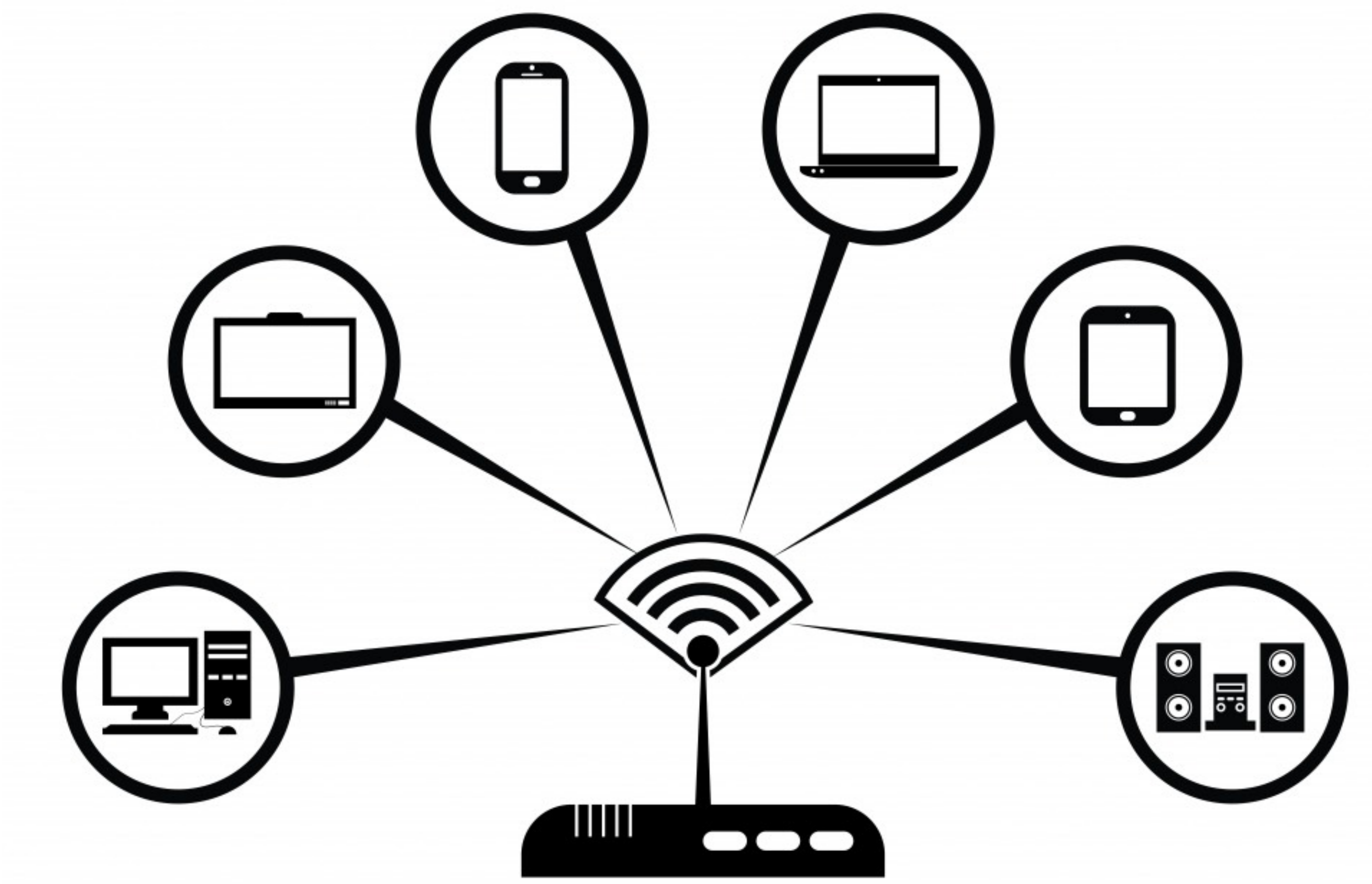
3. No resource wastage

100 CPUs, 4 Users	Carol	Dave	Eve	Frank
Demands	50	26	10	80
Rnd 1: fair share	25	25	25	25
Allocation			10	
Rnd 2: fair share	30	30	-	30
Allocation		26	-	
Rnd 3: fair share	32	-	-	32
Allocation	32	-	-	32

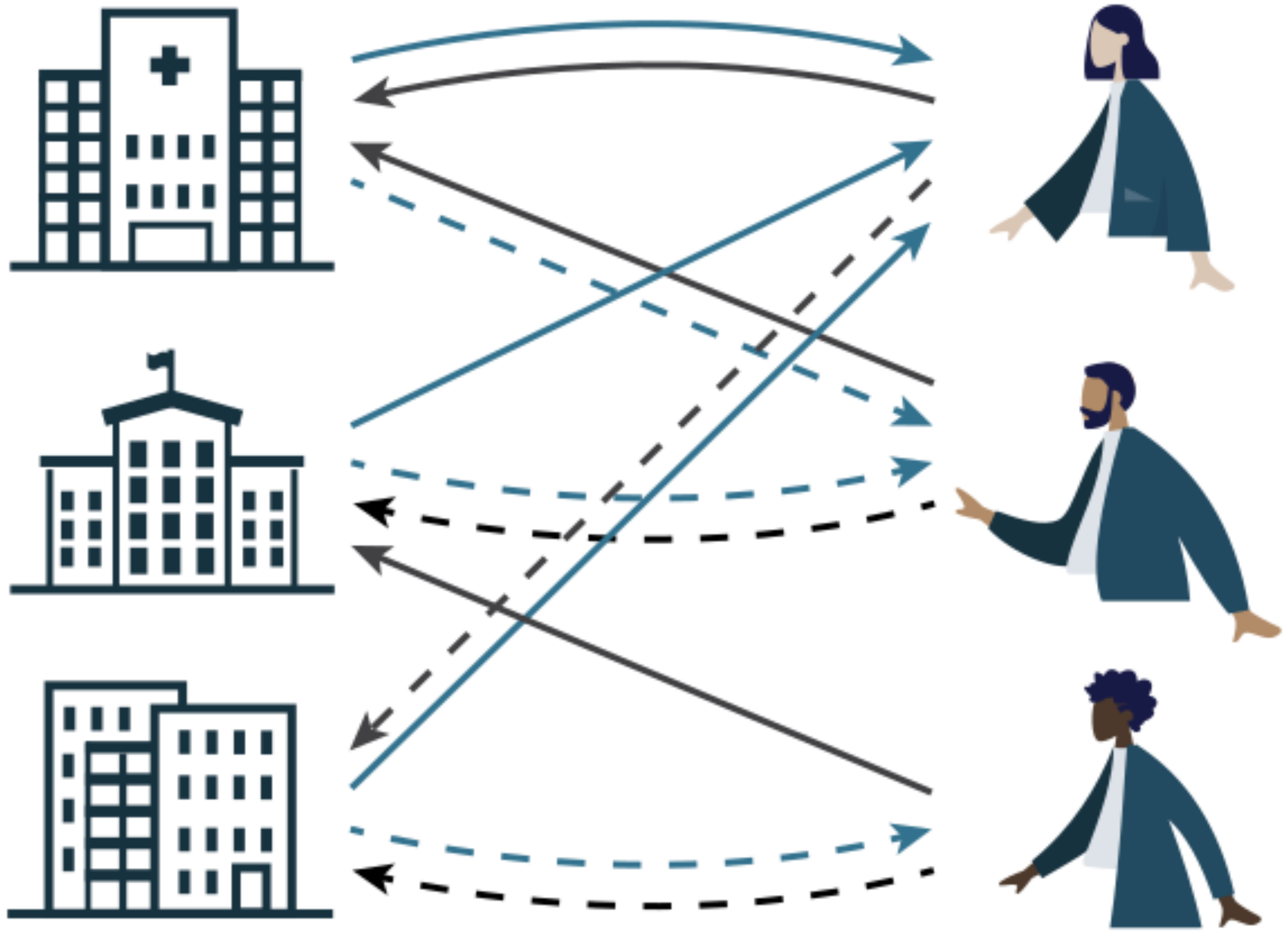
Fair resource allocation in real world cluster managers

Bandwidth allocation in WIFI and Broadband





Example 2: Stable matching



NRMP: National Residency Matching Program

Each year medical school graduates apply to the NRMP.

Hospitals rank the residents.

Residents can rank up to N hospitals (In NRMP, $N = 20$).

Goal: Match residents to hospitals based on submitted rankings.

Cooperative Game Theory

A framework for studying situations where agents can make a mutually beneficial agreement, but have a conflict of interest about which agreement to make.

Example: How to divide wealth created?

Two workers decide to team up to produce tables.

- On their own, they can each make $10 per day.
- If they work together, they can make $100 per day.

Working together is clearly beneficial. But how do they split up the $100 between them?

$50 each seems natural.

Example (cont'd): How to divide wealth created?

A worker and employer decide to team up to produce tables.

- An employer on her own can make $50 per day.
- The worker on her own can make $10 per day.
- If they work together, they can make $100 per day.

Working together is clearly beneficial. But how do they split up the $100 between them?

No, one right solution.

- But in any solution, employer gets at least $50, worker gets at least $10. Otherwise, they will not be willing to work together.
- **Axiomatic bargaining** provides a framework to split the remaining $40.

Some desirable properties

Necessary

- *Individual rationality:* Employer should get at least \$50, worker should get at least \$10. Otherwise, they will not be willing to work together.

Nice to have

- The total allocation should be \$100.
- Scale invariance. (E.g allocation should not change if we do the calculation in cents and not dollars.)
- Anonymity: changing labels of agents should not change allocation.

Other nice properties we will explore in class.

Outline

1. Course logistics
2. Grading
3. Syllabus
4. Who should take this class? Prerequisites and expectations

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Lectures, Enrollment

- **Lectures**
  - Tuesday & Thursday, 11 am - 12.15 pm at Psychology 103
  - Lectures will be on slides, with mathematically intensive portions written out on a tablet and projected.
  - *Complete* slides will be made available prior to class, but are not a substitute for attending lectures.
- **Enrollment**
  - At capacity. A few on the waitlist.
  - Continue to come to class, some students will likely drop.

Recommended material

- Recommended textbook: **Game Theory, Alive** by Anna Karlin & Yuval Peres
- Other useful resources
    - Algorithmic Game Theory, by Nisan, Roughgarden, Tardos, Vazirani.
    - Tim Roughgarden's lecture notes, Incentives in Computer Science, Algorithmic Game Theory.
    - Amy Greenwald's lecture notes, Topics In Algorithmic Game Theory.

Course staff, Office hours

- **Instructor:** Kirthi Kandasamy
  - OHs: Tue 2.00 - 3.30 pm, MH 5506
  - E-mail: kandasamy [at] cs.wisc.edu.

- **Grader:** David Zinkel

Webpages

- **Course website**
  - pages.cs.wisc.edu/~kandasamy/courses/26spring-cs639/
  - General course information, syllabus, schedule, homeworks, and grading
- **Piazza**
  - piazza.com/wisc/spring2026/cs639005
  - Announcements, peer discussions on lectures, homework clarifications.
  - As a general rule, I will **not** be checking Piazza regularly.
- **Canvas**
  - Homeworks (and some announcements)
  - Please do not share material posted on canvas outside the classroom.

Contacting the Instructor

- Please read the course website and previous Piazza posts before you ask us.

- If you decide to contact me:

   1. OHs > Public piazza post > private piazza message > email
   2. If you think others will benefit from the answer, please ask as a public question on Piazza.
   3. Keep questions as concise as possible.

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Grading

- Proofreading slides and class participation: 10%
- Homeworks: 30%
- Midterm: 30%
- Final: 30%

Proofreading slides and class participation

- Each student will proofread 2-4 lectures. Two students per lecture. (This may change if enrolment drops.) See course website for sign-up link
- **Instructions (see course website as well)**
  - Proofreaders **must** attend class.
  - After class, carefully read and identify typos, errors, and unclear explanations.
  - Within **2 days**, each student should **email separate submissions**, either marked on downloaded slides or typed up as a separate pdf.
  - If you are unsure about taking the class, sign up for after Feb 23. If you decide to drop, *delete your name* ***and*** *email me*.
  - After you sign up, please don't change your slot without informing me.

Exams

- **Midterm: 30%**
  - Time: TBD, but likely sometime between Mar 16 - Mar 27 (likely Mar 16-20). **Do not make spring break travel plans for now.**
  - Location TBD.

- **Final: 30%**
  - Wednesday 05/06/2026 12.25 PM – 2.25 PM.
  - Location TBD.

- **Make-up exams:**
  - Only for *documented* emergencies and conference travel.
  - Otherwise, up to a 33% penalty.

Homework (30% of grade)

Read course webpage for all details,

- Homework 0, and another 6 Homeworks.
- Should be typeset (no written and scanned homeworks).
- Homeworks *will be difficult*.
    - Expect to spend multiple hours/days on some problems.
    - Unless otherwise specified, you *are allowed* to collaborate with up to 2 classmates.
- Do **not** release questions outside of class, or discuss them in public forums.

Homework (cont'd)

- Late homework policy:
  - You have 4 total late days to be used throughout the semester.
  - After that, 50% of score if you submit 2 days after the deadline, and 0% if you are later than 2 days.
  - Extensions are **very unlikely,** and will be *considered* only for documented emergencies, travel to academic conferences, and paper deadlines.
  - There are additional rules and we will follow them strictly. Please read the course website.

Homework (cont’d)

- Using LLM-based tools in your homework:
  - You are allowed to use LLM tools, however, if you entirely use LLMs to generate solutions, you will be very unprepared for your midterm and final.
  - Recommended way to use LLMs:
    - Always attempt the problem on your own first. After completing a solution, you may use an LLM to check your work.
    - If you are stuck after substantial effort (at least several hours), you may use an LLM for high-level guidance (e.g., how to approach the problem).
    - If you are still stuck (after a day or two), you may generate a solution using an LLM, but you must understand it fully, verify its correctness, and write the solution in your own words.

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3. **Syllabus**
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Syllabus: Overview

1. General sum games (4-6 lectures)
2. Zero sum games (1-2 lectures)
3. Solving games via linear programming (1-2 lectures)

Part I: Game theory fundamentals

4. Online learning (1-2 lectures)
5. Learning in games (3-4 lectures)

Part II: Learning in games

6. Mechanism design without money (4-6 lectures)
7. Mechanism design with money (3-5 lectures)

Part III: Mechanism design

8. Cooperative game theory (2-3 lectures)
9. Truthful information elicitation *(if time permits)*

Part IV: Other topics

I. Game theory fundamentals (Ch 1-3)

Basic tools to analyze games and predict behaviour of agents.

- General-sum games, equilibrium concepts
- Zero sum games, minimax theorem
- Potential games
- Price of anarchy/stability
- Computing equilibria via linear programming

II. Learning in games (Ch 4-5)

Modern topics in the intersection of ML, Game theory, and mechanism design

- Introduction to online learning
- Using online learning to approximate equilibria
- Proof of minimax theorem

III. Mechanism Design (Ch 6-7)

Designing games to achieve socially desirable outcomes. We will focus on common desiderata such as, individual rationality, incentive compatibility, fairness, and efficiency.

Applications: Auctions, Kidney exchange, Fair resource allocation, Stable matching

IV. Other topics (Ch 8)

Cooperative game theory: Dividing the value created when agents can cooperate to create more than the sum of their parts.

- Coalitional games
  - The core, Shapley value
- Axiomatic bargaining
  - Nash, utilitarian, and egalitarian solutions

IV. Other topics (Ch 9)

Truthful information elicitation (if time permits)**:** Designing rewards to truthfully elicit information from agents.

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Target audience for the class

- Advanced undergraduate and early graduate students with a strong background in mathematics

- **Background knowledge**
  - **Formal prerequisites:** (CS\MATH 240 or CS\MATH\STAT 475) and (MATH 320, 340, 341, 345 or 375).
  - Background in calculus, linear algebra, and probability.
  - Mathematical maturity, should be comfortable with proofs and logical reasoning.

- **No review** of background topics
  - But, if it is a new mathematical concept, I may explain things **once**.

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Homework 0

Three questions:

1. Mathematics background **(no collaboration on this question)**
2. Game theory: studying a simple game with tragedy of the commons
3. Cooperative game theory: A bargaining problem

Three Objectives

I. A preview of what's to come

II. Calibrate my teaching/expectations

III. Lets you assess if you are ready to take this class

General advice when taking this class

1. Focus on learning, and not on grades.
    - Class will be challenging. But if you are able to keep up, you will get a good grade.

2. Give me feedback about the course.

3. Be good citizens: attend class, ask questions, answer questions, let others answer/ask questions, respond to questions on piazza.