CIS 410/510 (Spring 2020): Multi-Agent Systems and Game Theory
Lecture 1: Introduction

Thanh H. Nguyen
University of Oregon

Many slides are by Haifeng Xu, Pieter Abbeel, Dan Klein, Milind Tambe, and Michael Wooldridge
Course Information

- Course website: [https://classes.cs.uoregon.edu/20S/cis410mas/](https://classes.cs.uoregon.edu/20S/cis410mas/)
- Instructor: Thanh H. Nguyen ([tnguye11@uoregon.edu](mailto:tnguye11@uoregon.edu))
- (Optional) books:
  - Multi-agent Systems (Shoham & Leyton-Brown) (e-book available)
  - Security and Game Theory (Tambe)
- Office hour: Email me to schedule meetings on Zoom
- Course work:
  - 3 programming assignments: 30%
  - 4 written assignments: 40%
  - 1 (take-home) final exam: 30%
Late Policy

- Grading rule:
  - <12 hours after the deadline: -10%
  - <24 hours after the deadline: -20%
  - <48 hours after the deadline: -40%
  - >48 hours: -100%

- You can ask for 1 extension at most. I probably say yes.

- Email: tnguye11@uoregon.edu
  - Title: CIS410/510: Homework # extension
Academic Honesty

Submit your own work:

- Write up homework solutions individually.
- You can discuss homework solutions with other students

Follow rules for collaboration:

- No notes (written or electronic) from study groups
- Acknowledge all collaborations
Today: Introduction and Overview

- What is Multi-Agent System (MAS)?
- What are applications of MAS?
- What is this course?
What is a MAS?

- A collection of multiple autonomous agents, each acting towards its objectives while all interacting in a shared environment, communicating and possibly coordinating their actions.

- Autonomous (intelligent) agent: an entity (software program) capable of highly autonomous rational action, aimed at achieving its private objective.

- Agent is autonomous, reactive, proactive and social.
Rational Decisions

We’ll use the term **rational** in a very specific, technical way:

- Rational: maximally achieving pre-defined goals
- Rationality only concerns what decisions are made (not the thought process behind them)
- Goals are expressed in terms of the **utility** of outcomes
- Being rational means **maximizing your expected utility**
Multi-Agent Systems

- In MAS, we address questions such as:
  - How can cooperation emerge in societies of self-interested agents?
  - How can self-interested agents recognize conflict, and how can they (nevertheless) reach agreement?
  - How can autonomous agents coordinate their activities so as to cooperatively achieve goals?
  - What kinds of languages can agents use to communicate?
Single-Agent Decision Making

- A decision maker picks an action $x \in X$, resulting in utility $f(x)$
- Typically an optimization problem:

$$\text{minimize (or maximize)} \quad f(x)$$
$$\text{subject to} \quad x \in X$$

- $x$: decision variable
- $f(x)$: objective function
- $X$: feasible set/region
- Optimal solution, optimal value

- Example 1: minimize $x^2$, s.t. $x \in [-1,1]$
- Example 2: pick a road to school
- Example 3: invest a subset of stocks
Multi-Agent Decision Making

- Usually, your payoffs affected not only by your actions, but also others’
- Agent $i$’s utility $f_i(x_i, x_{-i})$ depends on his own action $x_i$, as well as other agents’ actions $x_{-i}$
- Is this still an optimization problem? Should each agent $i$ just pick $x_i \in X_i$ to minimize $f_i(x_i, x_{-i})$?
  - $x_{-i}$ is not under $i$’s control
  - Think of rock-paper-scissor game
- Examples: stock investment, routing, sales, even taking courses...
Examples: Robotics

RoboCup

Autonomous vehicle

Images from RoboCup and Tesla
Examples: Societal Challenges

- Public Safety and Security
- Conservation
- Public Health
Examples: Markets on Amazon
Examples: Markets on Amazon

- Assume people will buy if the book price \( \leq \$200 \)
- Product cost = $20

If the market has only one book seller…

Q: What price should this monopoly set?

$200!
Examples: Markets on Amazon

- Assume people will buy if the book price ≤ $200
- Product cost = $20

What if the market has **two** book sellers…

Q: What price should each seller set?

Examples: Markets on Amazon

- Assume people will buy if the book price ≤ $200
- Product cost = $20

What if the market has **two** book sellers…

Q: What price should each seller set?
What if the market has two book sellers…

Q: What price should each seller set?

- The market reaches a “stable status” (a.k.a., equilibrium)
- Nobody can benefit via unilateral deviation

Examples: Markets on Amazon

- Assume people will buy if the book price ≤ $200
- Product cost = $20

• Bertrand competition
• Selfish behaviors result in inefficiency (to sellers)
Game Theory

Game Theory studies multiple-agent decision making in competitive scenarios where an agent’s payoff depends on other agents’ actions.

- Fundamental concept --- **Equilibrium**
  - A “stable status” at which any agent cannot improve his payoff through unilateral deviation
  - If exists, it should be what we expect to happen
  - Resembles “optimal decision” in single-agent case

- A central theme in game theory is to study the equilibrium
  - Different definitions of equilibria
  - May not exist; even exist, not necessarily unique
  - Understand properties of equilibrium, compute equilibria, how to improve inefficiency of equilibrium . . .
At a high level, the task is to learn a function $f: X \rightarrow Y$, where $(x, y) \in X \times Y$ is drawn from some distribution $D$

- **Input**: a set of samples $\{(x_i, y_i)\}_{i=1,2,...,n}$ drawn from $D$
- **Output**: an algorithm to determine $f(x)$ (usually based on a loss function)

**Examples**

- **Classification**: $X =$ feature vectors; $Y = \{0,1\}$
- **Regression**: $X =$ feature vectors; $Y = \mathbb{R}$
- **Reinforcement learning** has a slightly different setup, but can be thought as $X =$ state space, $Y =$ action space
Problems at Interface of Machine Learning and Game Theory

- If a game is unknown or too complex, can players learn to play the game optimally?
  - Yes, sometimes – no regret learning and convergence to equilibrium

- Can game-theoretic models inspire machine learning models?
  - Yes, GANs which are zero-sum games

- Data is the fuel for ML – Can we collect high-quality data from crowd?
  - Yes, via information elicitation mechanisms

- Can we learn to design games to achieve some goal?
  - Yes, learning optimal auction mechanisms

- Game-theoretic/strategic behaviors in ML? How to handle them?
  - Yes. E.g, learn whether to give loans to someone or whether to admit a student to UO based on their features
Main Topics of This Course

- Game theory basics
  - Normal-form games, extensive-form games
  - Security games
  - Coalitional games
  - Auctions

- Machine learning for game theory
  - Behavior modeling and learning
  - No-regret learning

- Game theory for machine learning
  - Handle strategic behavior in machine learning
Course Goal

- Get familiar with basics of game theory and learning

- Understand machine learning questions in game-theoretic settings, and how to deal with some of them

- Understand strategic aspects in machine learning tasks, and how to deal with some of them
Decision Under Uncertainty
Reminder: Probabilities

- A random variable represents an event whose outcome is unknown
- A probability distribution is an assignment of weights to outcomes

- Example: Traffic on freeway
  - Random variable: T = whether there’s traffic
  - Outcomes: T in \{none, light, heavy\}
  - Distribution: \(P(T=\text{none}) = 0.25, P(T=\text{light}) = 0.50, P(T=\text{heavy}) = 0.25\)

- Some laws of probability:
  - Probabilities are always non-negative
  - Probabilities over all possible outcomes sum to one

- As we get more evidence, probabilities may change:
  - \(P(T=\text{heavy}) = 0.25, P(T=\text{heavy} \mid \text{Hour=8am}) = 0.60\)
Reminder: Expectations

- The expected value of a function of a random variable is the average, weighted by the probability distribution over outcomes.

- Example: How long to get to the airport?

  \[
  \text{Time: } 20 \text{ min} \times 0.25 \quad + \quad 30 \text{ min} \times 0.50 \quad + \quad 60 \text{ min} \times 0.25 \quad = \quad 35 \text{ min}
  \]
Puzzle 1

- There are two expensive chocolates and a penny.
- You have a choice:
  - Get one chocolate right now: completely guaranteed!!
  - I will toss a coin and if it is heads you will get TWO chocolates + 1 penny
- Note: the coin is not biased
Puzzle 2

- I will toss a coin until I get heads
- I will pay student 1 as follows:
  - $1 if heads comes up on first toss and stop; play next round if not
  - $2 if heads comes up on second toss and stop; plan next round if not
  - $4 if heads comes up on the third toss and stop;...
  - $2^k$ if heads comes up on the (k+1)th toss and stop;...
  - ...

- What would you pay to take the position of student 1?
Utilities
Utilities

- Utilities are functions from outcomes (states of the world) to real numbers that describe an agent’s preferences.

- Where do utilities come from?
  - Poker games: simple (monetary outcomes)
  - Utilities summarize the agent’s goals
  - Theorem: any “rational” preferences can be summarized as a utility function.
Maximum Expected Utility

- Principle of maximum expected utility:
  - A rational agent should choose the action that maximizes its expected utility, given its knowledge
Human Utility
Puzzle 1

- What is EU of Not Playing?
- What is EU of Playing?
- What is rational choice?
Bernoulli and Risk Aversion

- People are “risk averse”
- Utility function is as follows:
  - 1st chocolate means a lot  $U(1\text{ bar}) = 10$
  - 2nd not as much  $U(2\text{ bars}) = 15$
  - 3rd even less so  $U(3\text{ bars}) = 18$
  - “The utility resulting from any small increase in wealth will be inversely proportionate to the quantity of goods previously possessed” [Bernoulli]

- Law of diminishing returns
  - Concave curve – Decreasing Slope
Risk Neutrality & Aversion

![Graph showing utility and chocolate consumption]

- Utility versus Chocolates
- Line graphs illustrate the relationship between chocolate consumption and perceived utility.
Next Lecture: Linear Programming

- **Assignment 0 (no grade):** Cplex optimization solver
  - Step 1: Register for IBM Academic Initiative to get free access to Cplex:

  - Step 2: Download and install ILOG CPLEX Optimization Studio

  - Step 3: Setting up the Python API of Cplex:

  - Step 4: Running some examples
    - Examples can be found in: `yourCplexhome/cplex/examples/src/python`