ECE700.07: Game Theory with Engineering Applications

Lecture 1: Introduction

Seyed Majid Zahedi
K-Beauty Contest Game

• Let’s start with playing game

• Everyone writes down a number between 0 and 100

• Person closest to $k = \frac{2}{3}$ of the average wins

• Example:
  • A says 50 - B says 10 - C says 90
  • $2/3$ of average(50, 10, 90) = $2/3 \times 50 = 33.33$
  • A is closest ($|50 - 33.33| = 16.67$), so A wins
Overview

• Course mechanics

• Outline and topics

• What is game theory?

• Examples
Course Mechanics

• All class information, lecture notes, assignments, FAQs, and announcements will be posted on course website
  
  https://ece.uwaterloo.ca/~smzahedi/crs/gtweaF18

• Office hours
  • Thursdays (14:30 to 15:30) and Tuesdays (after class)

• Prerequisites
  • No need, but would be helpful to have basic knowledge of algorithms, complexity, probability, optimization
Course Requirements

• Assignments 20%
  • Total of 4 or 5 during the semester, plus occasional reading assignments
  • Should be done individually, no group discussions

• Midterm 30% (date TBD)

• Project 50%
  • Could be done individually or in groups of 2
  • Ideally should be applications of game theory in your research problems
  • Experimental study via implementation and simulation of games or mechanisms
  • Theoretical analysis of game-theoretic models
  • Survey of areas not covered in class (e.g., cryptography, privacy, and security)
Text and References

• There is no required textbook, here are useful references
  
  • [GT] D. Fudenberg and J. Tirole, Game Theory
  
  • [CGT] M.J. Osborne and A. Rubinstein, A Course in Game Theory (freely available online)
  
  • [MT] A. Mas-Colell, M.D. Whinston, J.R. Green, Microeconomic Theory
  
  • [AGT] N. Nisan, T. Roughgarden, E. Tardos, V.V. Vazirani, Algorithmic Game Theory
  
  • [MAS] Y. Shoham and K. Leyton-Brown, Multi-agent Systems (freely available online)
  
  • [TLG] D. Fudenberg and D. Levine, The Theory of Learning in Games
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Course Information

• Introduce fundamentals of game theory and mechanism design

• Emphasize on theory, mathematical tools and models, and equilibrium notions

• Study examples from engineered systems
  • E.g., routing games, network formation games, selfish load balancing, resource allocation mechanisms, pricing in communications networks, incentives in p2p systems, strategies in electricity markets

• Appeal to ECE and CS students who need to use game theory in their research, also open to OR, Math, or Econ. students
Tentative Topics

• Strategic form games
  • Matrix and continuous games, strategic dominance, rationalizability, Nash equilibrium, mixed and correlated equilibrium, potential/congestion games, cooperative games and cost sharing

• Extensive games with perfect information
  • Backward induction and subgame perfect equilibrium

• Repeated games
  • Infinitely/finitely repeated games, trigger strategies, Folk theorems
Tentative Topics (cont.)

• Games with incomplete information
  • Bayesian games and Bayesian equilibrium, auctions with different formats, revenue and efficiency properties of different auctions

• Mechanism design
  • Optimal auctions, revenue-equivalence theorem, revelation principle, incentive compatibility, VCG mechanisms, mechanisms without money, Fisher market, Arrow–Debreu Model, Eisenberg–Gale Convex Program

• Learning in games
  • Fictitious play, Bayesian learning, regret minimization learning
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What is Game Theory?

Study of mathematical models of conflict and cooperation between intelligent rational decision-makers

[Roger Myerson, Game Theory: Analysis of Conflict]
Game Theory

• Optimization theory: optimize **single objective** over decision variable \( x \in \mathbb{R}^n \)

\[
\begin{align*}
\text{min.} & \quad f(x) \\
\text{s.t.} & \quad x \in X \subseteq \mathbb{R}^n
\end{align*}
\]

• Game theory: study **multi-agent decision making** to understand
  • Competition, coordination, and cooperation among self-interested agents
Game Theory (cont.)

• Game theory studies interactions of multiple agents who have
  • Different utility functions
  • Different actions that they can take
• Each agent’s utility depends on all agents’ actions
  • What is optimal for one agent depends on what other agents do
• Agents can rationally form beliefs over what others will do
  • Useful for decision making as well as predicting others’ behavior
Mechanism Design

“Mechanism design is a field in economics and game theory that takes an engineering approach to designing economic mechanisms or incentives, toward desired objectives, in strategic settings, where players act rationally.” [Wikipedia Aug. 2018]

- Design games to achieve desired objectives (inverse game theory)
- Use game theory to predict what will happen under mechanism
Overview

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• What is game theory?
• Examples
In 2020, U.S. data centers alone will consume 73 billion kWh. This is equal to the consumption of about 6.9 million households.
Sharing Amortizes Cost

- Server utilization is between 15-25%
- Sharing improves utilization and efficiency
- Sharing also amortizes capital, operating, and infrastructure costs
- Sharing is plausible because demands are complementary

Fig. from R. Sen and D. Wood “Energy-Proportional Computing: A New Definition”
Sharing Creates Competition

• Agents **manipulate** management systems
• Real-life Examples
  • Yahoo! MapReduce datacenter [A. Ghodsi et al. 2011]
    Map slots were congested, users ran **long reduce tasks**
  • Google Borg [A. Verma et al. 2015]
    Users **inflated demands** to avoid colocated tasks
    Users **deflated demands** to fit in on any machine
Game Theory and Networks

- File sharing in p2p networks
  - Agents provide service for each other
  - **Scrip system** could prevent free-riding
    [E. Friedman et al. 2006]

- Cognitive radio in wireless networks
  - Automatically detect available channels
  - Punishment-based **repeated game** could encourage cooperation
    [Y. Wu et al. 2009]
Game Theory and Electrical Markets

- Generators supply energy into grid
- Operator balances demand/supply
- Generators can strategically curtail generation to manipulate prices
- Electricity markets should be carefully studied, designed and regulated
  - Networked Cournot competition [W. Lin et al. 2017]
  - Networked Stackelberg competition [Y. Xu et al. 2017]
Game Theory and Blockchains

- Game theory is deployed to design atomic swap protocol that guarantees [M. Herlihy 2018]
  - No coalition has an incentive to deviate
  - If some coalition deviates, then no participating agent is worse of
Game Theory and Autonomous Cars

• Autonomous cars constantly interact with other drivers

• Different drivers deploy different decision making policies

• Safety needs to be verified
  • Requires 275 million miles of driving

• Game-theoretic traffic models could be used to test, compare, and calibrate control systems [N. Li et al. 2017]
Real-world Security  

[TEAMCORE group (USC)]

- **Airport security**: where to put checkpoints?
  - Deployed at LAX

- **Federal Air Marshals**: which flights get FAM?

- **USA Coast Guard**: which routes should be followed?
  - Deployed in Boston Harbor
Questions?
Acknowledgement

• This lecture is a slightly modified version of ones prepared by
  • Asu Ozdaglar [MIT 6.254]
  • Vincent Conitzer [Duke CPS 590.4]