Game Theory and Its Applications

Syllabus

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What is Game Theory?

- the study of mathematical models of strategic interaction between rational decision-makers.
- Which are in the field of game theory?

chess playing? **bidding?**

trade war? **buying a lottery?**

solving a puzzle? **bargaining?**

playing Sudoku? **forming an alliance?**

What's the difference?

- Whether your choice is good or not depends on other people's choice(s).
  - and vice versa

Interdependence

So What?

- 'I can select a best choice considering all other people's possible choices.'--- a belief
- Sometimes you have no knowledge of other people's choices.
- Sometimes there are just too many possible choices to consider
- Sometimes everyone's best choice (despite thoughtful) is not the best as a whole

You certainly know …

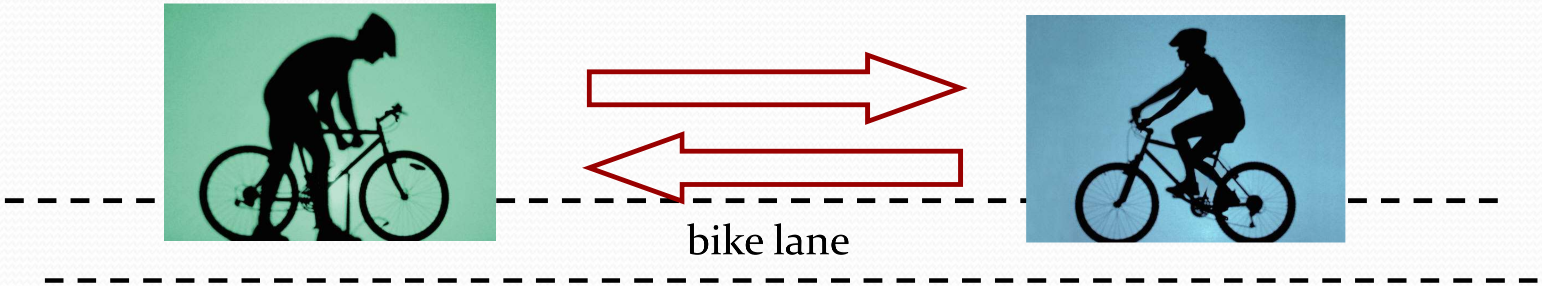
- The best outcome for one may not be the best for the other

WIN

LOSE

And sometimes

- we can reach a 'win-win' outcome



- But can we reach an outcome that dissatisfies everyone?

Let’s take a look at a classic example

Prisoner's Dilemma

- Two gangsters (A and B) are arrested and imprisoned
- They are interrogated separately with no means of communicating with the other

A \ B	B stays silent	B betrays
A stays silent	-1 (A), -1 (B)	-3 (A), 0 (B)
A betrays	0 (A), -3 (B)	-2 (A), -2 (B)

https://en.wikipedia.org/wiki/Prisoner%27s_dilemma

If you were Prisoner A …

- What would be your choice? Remember you don't know B's choice (but you may know B's payoffs because the matrix is likely symmetric)

B A	B stays silent	B betrays
A stays silent	-1 -1	0 -3
A betrays	-3 0	-2 -2

Even if you don't know your partner's payoff…

- What would be your choice?

B \ A	B stays silent	B betrays
A stays silent	? / -1	? / -3
A betrays	? / 0	? / -2

If you consider Prisoner B …

- What would be B's best choice?
- What will be your best response?
- Will B change her choice knowing your best response?
- Is there any better result?

B A	B stays silent	B betrays
A stays silent	-1 -1	0 -3
A betrays	-3 0	-2 -2

Why should I learn this?

- Traditionally, computer scientists play the role of a god, controlling and manipulating everything
- “Objects” (devices, resources, processes) do not have their own interests

The Game from a Computer Scientist's View

- You play the role of a god (omniscience)
- You figure out that 'stays silent' is the best choice for both prisoners
- You instruct each prisoner to take that strategy
- That's it
- If prisoners have free will and are self-interested, they may not follow your instruction

B A	B stays silent	B betrays
A stays silent	-1 -1	0 -3
A betrays	-3 0	-2 -2

Game-Theoretic Approach

- design rules for game players (software agents)
- Players act in their own self-interest, as an indirect way to achieve society's economic goals (i.e., your system goal)
- For scenarios like
  - Task allocations among a fleet of robots, UAVs, or autonomous cars
  - Resource sharing among users, operators, or tenants
  - Clustering, grouping, or federation of a bunch of resource/task producers or consumers
  - Matching resource buyers with sellers or vice versa

Course Goals

- Game theory as an analytic model
  - to model your problem (but you solve it by another means)
- Game theory for mechanism design
  - to solve your problem in a decentralized and autonomous way
  - yields an outcome that is accepted by everyone
- Learning some well-known mechanism designs
- Solving games

So this course is not to …

- study how to design a fancy computer game
  - You should courses like "3D Game Programming" (by Prof. Sai-Keung Wong)
- (in most of the time) study how to design a computer program to win a game (e.g., Go and Chess)
  - You should take "Theory of Computer Games" (by Prof. I-Chen Wu)

Compared with other Game Theory courses

- This course offers a broader coverage
  - It covers non-cooperative game, coalition game, matching, auction and related examples in CS/commun./networks
  - Many other courses cover only the first two topics
- This course does not cover applications of Game theory to economics, politics, and biography
- This course minimizes the use of math. formulas
  - focus on concepts rather than math.

Criticisms of Game Theory

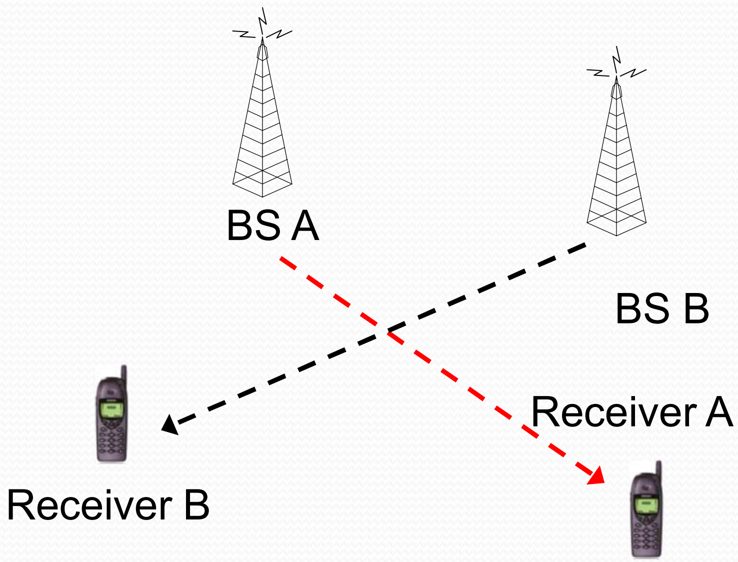
- They say: people are not always rational or self-interested
  - people may show mercy or tend to cooperate
  - Particularly in making economic or political decisions
- Not a problem at all in our case: we consider software agents, not human beings

Course Goal One: Help Us Analyze

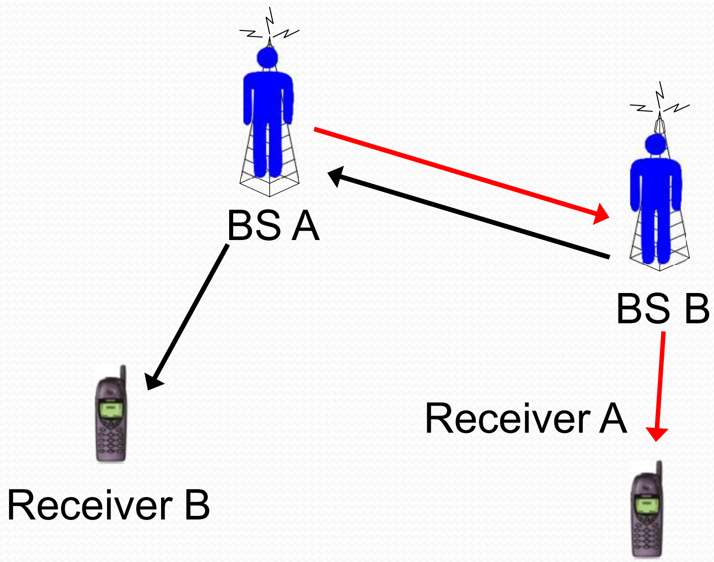
- Game theory as an analytic model
  - To predict what will happen next
  - To see if the interactions among players can lead to a stable outcome (accepted by every player)
  - To see whether we can make an improvement (if any)
  - primary concerns of Economists

Example: Wireless Relay System

- Will a BS relay signal for the other?
- Can we motivate cooperation?



Direct Transmission



Relay Transmission

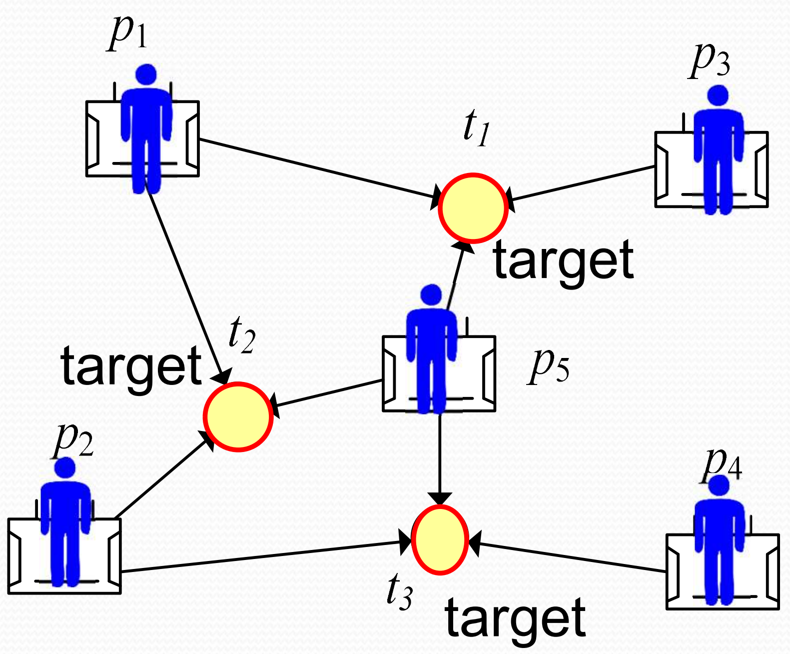
Course Goal Two: Help Us Design

- Game theory for mechanism design
  - To achieve a system goal via incentive-compatible rules
  - Design game rules for selfish yet rational players
  - yet achieve system goal
  - Decentralized, autonomous, adaptive, self-stabilizing, self-optimizing
  - main focus of computer scientist

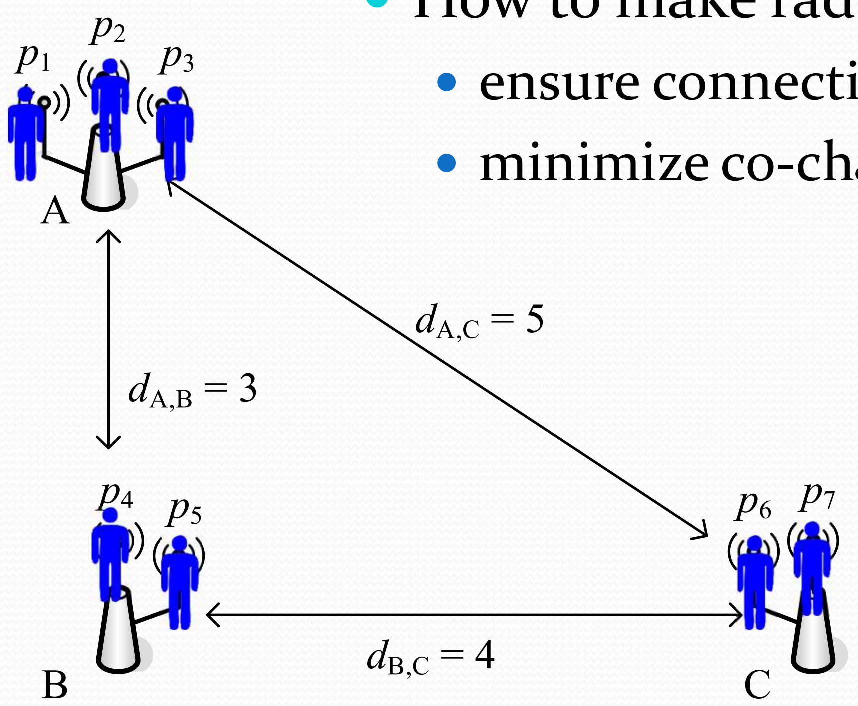
Example: Sensor Coverage

- n sensors are densely deployed to monitor m targets
- Target j must be covered by q_j sensors
- How to motivate sensors (game players) to meet coverage requirement while turning off sensors as many as possible?

$$\boldsymbol{Q} = (q_1, q_2, \ldots, q_m)$$



Example: Channel Selection



- How to make radios select channels to
  - ensure connectivity
  - minimize co-channel interference

Course Goal Three: Help Us Know

- Learn some well-known mechanism designs
  - Auction
  - Matching
- with system goals
  - Pareto optimality
  - stability
  - social welfare

Example: Combinatorial Auctions

- How to select the set of winning bidders to maximize social welfare?
- How to enforce truthful bidding (bid indicates valuation)?

bidder	P1	P2	P3	P4	P5
valuation	$63	$54	$93	$70	$28
bundle	{A,C,D}	{A,B,C}	{B,D,E}	{D,E}	{A,C}
bid					

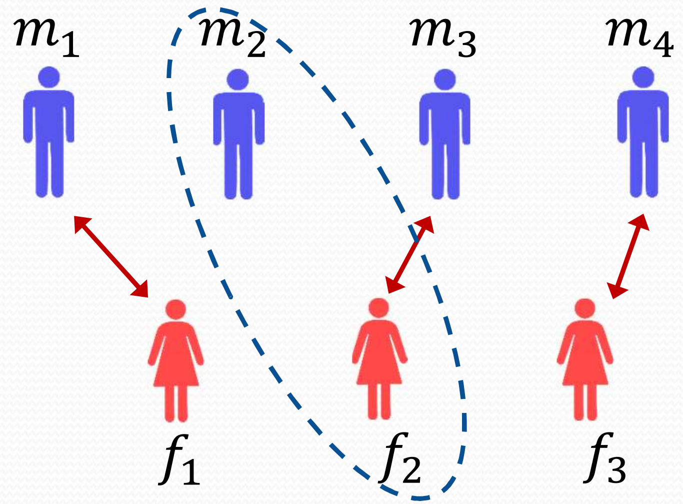
A
B
C
D
E

Example: Matching

- How to match females with males so that
  - no pair wants to deviate from the result?
  - no pair can be better off without hurting any others?

Male	Preference
m_1	$f_1 \succ f_2 \succ f_3 \succ m_1$
m_2	$f_1 \succ f_2 \succ f_3 \succ m_2$
m_3	$f_2 \succ f_1 \succ m_3 \succ f_3$
m_4	$f_2 \succ f_3 \succ f_1 \succ m_4$

Female	Preference
f_1	$m_4 \succ m_1 \succ m_2 \succ m_3 \succ f_1$
f_2	$m_2 \succ m_1 \succ m_3 \succ m_4 \succ f_2$
f_3	$m_3 \succ m_1 \succ m_2 \succ m_4 \succ f_3$



Example: Coalition Game

- What coalitions will be formed?
- How to distribute profits to coalition members to make the coalition stable?

	$\{P_1\}$	$\{P_2\}$	$\{P_3\}$	$\{P_1, P_2\}$	$\{P_1, P_3\}$	$\{P_2, P_3\}$	$\{P_1, P_2, P_3\}$
profit	2	6	12	9	15	21	24

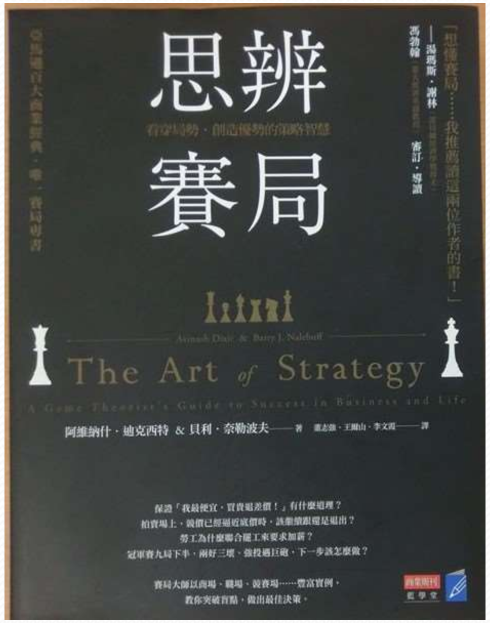
- Suppose $(x_1, x_2, x_3) = (5, 6, 13)$
- Can $\{P_1, P_2\}$ block (x_1, x_2, x_3)?
- Can $\{P_2, P_3\}$ block (x_1, x_2, x_3)?
- What are the results if $(x_1, x_2, x_3) = (3, 7, 14)$?

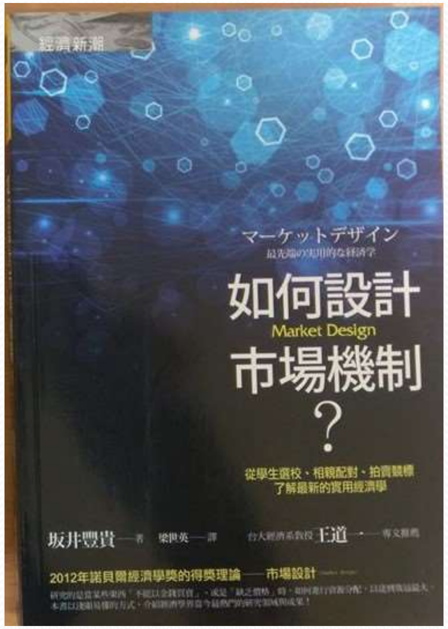
Course Goal Four: Help Us Solve

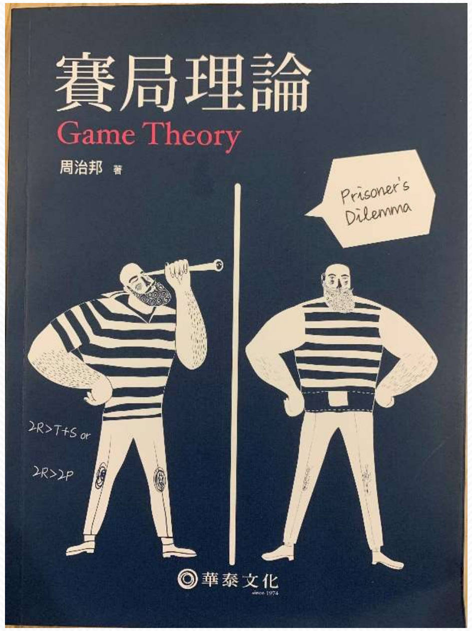
- Compute strategies for players to stabilize or improve the game
  - perhaps without full knowledge of the game
- Reinforcement learning may help
- Challenge: multiple agents with diverse goals

Text Book: None

- Reference books (in Chinese)







Schedule (tentative)

week	contents	week	contents
1	Introduction and non-cooperative games	9	Matching Theory (1/2)
2	Non-cooperative games (cont.)	10	Matching Theory (2/2)
3	Some Useful Non-Cooperative Games	11	Auctions
4	Game Designs for Network Problems (1/2)	12	Coalition Game (1/2)
5	Game Designs for Network Problems (2/2)	13	Coalition Game (2/2)
6	Game Designs for Graph Problems	14	Report & presentation (1)
7	Learning for non-cooperative games	15	Report & presentation (2)
8	Review and Mid-term Exam.	16	Final Exam.

Scoring Policy

- (60+%) Quizzes + Assignments
  - 5 quizzes (only four highest scores count; 10% each)
  - 2 program assignments (10% each)
- (20%) Mid-term exam.
- (20%) Final exam.

Teaching Assistants (TAs)

Name	E-mail	Phone	TA Time/Place
Yung-Lun Yang (Mr.)	ylyang.cs11@nycu.edu.tw	ext. 56674	15:30~17:00 Mon. @ES703B
Pin-Chun Chen (Mr.)	cpc17422@gmail.com	ext. 56674	13:30-~15:00 Wed. @ES703B

ES: Microelectronics and Information Systems Research Center (電子與資訊研究中心)

Course Materials

- All lectures will be recorded and put online
- Slides are placed in E3 Learning Management System: https://e3.nycu.edu.tw/
- Because all announcements are sent via E3, please confirm your e-mail address setting in E3 is correct
- Instructor's e-mail: lhyen@nycu.edu.tw