Game Theory and Its Applications

Syllabus

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What is Game Theory?

- the study of mathematical models of strategic interaction in 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

What are the issues anyway?

- '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 be considered
- Sometimes everyone's best choice (despite thoughtful) is not the best as a whole

Why should a CS major learn this?

- Traditionally, computer scientists play the role of God, controlling and manipulating everything
- "Objects" do not have their own interests

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
- 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
- Game theory for mechanism design
- Learning some well-known mechanism designs
- Applications to CS or network problems

Prisoner's Dilemma

- Two gangsters (A and B) are arrested and imprisoned
- Each prisoner is in solitary confinement with no means of communicating with the other

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

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

If you were Prisoner A …

- What would be your choice?

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

If you were Prisoner B …

- What would be your choice?
- What will be the result of the game?
- Is there any better result?
- How can you get an improved result?

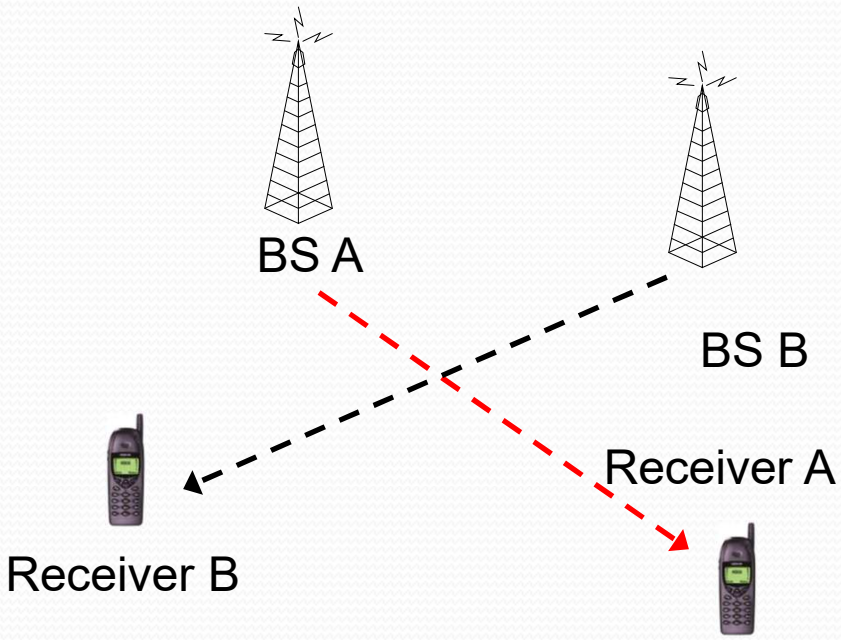
A \ B	B stays silent	B betrays
A stays silent	-1 / -1	0 / -3
A betrays	-3 / 0	-2 / -2

Course Goal One

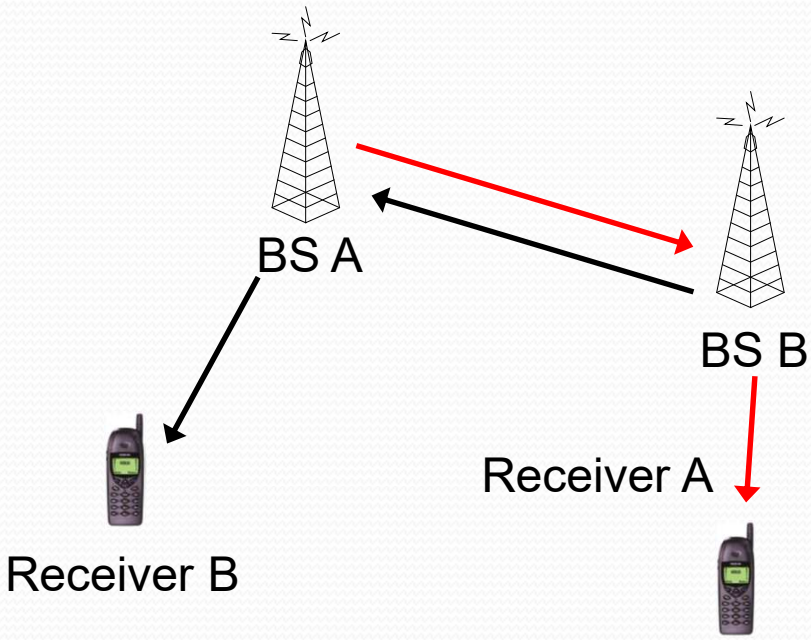
- Game theory as an analytic model
  - To predict what will happen
  - To figure out what went wrong
  - To see how to make an improvement (if any)
  - primarily concerns of Economists

Example: Wireless Relay System

- Will a BS relay signal for the other?
- How to motivate cooperation?



Direct Transmission



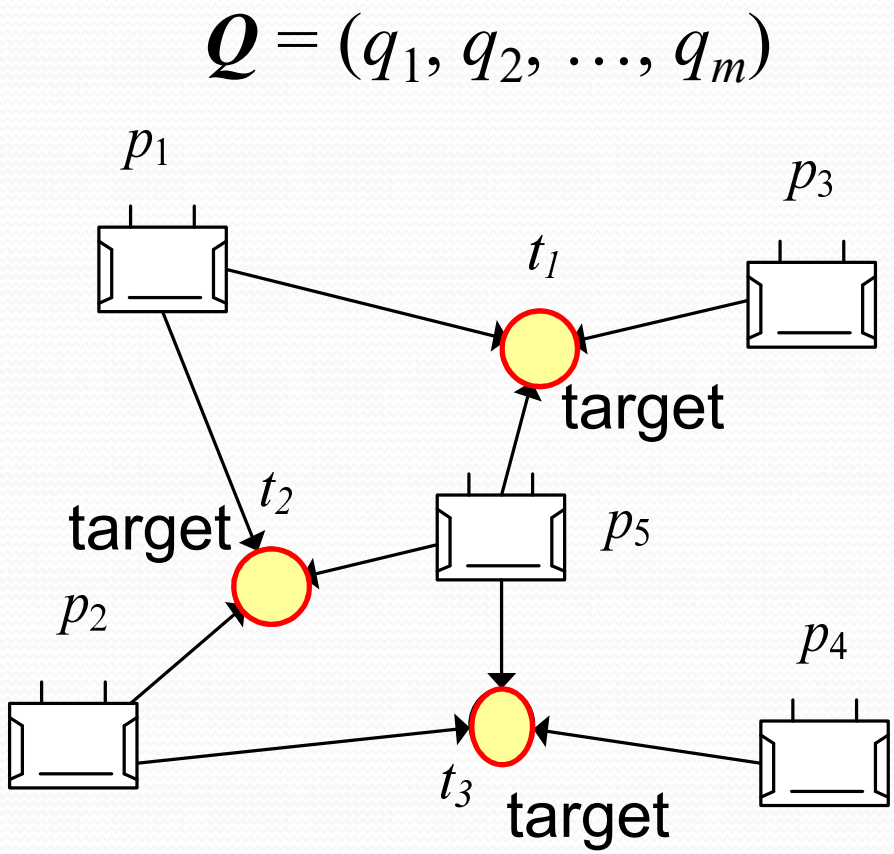
Relay Transmission

Course Goal Two

- Game theory for mechanism design
  - Design game rules for selfish yet rational players
  - yet achieve system goal
  - 'reverse game theory'
  - main focus of computer scientist

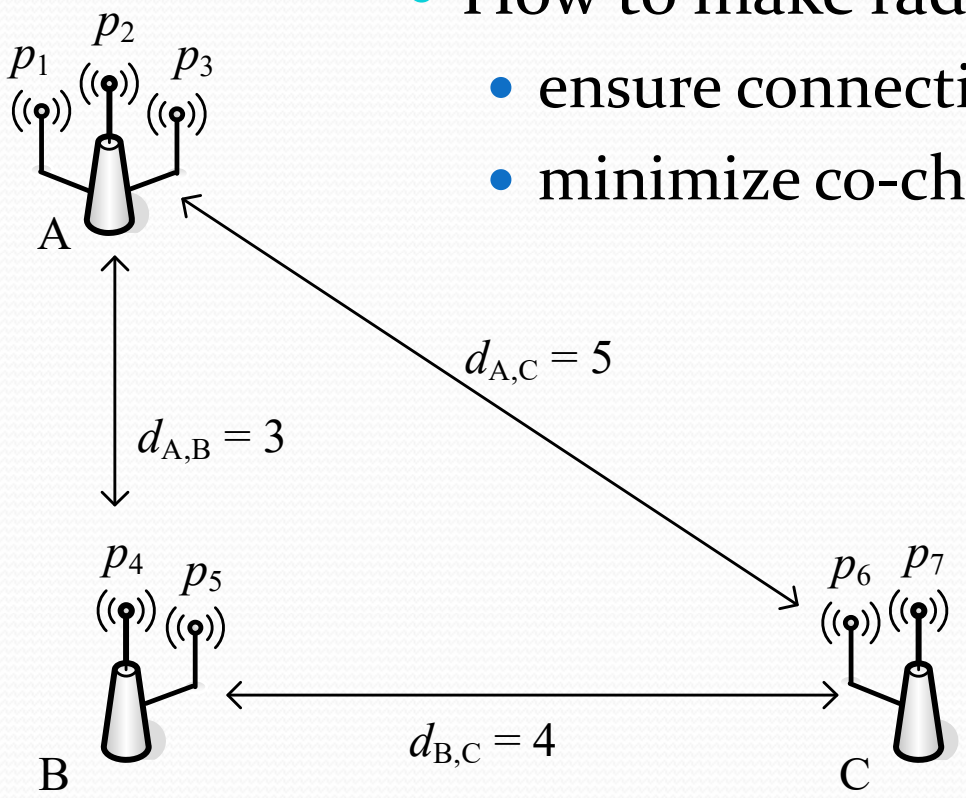
Example: Sensor Coverage

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



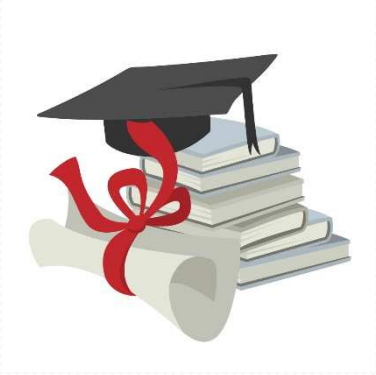
Example: Channel Selection

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



Course Goal Three

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



Example: Combinatorial Auctions

- How to select the set of winning bids?
- How to enforce truthful bidding?
- What is the pricing rule?

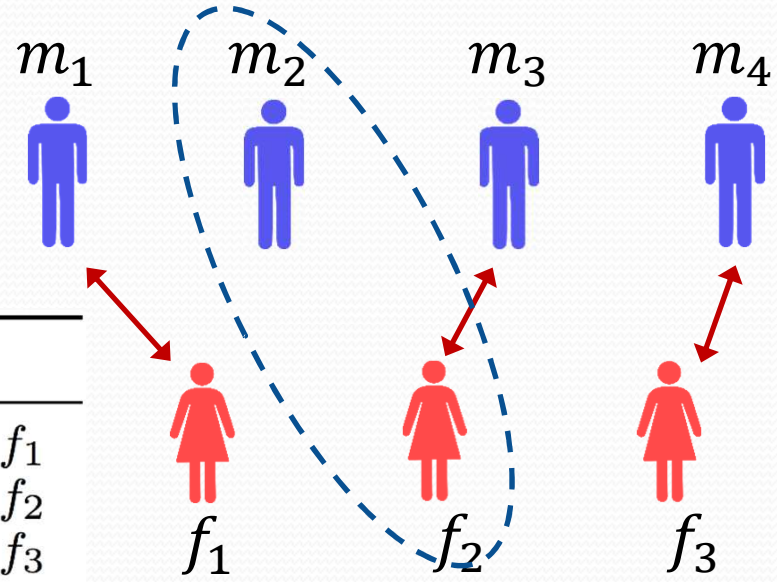
bidder	P1	P2	P3	P4	P5
bid	$63	$54	$93	$70	$28
bundle	{A,C,D}	{A,B,C}	{B,D,E}	{D,E}	{A,C}

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

- How to efficiently form coalitions to maximize profits?
- How to distribute profits to coalition members?

	$\{P_1\}$	$\{P_2\}$	$\{P_3\}$	$\{P_1, P_2\}$	$\{P_1, P_3\}$	$\{P_2, P_3\}$	$\{P_1, P_2, P_3\}$
$v(\cdot)$	2	6	12	9	15	21	24

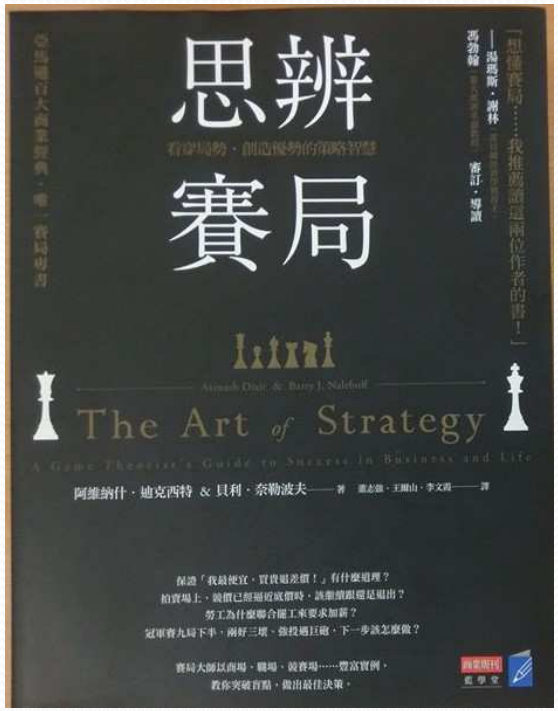
- Suppose $(x_1, x_2, x_3) = (5, 6, 13)$
- Can $\{P_1, P_2\}$ block (x_1, x_2, x_3)?
- Can $\{P_2, P_3\}$ block (x_1, x_2, x_3)?
- What are the results if $(x_1, x_2, x_3) = (3, 7, 14)$?

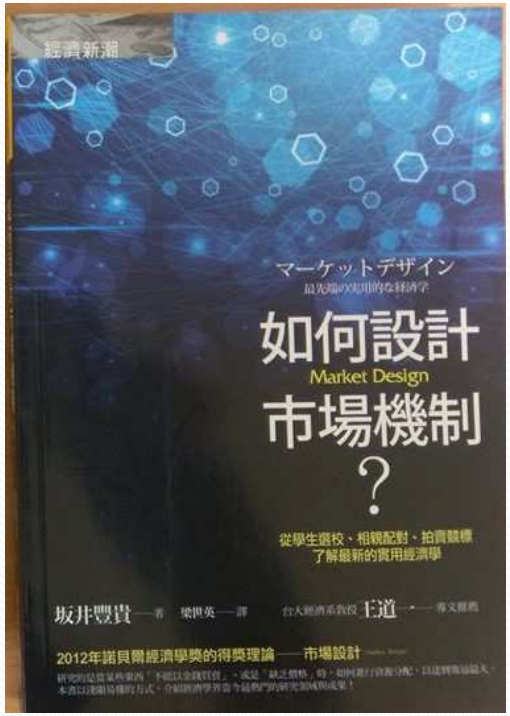
Course Goal Four: Application

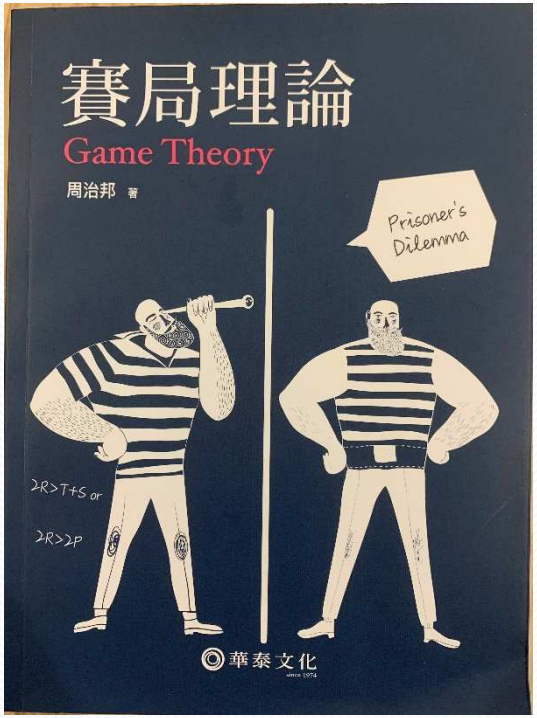
- Able to apply what you have learned to a specific problem in CS or networks
- Understand how game theory could help people solve a CS/network problem

Text Book: None

- Reference books







Schedule (tentative)

week	contents	week	contents
1	Introduction (mid-autumn festival)	10	Matching: Resource allocations/computation offloading in IoT/D2D/edge
2	Non-cooperative games:	11	Matching with (money) Report & presentation
3	Non-cooperative games: Channel selection, file sharing in P2P	12	cooperative game
4	Coordination game: MAC, power control, cognitive radio	13	federation of cloud and edge systems
5	Potential game and congestion game: routing, network/AP selection, self-stabilizing algorithm	14	Report & presentation
6	mixed-strategy: spectrum access	15	Report & presentation
7	Auctions: Robot task allocations	16	Report & presentation
8	Combinatorial auction: Resource allocation in cloud and edge	17	Report & presentation
9	Review and Mid-term Exam.	18	Final Exam.

Scoring Policy

- (30+%) Quizzes
  - 4 quizzes
- (40%) Mid-term exam.
- (30%) Final report

Course Materials

- Slides are placed in new e3 system: https://dcpc.nctu.edu.tw/
- All announcements are available in e3 system: https://dcpc.nctu.edu.tw/
- Instructor's e-mail: lhyen@nctu.edu.tw