Università degli Studi di Padova

Dipartimento di Ingegneria dell'Informazione

Lecture 09
Projects

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How to make a 7/7 project

1. Choose a topic (of scientific interest), and find a problem that is suitable for game-theoretic analysis
   - Multiple players, different objectives
2. Check what other people have already done on the topic
   - No need for a systematic review, but at least make sure not to reinvent the wheel!
3. Start simple, make a lot of assumptions, and then gradually drop them
   - Even simple models can provide good insights on a problem (e.g., Cournot duopoly)
4. When possible, run experiments/simulations and evaluate objective metrics (e.g., throughput for networks, monetary cost for power grids)
   - Does the game-theoretic solution lead to good outcomes? Comparison with optimization? Price of Anarchy?

How to make a 7/7 project

- More tips:
  - Your grade is not proportional to the complexity of your game: focus on a model that accurately describes your problem
  - When investigating related work, do not invest too much time on the math, especially when it is overly complicated: focus on experimental results and takeaways
  - ChatGPT-generated text = 0 points (you can use it to check the grammar, though)
  - Plagiarism = 0 points

How to make a 7/7 project

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- Deliverables:
  - Report: 5–8 pages, double column, 10 pt
- Report sections:
  - Introduction: describe the setting and the problem that you are investigating; explain the core idea of your project
  - Related work: report *few* references that are closely related to your work or that investigate analogous problems
  - Analysis: characterize the game that you are considering, clearly defining players, strategies and payoffs; find NE, subgame-perfect NE, Bayesian NE, etc.; if your analysis results in an algorithm, it should be reported in this section
  - Results: show the obtained results, preferably using plots, tables,etc.; compare them with other works, and/or with other possible solutions (e.g., computing the PoA)
  - Discussion: discuss limitations and/or possible extensions
  - Conclusion: summarize your results in few words

Topics

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- Automatically accepted topics
  - Anything of scientific interest *and novel*
- Conditionally accepted topics
  - Inflated topics (blockchain, 6G, edge/fog computing) → Lots of game theory works on these topics, you must come up with something really novel/interesting
  - Quantum game theory
  - Board games and videogames → Models must be realistic and lead to algorithms that can actually be implemented (that means no chess, no poker, and no Starcraft)
- Automatically rejected topics
  - Politics and elections
  - Any model that is too scuffed or arbitrary
- **Advice**: Choose a topic that is interesting for you (related to your thesis, previous projects, or personal interests)

Topics

- If you are not sure whether your topic is acceptable, just ask
- Different groups can choose the same topic but cannot do the same game-theoretic analysis
- References and examples of previous projects will be uploaded on e-learning

Project opportunity

- **Important**: On November 16, 2023, 14:30 there will be a presentation in **classroom Te** about some tabletop games
- These games are valid project topics (automatically accepted)
- Of course, your grade will still depend on the quality of your game-theoretic analysis

Deadlines

- **Group formation and topic selection**: November 20, 2023, 23:59 (Italian time)
- **Project submission**: January 28, 2024, 23:59 (Italian time)
  - E-learning forms will be soon available
  - You can withdraw from the project at any point in time before the deadline and receive the 3-point bonus
  - Once you have withdrawn from a project, you cannot re-join it or join another one

LoRa networks

Topics: Networks, IoT

LoRa Networks

- **LoRa**: proprietary modulation designed for energy-constrained devices (e.g., IoT) that need to communicate at long distance (LoRa = long-range)
- LoRa modulation utilizes a technique called "chirp spread spectrum"
- The modulation is parametrized by a number called **spreading factor** (SF)$\in \{7, 8, \ldots, 12\}$
  - A low SF means higher data rate $\rightarrow$ faster transmission, preferable for the transmitting device
  - A higher SF means more reliable transmission (devices that are more distant from the base station must use a higher SF)
  - Multiple devices using the same SF interfere with each other $\rightarrow$ want to avoid using the same SF as other devices

Spreading factor allocation

- *Main reference*: Tolio et al. Spreading factor allocation in LoRa networks through a game theoretic approach. In ICC 2020-2020 IEEE International Conference on Communications (ICC) (pp. 1-6). IEEE.
- **Spreading factor allocation problem**: There are N devices scattered around a base station, they must decide which SF to use
- If there is only one device, it's easy: just set SF=7
- If there are multiple devices, you need to account for interference

Spreading factor allocation

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- Optimization model: the base station assigns the SF to each device
- **Game theory model**: the devices decide their own SF according to their belief about the rest of the network
  - *Multiple players*: the devices
  - *Actions*: the spreading factor SF$\in \{7, 8, \ldots, 12\}$
  - *Multiple objectives*: data rate of each device (lower in case of interference)

Simplified game

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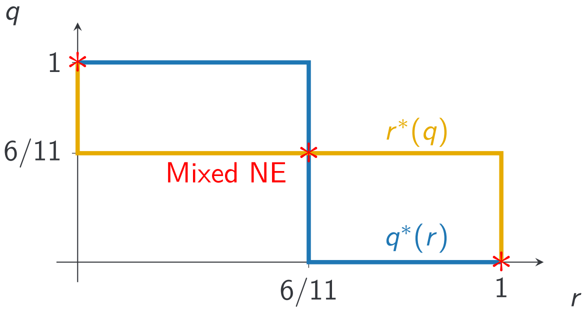
- Assumptions: only 2 devices; both close enough to the base station (can use SF7); if no interference $\rightarrow$ utility $=$ 13 - SF; if interference $\rightarrow$ utility $= 0$
- $N = 2$ devices with $S_1 = S_2 = \{\text{SF7}, \text{SF8}\}$ (SF9 or higher is strictly dominated)

		Device 2: SF7	Device 2: SF8
Device 1	SF7	0, 0	6, 5
Device 1	SF8	5, 6	0, 0

- This becomes a simple **anti-coordination** game

Simplified game

- q = probability device 1 plays SF7
- r = probability device 2 plays SF7



- **Algorithm**: devices play SF7 with probability 6/11, SF8 with probability 5/11

Dropping some assumptions

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- Assumptions: only 2 devices; ~~both close enough to the base station (can use SF7)~~; if no interference $\rightarrow$ utility $=$ 13 - SF; if interference $\rightarrow$ utility $=$ 0
- Same-distance case (minimum SF is SFj for both)

Device 1 \ Device 2	SFj	SF$j+1$
SFj	0, 0	$12-j$, $12-j-1$
SF$j+1$	$12-j-1$, $12-j$	0, 0

- Need to handle also other cases (see paper)

Algorithm

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- Result of the game-theoretical analysis: algorithm that each device executes locally
- Input: distance from base station
- Output: probability $p(\mathrm{SF}j)$ associated with each SF
- Devices choose their SF according to p

Simulation

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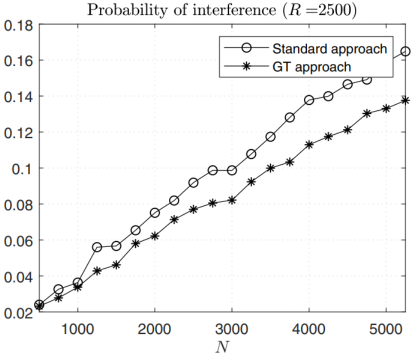
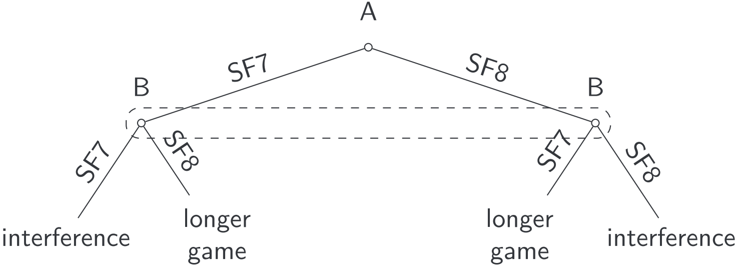
- Publicly available ns-3 simulator for LoRa networks: `https://github.com/signetlabdei/lorawan`
- Simulation: game theory algorithm versus baseline approach (use lowest available SF) for variable number of devices (N)



What can be improved?

- Previous model is a static game: time dimension is neglected
- One may consider a dynamic game where devices have the option to alternate SF



Takeaways

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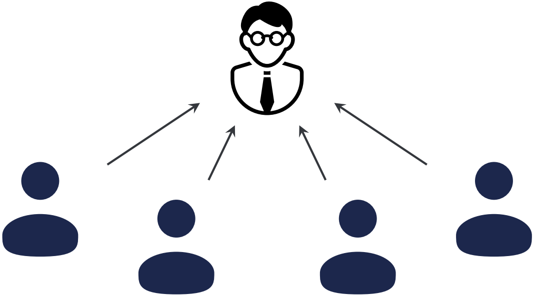
- Many resource allocation problems can be modeled as anti-coordination games
- Players maximize their utility when choosing different options
- Similar to multi-path routing problems, in which nodes prefer to choose different paths
- Analysis of long-term collaboration $\rightarrow$ Multi-stage or repeated games
- Modeling uncertainty about nodes status $\rightarrow$ Bayesian games

Mobile/IoT Crowdsourcing

Topics: Data science, IoT, Privacy

Crowdsourcing

- Organizing large-scale data collection is hard
- Possible solution: **crowdsourcing**, i.e., an organization or research team collects data from volunteers through an online platform



Crowdsourcing

- *Main reference*: Dasari et al., 2020. Game theory in mobile crowdsensing: A comprehensive survey. Sensors, 20(7), p.2055.
- Data collected via crowdsourcing: mobile data, IoT data, wearable data
- Main hurdles:
  - **Privacy**: Collected data is often sensitive (location, activity data, lifestyle) → How do users know that they can entrust this information to the data collector?
  - **Quality of data**: In contexts where users receive a reward, they may decide to send inaccurate data o large volumes of data → How does the data collector handle these cases?

Toy example

- Game between user and data collector
- User has possible strategies: donate (D) or not (N) his/her data
- Data collector has possible strategies: use privacy-preserving algorithms (P) or use standard algorithm (S)
  - Standard algorithms give higher utility K to the data collector but may lead to privacy leaks with probability q; privacy-preserving algorithms give lower utility k
  - The user receives a reward r in exchange for their data; however, privacy leaks cause a loss in utility $-\ell$

Data collector

User		P	S
	D	r, k	$r-\ell$, K
	N	0, 0	0, 0

Toy example

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- Numerical example: $K = 2,\ k = 1,\ r = 1,\ \ell = 2$

Data collector

User		P	S
	D	1, 1	-1, 2
	N	0, 0	0, 0

- In this case, there is only one NE
- However, cooperation may be enforced via repetition of the game (we will see this later in the course)
- Intuition: building a good reputation to increase payoff on the long term

Power grids (smart and non-smart)

Topics: Electrical engineering

Power grid

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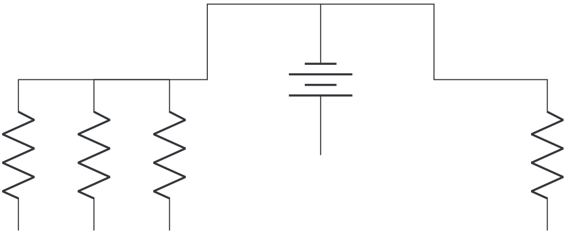
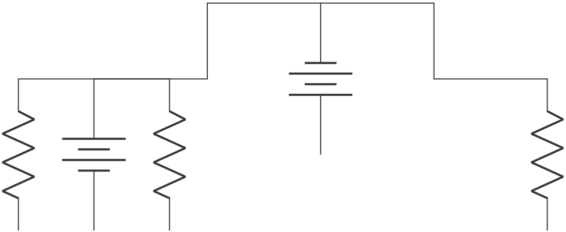
- **Traditional grid model**: centralized distribution network (generator) that produces alternate current powering the whole network



Power grid

- **Modern power grid**: some of the consumers are also generators (solar panels, wind turbines, etc.)
- This may lead to interference with the central distribution
- Sometimes power *curtailment* is necessary (central distribution pays solar panel owners to limit production)



Smart grid

- **Smart grid**: decentralized distribution network where
  - power usage and loss are monitored by sensors
  - multiple power sources (micro-grids) communicate with each other
  - automatic decisions are possible
- current use cases: retailers profiling their customers
- ideal use case: automatic handling of conflicts and power loss

Smart grid

- **Possible games** (*main reference*: Saad et al., 2012. Game-theoretic methods for the smart grid: An overview of microgrid systems, demand-side management, and smart grid communications. IEEE Signal Processing Magazine, 29(5), pp.86-105.):
  - Cooperative games between micro-grids to minimize power loss $\rightarrow$ are coalitions sustainable?
  - (Bayesian) non-cooperative games between consumers $\rightarrow$ selfish consumption may lead to power outages
- Remark: In these applications, strategy sets are typically continuous (how much energy to buy, sell, etc.) $\rightarrow$ NE are found as stationary points as in the Cournot duopoly
- You may use PandaPower for simulations: `http://www.pandapower.org/`

Network intrusion detection and response

Topics: security, networks

Intrusion detection and response

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- Network **intrusion detection** consists in the task of identifying ongoing attacks within a network (reconnaissance, phishing, malware, DoS, etc.)
  - NID is not an exact science, you have uncertainty in the detection
- Network **intrusion response** is how attacks are handled
  - You cannot just block all traffic and interrupt all services (that would be the perfect DoS)

Intrusion detection game

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- An intrusion detection game is an adversarial game between an attacker (hacker) and a defender (the target network/company)
- However, it is not necessarily a zero-sum game: the defender wants not only to protect itself from the attack, but also to maintain the usual activity
  - Utility function can be application-specific
- Simplest case: the attacker chooses between different types of attack, some easier to detect than others; the defender decides on the policy to adopt, it could be a conservative policy or a relaxed policy

Intrusion detection game

- More possible games (*main reference*: Kiennert et al., 2018. A survey on game-theoretic approaches for intrusion detection and response optimization. ACM Computing Surveys (CSUR), 51(5), pp.1-31.):
  - Resource allocation → Which nodes in the network should be monitored?
  - Response optimization → React immediately, or wait and collect information on the attacker?

- Tips for a more realistic model:
  - Rather than a generic network, think of a specific target for an attacker (a bank? a factory? a hospital?)
  - Different networks may have different vulnerabilities and may be targeted by different types of attack
  - E.g., see: Hu et al., 2020. Optimal decision making approach for cyber security defense using evolutionary game. IEEE Transactions on Network and Service Management, 17(3), pp.1683-1700.
  - Once you have decided on a target, you can use knowledge-bases like Mitre Att&ck (`https://attack.mitre.org/`) to research common attacks used against similar targets

Shapley value and data/feature selection

Topics: machine learning, data science

Shapley value

- In machine learning, we may encounter the following problems:
  - Too many features, need to determine which ones are important (feature selection)
  - Different data sources, need to estimate their individual value (data valuation)
- The Shapley value allows to estimate the value of features or data sources
- Game-theoretic intuition: consider a coalition of n players (features or data sources); the Shapley value of player i is its marginal contribution to the coalition

Shapley value

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- Consider a coalition $C = \{1, \ldots, n\}$ of n players, and a utility function $v : 2^C \to \mathbb{R}^+$ representing the value of sub-coalitions
- The Shapley value of i is computed as

$$\varphi_i = \sum_{S \subseteq C \setminus \{i\}} w(|S|) \cdot (v(S \cup \{i\}) - v(S))$$

with

$$w(k) = \frac{k!(n-k-1)!}{n!}$$

- The weight $w(|S|)$ is to compensate for having $1/w(|S|)$ possible coalitions of size $|S|$

Shapley value in ML

- Consider a ML problem where you have either many features or heterogeneous data sources
- Choose a suitable utility function (e.g., accuracy for classification problems)
- Select top k features or data sources out of n according to their Shapley value
- Bonus: Shapley value is hard to compute for large values of n (Complexity is $O(2^n)$); use approximators such as Monte Carlo estimation or gradient-based methods
- *Main reference*: Ghorbani and Zou, 2019, May. Data shapley: Equitable valuation of data for machine learning. In International conference on machine learning (pp. 2242-2251). PMLR.

More topics

Autonomous vehicles

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- Autonomous vehicles = self-driving cars
- Traffic-related scenarios can be modeled as games: reacting to moving obstacles, multi-story parking
- *Main reference*: Crosara et al., 2023, June. Game Theoretic Analysis of Overtaking Maneuvers for Autonomous Vehicles with Moving Obstacles. In 2023 International Balkan Conference on Communications and Networking (BalkanCom) (pp. 1-6). IEEE.

Jamming

- Jamming = an attacker aims to disrupt communications at the physical layer using noise
- Simplest jamming game: multiple available channels, attacker needs to decide which channel to disrupt, transmitter should try to avoid that channel (zero-sum game)
- *Main reference*: Scalabrin et al. A zero-sum jamming game with incomplete position information in wireless scenarios. InProceedings of European Wireless 2015; 21th European Wireless Conference 2015 May 20 (pp. 1-6). VDE.