GAME THEORY

Elvina Gindullina
elvina.gindullina@unipd.it
Department of Information Engineering, University of Padova

A course for the MSc in:

-
- computer engineering
- computer science
- data science, etc

PROJECTS

A RESEARCH WORK IN WHICH YOU ARE ADVISED TO APPLY THE GAME-THEORETIC APPROACH TO THE ACTUAL ENGINEERING /SCIENTIFIC PROBLEM.

TOPICS

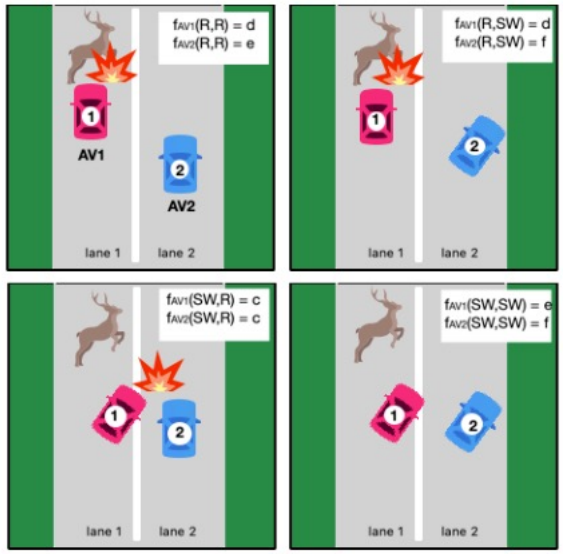
PROJECT 1: AUTONOMOUS DRIVING / MANOEUVRE GAMES

- **Example.** An autonomous vehicle t performs the lane-change manoeuvre and is controlled by the game theory-based strategy.
- **Task:** routing s.t. collisions are avoided, speed limits are respected

- **References:**
  https://www.researchgate.net/publication/340809748_Game_Theory_For_Self-Driving_Cars
- https://www.mdpi.com/1424-8220/21/4/1523/pdf
- https://msl.stanford.edu/projects/game_theoretic_planning

PROJECT 1.1: MANOEUVRE GAMES

- **Scenario:** an autonomous vehicle performs the line-changing manoeuvre in order to avoid the collision with a moving obstacle
- Actions: swerving right (*SW*) or remaining on the same line (*R*)
- Payoffs: c if the two cars crash, d is a car hits the deer, f if a car swerves off the road and e if a car keeps driving on the road as intended



- Task I:
  - simulate a static base game (table I – project I materials) within *T* rounds: play NE each round, play random strategy each round, play always SW or R each round
- Task II:
  - Simulate the Bayesian game (table VI – project I materials): play BNE each round, play random strategy and (R, (R,R,R))

AV1 \ AV2	SW	R
SW	e, f	c, c
R	d, f	d, e

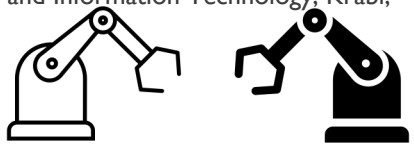
PROJECT 1.2: MANOEUVRE GAMES

- Consider the same scenario
- Extend the game by adding 3rd strategy (overpass an obstacle)
- It implies:
  - Violation of speed limit (that would reflect the payoffs)
  - Consider static and Bayesian version (probabilistic behaviour of a moving obstacle)

PROJECT 2: ROBOTIC COOPERATION

- One of the common application: motion planning.
- The common workspace with multiple robots is typically considered.
- The game-theoretical approach provides decentralized decision making in order, for instance, avoid collisions.
- ***Idea: design a system that controls the multiple robots systems, it can be either cooperative or non-cooperative tasks.***
- *References:*

  - M. J. Mataric, M. Nilsson and K. T. Simsarin, "Cooperative multi-robot box-pushing," Proceedings 1995 IEEE/RSJ International Conference on Intelligent Robots and Systems. Human Robot Interaction and Cooperative Robots, Pittsburgh, PA, USA, 1995, pp. 556-561 vol.3, doi: 10.1109/IROS.1995.525940.
  - Ping Yang, Cui-ming Li and Xiao-xing Shi, "Game theory-based research on cooperative behavior of group robots," 2011 Second International Conference on Mechanic Automation and Control Engineering, Hohhot, 2011, pp. 317-320, doi: 10.1109/MACE.2011.5986922.
  - F. Amigoni, N. Gatti and A. Ippedico, "A Game-Theoretic Approach to Determining Efficient Patrolling Strategies for Mobile Robots" 2008 IEEE/WIC/ACM International Conference on Web Intelligence and Intelligent Agent Technology, Sydney, NSW, 2008, pp. 500-503, doi: 10.1109/WIIAT.2008.324.
  - W. Inujima, K. Nakano and S. Hosokawa, "Multi-robot coordination using switching of methods for deriving equilibrium in game theory" 2013 10th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology, Krabi, 2013, pp. 1-6, doi: 10.1109/ECTICon.2013.6559667.



PROJECT 2: ROBOTIC COOPERATION

- **Scenario:** robotic cooperation in harsh conditions (or earth/planet exploration)
- **Task:** consider a complimentary rovers which are able
  - Explore or extract a probe
  - Repair each other
  - Send images to earth
- **Each tasks provides:**
  - Payoff = {number of info units * P / unit (if exploring or sending images), 0 (if repair)};
  - Consumption = {number of info units (if exploring or sending images) * C/unit, W (if repair)}
  - The game can be framed as a dynamic game
- **Uncertainties can be included**
  - probability of broken robot
  - Probability of successful exploration
  - Probability of successful trannsmission

PROJECT 3: ENERGY HARVESTING

- We can consider two contests

Smart Grid

Wireless sensor network

PROJECT 3: ENERGY HARVESTING (SMART GRID)

- An electrical grid which includes various entities such as smart meters, micro-grids, energy grid, renewable energy and other energy-efficient resources which have different objectives and capabilities.
- Game theory is applied to a smart grid in order to design efficient power systems.
- Different from the traditional power grid, the concept of the smart grid represents the decentralized system with the distributed operation of the smart grid nodes.

PROJECT 3: ENERGY HARVESTING (SMART GRID)

Task

- to consider competitive or collaborative scenarios between the various entities of the smart grid. ***Such an economical factors as dynamic pricing is an essential part of the smart grid.***

Design of the microgrid systems

- Micro-grid is defined as a networked group of distributed energy sources such as solar panels or wind turbines. Investigate collaborative or non-collaborative scenarios.
- **Example:** energy trading or energy exchange between elements of the micro-grid.

PROJECT 3: ENERGY HARVESTING (SMART GRID)

Investigating energy storage strategies

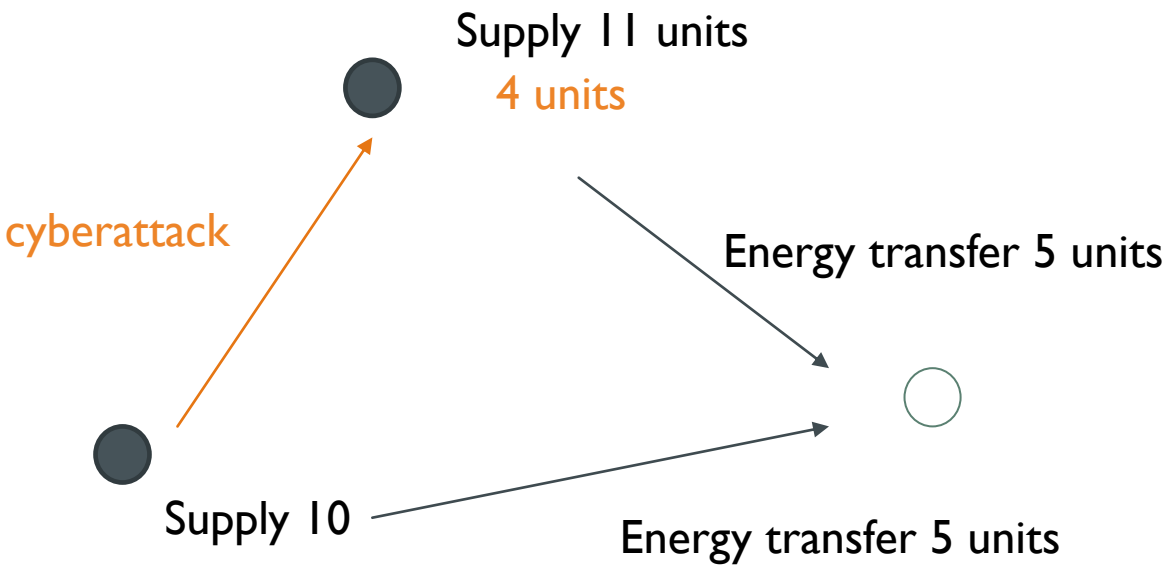
- This problem might impose the questions of whether it is more rational to store energy or sell, whether to discharge or charge the storage device, size of the storage elements in order to avoid blackouts.

Investigate the scenarios of security attacks on smart grid / smart meters

- For example, the attackers might intercept forecasting data from all the other players (households) and replace them, in order to get the profit.

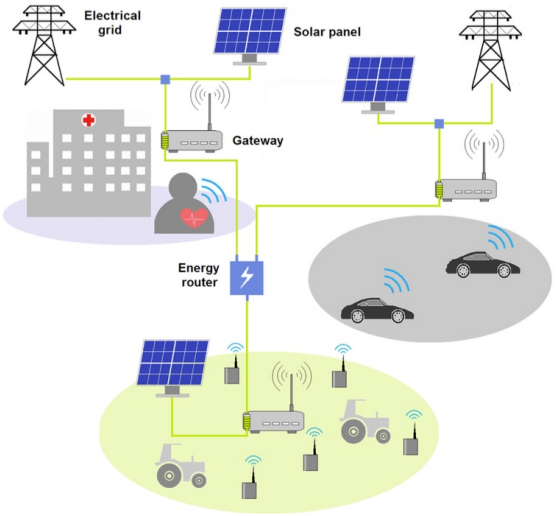
PROJECT 3.1: ENERGY HARVESTING (SMART GRID)

Framework: set of energy prosumers and energy consumers



PROJECT 3.2: ENERGY HARVESTING (SMART GRID)

- **Scenario:** Gambin, Á. F., Gindullina, E., Badia, L., & Rossi, M. (2018, April). Energy cooperation for sustainable IoT services within smart cities. In *2018 IEEE Wireless Communications and Networking Conference (WCNC)* (pp. 1-6). IEEE



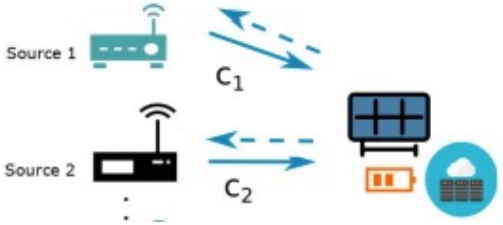
- Set of interconnected services. We can consider 2 types:
  - One connected to both solar panel and power grid (ongrid)
  - One connected to solar panels only (offgrid)
- Possible actions:
  - Transfer energy
  - Request energy from electrical grid
- Consideration:
  - fluctuations in energy arrivals, (energy model)
  - different energy consumption per gateway (function of multiple parameters (see the reference))
- Task:
- Represent a game as a single shot static game
- Simulate a game in T hours implementing multiple strategies: NE, random, centralised (if time)

PROJECT 4: AGE OF INFORMATION

- Age of information is a key performance metric for IoT (especially critical-mission IoT), in which timely status updates are essential
- Monitoring chemical/nuclear/industrial processes , healthcare, remote surgeries
- AoI quantifies the freshness of the knowledge

PROJECT 4: AGE OF INFORMATION

- **Framework:** consider 2 (or more) intelligent nodes (f.i, sensors, sources) that sends status updates (data packets) to a monitoring node (gateway, receiver)
- **Constraints:** energy supply
- **Actions:**
  - Update monitoring node (AoI = {0, AoI_i})
  - Rest (AoI = AoI + 1)



- **Considerations:**
  - heterogeneous scenario that implies the differences in consumption as well as Aoli
  - Uncertainties, i.e. one of the source might be out of energy with prob p
- Consider Static and Bayesian case of such a game

SOME OTHER IDEAS

MOBILE CROWDSOURCING (MSC)

- the distributed acquisition of sensed data.
- interaction between a crowdsourced and a large number of users to enable access to the built-in sensors in their mobile devices and share sensed data to ensure high value and high veracity of big sensed data.
- faces the following challenges that could be accessed with the means of game theory:
  - privacy/ security,
  - quality of data,
  - trustworthiness,
  - energy

MOBILE CROWDSOURCING

Privacy/ security:

- the shared by a user data may contain sensitive and private information. Access control should be permitted based on pre-established trust between user and service provider. The setup might include the crowdsourcer reputation, the (privacy preservation/ or not), etc.

Quality of data:

- the data acquired by a user might be characterised as low quality due to the sensor damage or low resolution. But excessively high-quality data might not provide any additional value for a crowdsourcer and take lots of space on the server.

MOBILE CROWDSOURCING

Trustworthiness:

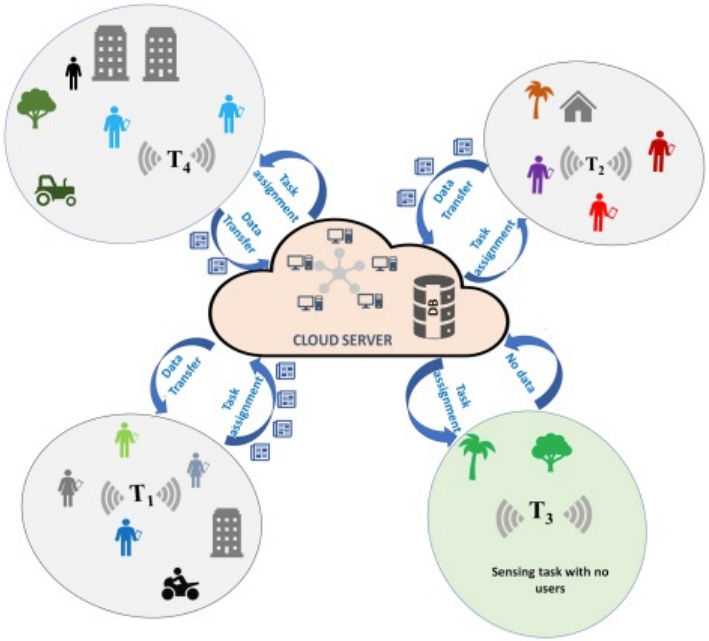
- similarly with crowdsourcer's trustworthiness, the reliability of a user is an issue to be addressed. The game-theoretical setup might include a user's reliability, malicious users, etc.

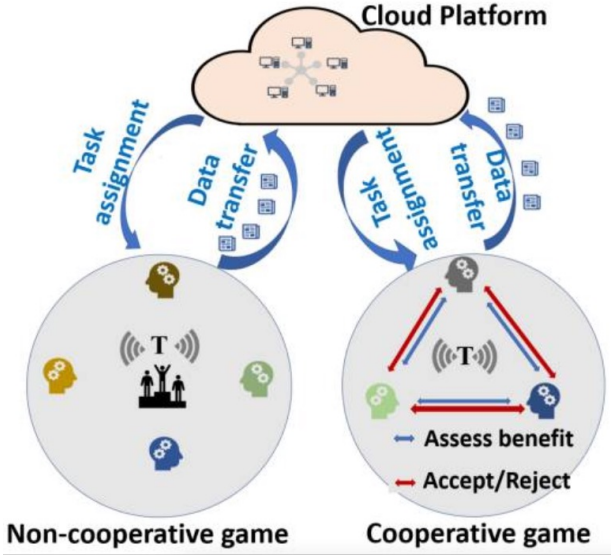
Energy:

- to provide high-quality information to a crowdsourcer, the mobile user consumes energy caused by the chosen sampling rate, transmission cost and other parameters, while crowdsource's interest is the sufficiently high quality of information. The energy aspects to be considered.

MOBILE CROWDSOURCING

- https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7180814/
- https://www.mdpi.com/1424-8220/20/7/2055





CYBERSECURITY

- **Cloud cyber security:**
  - in this application, the general setup can include, public clouds, cloud providers, virtual machines and clients.
  - The interaction between these entities might include lots of aspects, such as data loss, transparency, hacked interfaces, DDoS attacks, etc.
  - The goal is to consider scenario taking into account the aforementioned aspects.

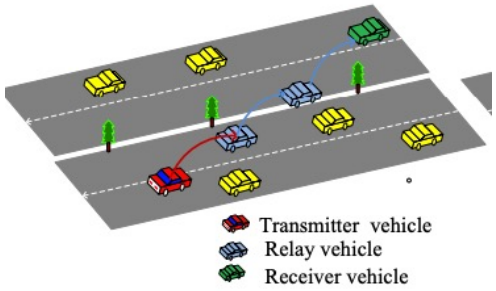
CYBERSECURITY

	Computation (C)	DDoS (D)
Computation (C)	$P_1(CC), P_2(CC)$	$P_1(CD), P_2(CD)$
DDoS (D)	$P_1(DC), P_2(DC)$	$P_1(DD), P_2(DD)$

- **Question:** to increase the computational power of your own resources or to attack the competitor's resources
- **Task:** extend to the dynamic / Bayesian case

CYBERSECURITY

- **Vehicular Networks (VANETs) security / self-driving car:**
  - the malicious attacks on the vehicular systems, in particular, self-driving car on-board systems is a promising revenue to be considered.
  - **Reference:** https://arxiv.org/pdf/2006.00992.pdf



CYBERSECURITY

- **Sharing private information or data between individuals or organizations.**
  - Modelling and designing incentive mechanisms to protect privacy in information sharing, especially considering the nature of sharing data that requires distributed protocols.
  - **References:** https://www.sciencedirect.com/science/article/pii/S0957417417304669 (*n* firms and an attacker is presented, each firm invests to protect its information assets. The attacker invests to damage or misuse the firms' information systems in a cyber-attack process, Firms can improve their security level by sharing their security information with ISAC.)
  - Task: Bayesian games, evaluate the effect of creating collations based on Shapley value

CYBERSECURITY

- Aircraft boarding systems and wireless networks security is an object of the attack over oceans and within an aircraft.
- **Task:** is to investigate the aircraft boarding system attacks and to propose the game-theoretical solution.

DISTRIBUTED COMPUTING

- **Distributed computing** refers to the use of distributed systems to solve computational problems. In *distributed computing*, a problem is divided into many tasks, each of which is solved by one or more computers, which communicate with each other via message passing.
- **Task:** to consider a decentralized system with computational nodes that interact strategically. Each of the computational nodes performs one or more tasks to be either performed using its own computational resources or to be 'outsourced'.

VEHICULAR NETWORKS (INTELLIGENT TRANSPORTATION SYSTEMS)

- **Objective:**
  - effective and secure traffic
  - Satisfying the requirements: QoS, security
- **Overview:**
  - Sun, Z., Liu, Y., Wang, J., Anil, C., & Cao, D. (2020). Game theoretic approaches in vehicular networks: A survey
- **Framework**
  - Intelligent nodes (traffic participants) compete or cooperate for limited resources
  - such as **power, frequency spectrum, bandwidth**

VEHICULAR NETWORKS (INTELLIGENT TRANSPORTATION SYSTEMS)

Propose to focus on: game theory in heterogeneous VN

Different technologies, power sources or computational capabilities of on-board systems

Problem of fair resource allocations (for instance: radio resource allocations – bandwidth, power frequency)

Another interesting starting point for a project: Risk aware game theory
https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=9303958&casa_token=3Wyn9_FZgoEAAAAA:RZ5MFRG4ebBGkGCQL9pFWrFapX-Qsh4bopUC1z-AcFwYuENk_O-z8OsRkfMMGMTNeYD7FJBu&tag=1

ML

- **Task:** compute Shapley values (cooperation gain) for coalition of players that cooperates (how important is each player to the overall cooperation?) applied to features.
- **How to proceed:**
  - choose an application/ problem which is solved using ML related to one of the engineering topics preferably presented today
  - It could be the project from your ML course
  - compute Shapley values
  - https://arxiv.org/abs/2101.02153
  - https://arxiv.org/abs/1904.02868
  - https://nyuscholars.nyu.edu/en/publications/explainable-classification-of-eeg-data-for-an-active-touch-task-u

GENERAL INFORMATION

- **Steps:**
  - Identification of the field of interest (i.e choose/propose the interesting topic you would like to work on)
  - Literature review (please check what has been already done in the literature)
  - Problem formulation and modelling
  - Numerical results/ analysis
- **Report:** 5-8 pages of double column text, 10pt.
- You can develop a project in a group of 2-3 students. If you are alone, please cooperate with others (you can write in the forum in order to find project mates). The project with a single author are not accepted.
- ***Hard deadline:*** January 20, 2022. You cannot deliver the project after this date, you are encouraged to deliver it sooner.

NOT ACCEPTED TOPICS

- Politics and elections (unless applied to one of the suggested topics).
- Blockchain
- Pokemon
- Card/board games
- Sustainability and environment, climate change
- Quantum game theory

SOME OTHER NOTES

- There could be multiple groups doing the same thing / topic => from aa single topic many different projects can be developed
- The topic is of your choice. I recommend to browse the slides, read/study references (find more references in google scholar if needed), brainstorm with your teammates, develop the model and the project in full autonomous mode.
- Try to integrate the ideas presented today with the of course with the course materials.

- Forum to find a project mate:
- https://stem.elearning.unipd.it/mod/forum/view.php?id=159407
- Fill in the form with family names and name of the project (deadline November 10):
- https://docs.google.com/spreadsheets/d/1RX8bzUYPW9ZqdCV8vNQHHqQ4ZiPtae1_PvGmabPIEw0/edit?usp=sharing