Projektvalskatalog

EF112X kandidatexamensarbete inom elektroteknik (15 hp) våren 2025

I denna katalog kan du hitta information om alla valbara projekt inom kursen EF112X kandidatexamensarbete inom elektroteknik (15 hp) som erbjuds våren 2025 vid EECS skolan, KTH. Kursen EF112X pågår hela vårterminen från mitten av januari till slutet av maj. Projekten utförs i grupper om två. I år finns 64 projekt att välja emellan inom ramen av 16 olika kontext.

Kontext inom systemteknik och robotik

- Kontext A: The dynamics of a sustainable society (*Matthieu Barreau*)
- Kontext B: Autonomous electrical power grids (*Giuseppe Belgioioso)*
- Kontext C: Smart and sustainable buildings (*Angela Fontan*)

Kontext inom inbyggda system och elkraftteknik

- Kontext D: Electric transportation (*Mats Leksell*)
- Kontext E: Kraftsystemstyrning (*Qianwen Xu*)
- Kontext F: Hydro power modelling (*Mikael Amelin)*
- Kontext G: HVDC supergrids for offshore wind (*Ilka Jahn*)
- Kontext H: Predicting the future sustainable power system (*Lars Nordström*)

Kontext inom elektromagnetism, fusion och rymdteknik

- Kontext I: Design and testing of novel microwave/antenna technologies (*O. Q.-Teruel*)
- Kontext J: Fusion - solens energikälla på jorden (*Thomas Jonsson*)
- Kontext K: Solar wind and planetary environments (*Lorentz Roth*)
- Kontext L: Aerospace systems testing (*Nickolay Ivchenko*)

Kontext inom information och nätverksteknik

- Kontext M: Machine learning over networks (*Carlo Fischione*)
- Kontext N: Machine learning over networks (*Rolf Stadler*)
- Kontext O: Information engineering: Big Data & AI (*Tobias Oechtering*)

Kontext inom datavetenskap och maskininlärning

- Kontext P: AI, games, and strategy (*Mika Cohen*)
- Kontext Q: Computational brain modelling and brain-like computing (*Pawel Herman)*
- Kontext R: Automatic bug fixing and Securing Software Supply Chains (*M. Monperrus*)

Tillgängliga projekt 2025

Alla projekt som erbjuds vårterminen 2025 finns beskrivna i denna pdf-fil. Läs igenom projektbeskrivningarna noggrant. I valet markerar du vilka projekt du helst vill göra. Obs, inom ramen av denna kurs kan man inte "skräddarsy" sitt eget projekt eller göra ett industriprojekt. Du måste välja ett av de tillgängliga projekten som finns beskrivna i denna katalog.

Viktiga datum

- **Informationsmöte om projektvalet:** Måndag, 14 okt 2024, kl 13:00-16:00, sal D2
- **Projektval:** 1-15 nov 2024
- **Kursstart:** vecka 3, 2025 (uppstart-möte, i anslutning första träff med handledaren)
- **Kursslut:** vecka 21, 2025 (heldag KEX-presentation)

Kurs-PM

All information om kursens uppbyggnad finns i kurs-PM. Kurs-PM:et läggs ut senast den 1 november 2024 på projektvalsidan: www.kth.se/social/course/EF112X/

Behörighet

Minst 104 högskolepoäng från kurser i utbildningsplanen, till och med period 1 i årskurs 3, ska vara avklarade senast vid startdatum för period 2 för att studenten ska få påbörja kandidat-examensarbetet.

Anmälan till KEX-kursen

Elektroteknikstudenter: Om du går i årskurs tre (CELTE-3) och ligger i fas med studierna, ska du välja villkorligt valfria, och/eller den helt valfria kursen, och kandidatexjobbskursen EF112X mellan 1-15 november via antagning.se. Logga in med ditt kth.se konto.

Om du antogs till elektroteknik 300 hp år 2021 eller tidigare, sker anmälan till kandidat-exjobbskursen EF112X istället via e-post till svl-celte@kth.se mellan 1-15 november.

Om du är från en annan KTH skola (fysik, farkost, teknisk matematik eller energi och miljö programmet), anmäler du att du vill göra kandidatexjobbskursen EF112X till studievägledaren vid respektive KTH skola.

Val av projekt

Förutom att anmäla dig till kandidatexjobbskursen behöver du (oberoende från vilken skola du kommer) välja på internet själva kandidatexjobbsprojektet du vill jobba med.

När sker valet?

Valet av kandidatexjobbprojekten görs under perioden 1-15 november 2024. Resultatet påverkas ej av när du väljer under valperioden.

Projektgruppen

Kandidatexjobbsprojektet utförs i grupper om två studenter. Om du inte lyckas hitta en projektpartner, tilldelas du en partner med liknande projektönskemål som du.

Gör ditt val

Anmälan görs på projektvalsidan (www.kth.se/social/course/EF112X/). Välj de sju mest intressanta projekten ur denna projektvalskatalog. Du kommer kunna ange din prioriteringsordning när du väljer (prio 1= projektet du helst vill ha). Om du redan har hittat en projektpartner, fyll i bådas namn, e-mail och program i samma anmälan. Gör endast **en** anmälan per grupp. Om du inte har en projektpartner än, anmäl dig ensam (du kommer sedan tilldelas en projektpartner).

Lycka till!

Anita Kullen (kullen@kth.se)
Kursledare för kandidatexjobbskursen EF112X
Stockholm, 1 oktober 2024

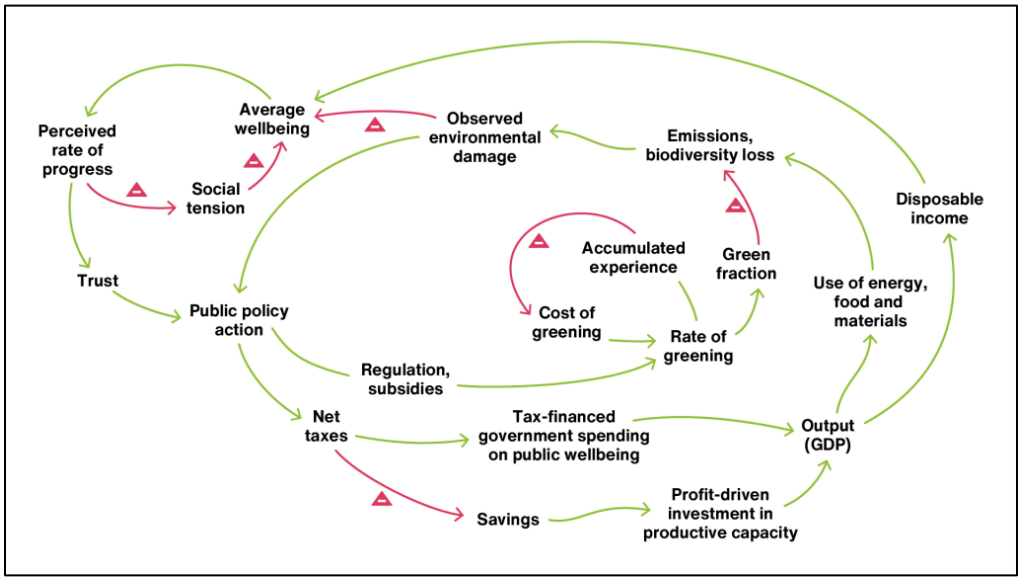
Context A: The Dynamics of a Sustainable Society

Context Responsible: Matthieu Barreau, barreau@kth.se Decision and Control Systems

"*Meeting the needs of the present without compromising the ability of future generations to meet their own needs.*"

This is the well-known sustainability definition by the United Nations Brundtland Commission in 1987. Sustainable development is then taking into consideration environmental concerns along with economic development and social aspects. The 17 Sustainable Development Goals is a framework for improving the lives of populations around the world and mitigating the hazardous man-made effects.

But how is this done? We are dealing with an extremely complex and complicated problem that involves the law of nature, global politics and economics, cultures, human behavior, and technical solutions, to name just a few of the aspects. And we need to deal with long time scales and complex interplay between different domains. In these projects we will approach this problem by dynamical systems modelling.

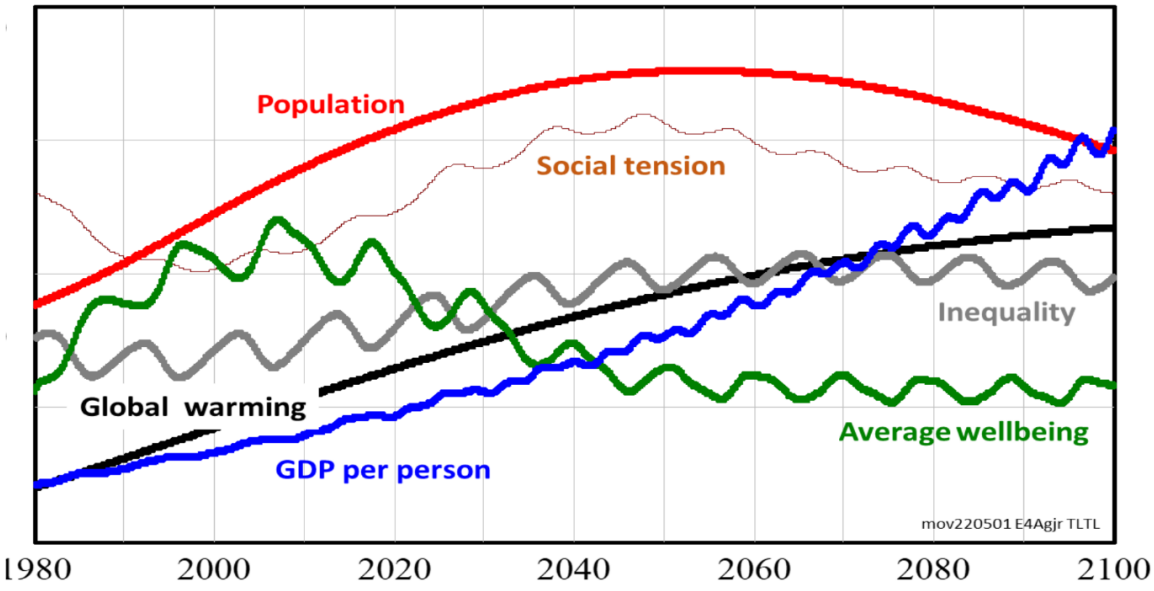


The World3 model, presented in the book "The Limits to Growth" was a pioneering computer-based system dynamics model that aimed to shed light on the complex interactions between population growth, resource depletion, industrialization, and environmental impacts. The central message of the model was that if left unchecked, human activities such as rapid population growth and excessive resource consumption would eventually lead to ecological and societal challenges. This model has been updated multiple times and totally rewritten in 2022 with the new name Earth4All.

It generated heated debates and criticism, particularly regarding the assumptions made, predictions capabilities, and policy implications. While the model had its limitations, it played a pivotal role in raising awareness about the challenges of sustainable development and the importance of considering the finite nature of Earth's resources in shaping our future. The ongoing debates surrounding the model continue to shape discussions on environmental and economic policy.

Projects A1 – A3: Modeling the world

This context has three projects. The aim of these three projects is to analyze and experiment with the Earth4All model. The focus of each project is different but there is a common ground. There will be three independent projects A1 – A3, but you will interact between the groups in multiple workshops, where you will share knowledge and identify connections between the methods.



The Earth4All model is a dynamic model with interconnected subsystems describing: 1) food production and agriculture, 2) industrial production, 3) human population, 4) non-renewable resources, and 5) pollution. A typical simulation of the model is shown to the top. The initial step will be common for all projects. The students will first make use of a web graphical interface of the Earth4All model, to understand its structure and build some intuitive understanding. In the later phase you will use and modify a Python implementation of the model.

Project A1: Modeling the world – Exploring possible futures with systems thinking

Supervisor: Matthieu Barreau, barreau@kth.se, Division of Decision and Control Systems

In this project you will work with the Earth4All model to explore possible futures of our world. You will work on a subpart of the model since it contains many variables that are dynamically interconnected in reinforcing and stabilizing loops. You will use systems thinking and control/systems theory to analyze it and to propose and evaluate aspects with an implication on sustainability.

(1) Analyze the causal loop diagram to understand its structure. Find the main relations between the variables of the model. Identify important loops. Define the variables and the external inputs.
(2) Use a mix of simulation and analysis to understand the behavior of the model. Use sensitivity analysis to identify variables and inputs of importance. Identify important delays and inertia that affect the dynamic response of the model.

(3) Based on your systems understanding, explore different possible futures, for example new policies, changed behavior, technology development, or other important factors. Use simulation and analysis to explain the effects. Experiment with the model and modify it, if necessary, for example by changing parameters or introducing/removing links.

Project A2: Modeling the world – Model identification using physics-informed learning

Supervisor: Matthieu Barreau, barreau@kth.se, Division of Decision and Control Systems

The dynamics of one sector is very complex and not written in a form suitable for control. The tool you will use is Physics Informed Learning.

1) You will first assume no knowledge of the original system and try to find a nonlinear dynamical model using a neural network. You will need to collect data and train the model.
2) The second step is to try to simplify the neural network from the previous part. You can investigate the dimension of the original system but also try to simplify the model by identifying key signals.
3) You will go deeper into the identification by considering submodels and repeating the first step with this new system design.
4) From your understanding of the different variables, you will try to find which ones are measurable. The final identified model should be interpretable and have a physical sense. This model should help you to highlight the most important features and the policies with the most impact.

Project A3: Modeling the world – Optimal policies with reinforcement learning

Supervisor: Matthieu Barreau, barreau@kth.se, Division of Decision and Control Systems

Reinforcement Learning (RL) is a well-known machine learning technique often used to find an optimal policy for controlling a dynamic system in order to maximize a reward cumulated over time. At each time step, the agent takes an action, influencing the system's evolution over time. The agent then observes the updated states and receives a reward based on the transition. RL is often used in uncertain environments where the dynamics of the system need to be learned while interacting with the system itself. Over time, the agent gathers more information, enhancing its understanding of the system dynamics for more informed decisions. RL is used for many applications such as robotics, automation, video games, and finance and recommendation systems.

In this thesis, we propose the application of RL techniques to a subsystem of the World3 model, a well-known system dynamics model used for studying global sustainability. Using RL the students should try to derive the optimal control policy with respect to a given cost. Constraints on the measurements (availability of the measure, sampling…) and the control inputs (delayed inputs, quantization…) can be considered. More precisely, the aim is to optimize resource allocation and policy decisions within the selected subsystem, with the overarching goal of contributing to a specific UN sustainability goal. The World3 model provides a comprehensive

framework for simulating interactions between population, resources and the environment, making it a good testbed for the students' RL experiments.

This thesis will require a thorough understanding of the structure and dynamics of a subsystem within the Earth4All model.

1) Identify relevant state variables, actions and their interdependencies.
2) Formulate a reward function that can well quantify the desired system behavior linked to a specific UN sustainability goal.
3) Train and evaluate the RL agent using appropriate algorithms, in order to derive an optimal control policy.
4) Assess the performance of the obtained control policy with simulation experiments and compare against a baseline approach.

Context B: Autonomous Electrical Power Grids

Context responsible: Giuseppe Belgioioso (giubel@kth.se)

Division: Decision and Control Systems

1) The Challenge

To achieve climate goals and enhance energy independence, an increasing amount of renewable power is being integrated into the grid and is replacing traditional form of generation. This renewable generation is typically dispersed across the grid or located where the primary energy source (wind, solar) is mostly available. Moreover, generation from renewable sources follows temporal patterns that are not fully predictable and depend as well on the generation technology. These temporal and spatial variability of generation, together with the increasing demand for electricity poses unprecedented challenges on the operation of power transmission grids: as the network reaches its limits, renewable power often needs to be curtailed to avoid congestion issues such as overloaded lines and over-voltages that can compromise the grid's safe operation.

Figure 1: Automation will play a key role in shaping future sustainable energy systems.

Industry state-of-the-art manual and semi-automated mechanisms for congestion control in power transmission grids are unsuited for these new tasks for two main reasons:

(1) they are not fast enough to safely respond to generation variability;
(2) they cannot handle the complexity of managing a large number of small-size generators.

Consequently, there is a growing need to enhance real-time automation and implement control actions at shorter intervals, ideally every few seconds. The French operator RTE estimates potential savings of billions of Euros over a decade if real-time control of power flows can prevent the construction or reinforcement of power lines. In the US, the connection of more than 2000 GW of renewable generation is currently being delayed due to grid capacity constraints.

2) Your Mission

This context consists of three different but interconnected projects. The common goal of the projects is to explore the implementation of smart control algorithms to autonomously control the world's largest and most complex machine, the electrical power grid. You will learn about:

(1) the power flow equations, governing the electrical power grid dynamics, and familiarize yourself with Panda Power, a Python tool for simulating electrical grids (https://pandapower.org)

(2) optimization and control principles, essential for designing smart congestion control algo- rithms, and gain hands-on experience with optimization solvers such as MOSEK (https://www.mosek.com);
(3) numerical simulations using real grid models and data to validate and analyze various aspects of your control algorithms

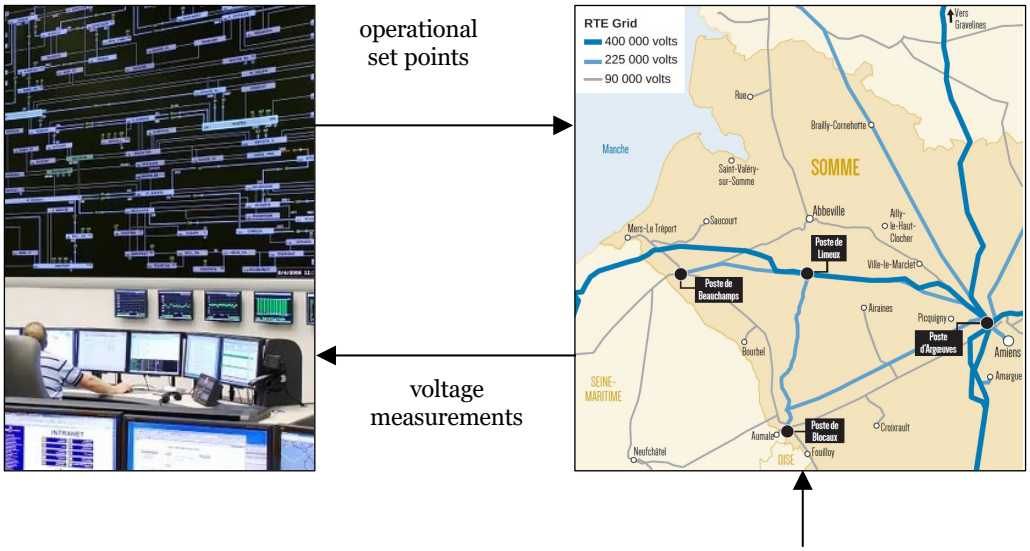


Figure 2: In future electrical power grids, generators and other grid actuators will be autonomously controlled in real-time via smart algorithms and without any human intervention.

Project B1: Feedforward vs Feedback Control

Industry state-of-the-art congestion control mechanisms heavily rely on grid models and forecasted disturbances to manage power flow. In control theory, this is referred to as feedforward control. The challenge arises when grid models or forecasts are inaccurate, leading to deviations between expected and actual outcomes. In practice, grid operators need to update forecasts and take corrective actions, a process known as re-dispatching. In this project, you will:

1. Familiarize yourself with the simulation environment;
2. Develop a feedforward controller for congestion management;
3. Validate the controller design in the simulation environment, showing how inaccurate forecasts lead to deviations in outcomes;
4. Explore alternative feedback control designs that mitigate these issues.

Project B2: Handling Complexity

Industry state-of-the-art congestion control mechanisms are based on mathematical optimization. Specifically, power generation set-points for the upcoming day are determined by solving an optimization problem of the form:

$$\min_{s} \quad \text{curtailment}(y) \qquad (1)$$

$$\text{s.t} \quad y = h(s, d) \qquad (2)$$

$$y \in \text{limits}, \qquad (3)$$

where s represents the generator set-points, y the grid's state, d the disturbance, and h is the outcome of the power-flow equations. Notably, the dimension of this optimization problem, depends both on the number of decision variable s and on the grid size (impacting h).

In this project, you will:

1. Familiarize yourself with the simulation environment;
2. Develop a congestion control algorithm;
3. Validate your design using the simulation environment;
4. Numerically explore the computational complexity of your smart control mechanism by deploying it on grids of increasing size.

Project B3: Centralized vs Multi-area Grids

Industry state-of-the-art congestion control mechanisms treat the transmission grid as an isolated system. However, modern transmission grids consist of multiple interconnected areas, each locally managed by different operators but physically interconnected. A natural question in this more realistic scenario is whether the overall multi-area grid, resulting from the interconnection of locally controlled areas, can retain efficiency properties.

In this project, you will:

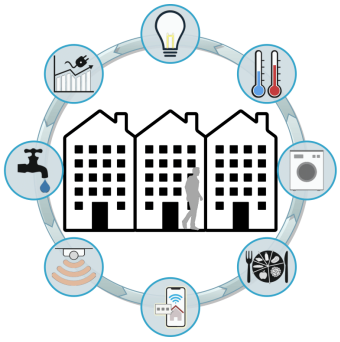
1. Familiarize yourself with the simulation environment;
2. Develop a congestion control algorithm;
3. Validate your design using the simulation environment on a single-area grid;
4. Study how the efficiency of the control algorithm changes as more areas are included in the grid.

Context C: Smart and Sustainable Buildings

Context Responsible: Angela Fontan, angfon@kth.se, Division of Decision and Control Systems

The building sector is facing a digital revolution that is bringing new opportunities for smart and sustainable buildings. The understanding of building dynamics has led to the acknowledgment that occupants are no longer seen as mere recipients of the indoor climate but as active agents in the optimal operation of buildings to achieve a better indoor climate and improved energy efficiency. Hence, while buildings are still operated based on outdated and simplistic assumptions about occupants, instead, they should be included as decision-makers whose dynamics are affected by and affect the surrounding building conditions. In parallel, occupancy patterns need to be taken into account for optimal building operation. Digitalization enables a better understanding of occupancy and behavioral patterns and their impact on energy use. In these projects, we will address unsolved challenges, using data-driven tools and digital twins.





Key aspects to achieve in these projects include the characterization of models of human behavior in smart buildings using data from real testbeds, the implementation of developed techniques on building simulation software, and the estimation of energy use. The projects will make use of KTH's unique testbed facilities, which are equipped with high-resolution monitoring and control systems, where close interaction with the building occupants is also possible.

Projects C1 – C3: Modeling occupants' behaviors in smart buildings

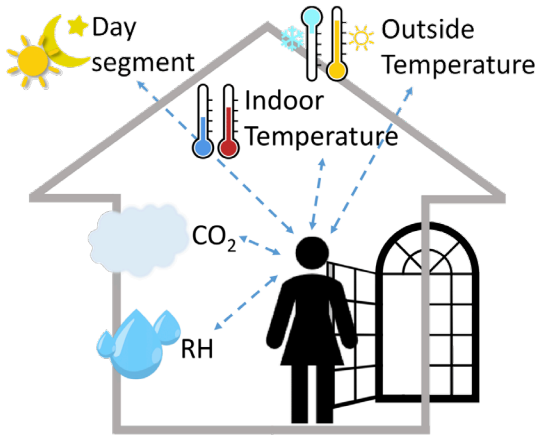
This context has three projects, C1 - C3. These three projects aim to analyze and experiment with the real-world data collected from the state-of-the-art testbed KTH Live-In-Lab. The three projects are focused on different aspects exploring the complex interactions between the building systems and occupants' behaviors. However, you will all share common datasets and have access to a digital twin environment that simulates the real building. Moreover, you will share and discuss potential methodologies and the energy and sustainability implications of your findings.

Project C1: Interaction between building systems and building occupants' behaviors: Modeling occupants' actions

Supervisor: Angela Fontan, angfon@kth.se, Division of Decision and Control Systems

In this project, you will work with data collected from the KTH Live-in-Lab to model different behaviors of occupants.

1. Preprocess and analyze the state-of-the-art sensor data from the KTH Live-in-Lab. Identify important variables, from state variables (such as relevant temperatures, CO2, RH), control inputs, and external inputs to the building system.
2. Explore and determine significant drivers of occupants' behaviors, including environmental (thermal, air quality, outside weather), categorical (time of the day), and social (decisions/behaviors of fellow tenants) variables.
3. Model occupant behaviors, known to affect energy and sustainability, using critical drivers. Use numerical simulations to showcase the findings.

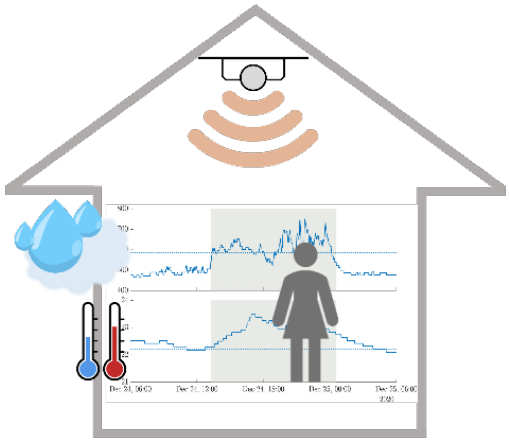


Project C2: Interaction between building systems and building occupants' behaviors: Modeling occupants' presence and activities

Supervisor: Angela Fontan, angfon@kth.se, Division of Decision and Control Systems

In this project, you will work with data collected from the KTH Live-in-Lab to detect and model occupancy.

1. Preprocess and analyze the state-of-the-art sensor data from the KTH Live-in-Lab. Identify important variables, from state variables (such as relevant temperatures, CO2, RH), control inputs, and external inputs to the building system.
2. Detect occupant(s) presence from relevant environmental drivers. As a starting point, use the CO2 levels in the room to estimate the presence profile of the occupant(s) in diverse rooms using mass balance equations.
3. Utilize information on occupant's behaviors (e.g., opening/closing window) to improve the analysis.
4. Test the model against the occupancy baseline obtained from sensor data.

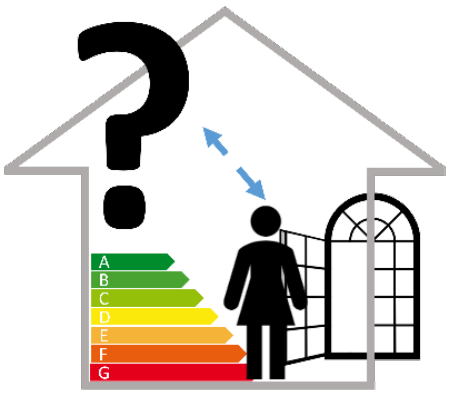


Project C3: Interaction between building systems and building occupants' behaviors: Evaluate energy impacts

Supervisor: Angela Fontan, angfon@kth.se, Division of Decision and Control Systems

In this project, you will work in parallel with data collected from the KTH Live-in-Lab and with building energy simulators, such as IDA ICE (Indoor Climate and Energy). IDA ICE is a multizone simulation application for the study of thermal indoor climate and building energy consumption.

1. Preprocess and analyze the state-of-the-art sensor data from the KTH Live-in-Lab. Identify important variables, from state variables (such as relevant temperatures, CO2, RH), control inputs, and external inputs to the building system. Propose energy performance indicators.
2. Use simulation analysis to understand the impact on energy consumption of occupants' behaviors, using prefixed schedules.
3. Implement known models of occupant behaviors in building energy simulators and explore the consequent energy impact, by means of numerical simulations. Compare your findings against energy baselines



Context D: Electric Transportation

Ansvarig för kontexteten: Nicholas Honeth

Introduktion

Dagens samhälle är starkt beroende av ett fungerande transportsystem för såväl människor som gods. Samtidigt står transporterna för en stor andel av världens koldioxidutsläpp i och med att det är framförallt olja som används som bränsle. Lösningen på det här problemet heter idag elektrifiering; det behövs elektriska farkoster för såväl väg som vatten.

I det här kontextet studeras flera farkoster som har det gemensamma att de ska utföra en uppgift så effektivt som möjligt. Det är en hyperavancerad racingbil, en flygande elbåt samt den vanliga personbilen. I en del av projekten ingår att bygga och utvärdera utrustning som kan effektivisera deras prestanda.

Tillsammans ska projektdeltagarna även sätta in sina system i det överordnade transportsystemet och reflektera över deras betydelse.

Project D1: Machine learning VESC motor drive parameter tuning for marine electromobility

General Information

Contact at EECS: Nicholas Honeth (honeth@kth.se) and Mats Leksell (leksell@kth.se)

Industry partner: Research affiliated to Next Generation Hydrofoil Systems for Robust and Cost Effective Electric Work Boats (NG-FREEBS)

Background

Marine electromobility is particularly challenging and interesting in this regard in that there is a complex interaction between the electric powertrain, propellers, the boat hull and conditions in the water. The NG-FREEBS project has developed a laboratory dynamometer rig for testing the submersible motors used in the hydrofoil system. The motor drives are the VESC project open-source hardware versions which allow a large amount of flexibility in how they are configured.

Goals

This project aims to use a machine learning tool of your choice to automate testing and parameter tuning on the dynamometer bench and VESC motor drives to get the best performance from the system.

The specific project goals include:

- Review and operation of the dynamometer system and VESC drives
- Development of competence in measurement and manual parameter tuning of the system
- Integration of automated GPIB or LXI data retrieval from measurement instruments
- Integration of parameter setting in the VESC tool console from your own code
- Selection and evaluation of a machine learning tool for the tuning process
- Development, integration and testing of the tuning process
- Analysis of the test results compared to e.g. a default setting base case
- Put the tools and measurement results into a larger context of electrification of light marine transports and discuss this in your final report

Prerequisites

Recommended: programming skills (Python), previous experience working with raspberry PI (Linux), comfortable working with laboratory instruments and test equipment.

Project D2: Direct drive propeller performance evaluation for marine electric propulsion

General Information

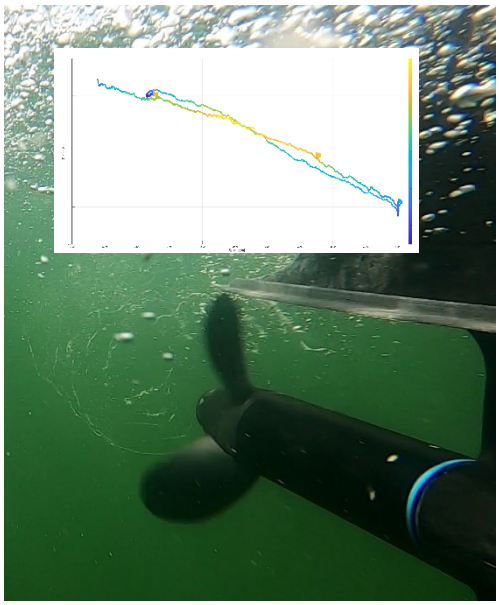
Contact at EECS: Nicholas Honeth (honeth@kth.se) and **someone**@zparq.se

Industry partner: Zparq AB

Background

Marine electromobility is particularly challenging and interesting in this regard in that there is a complex interaction between the electric powertrain, propellers, the boat hull and conditions in the water. Matching a propeller to a specific craft (what shape, how big, how heavy) and application (how fast, how far) is difficult and requires extensive testing, accurate measurement and rigorous data analysis.

Goals



This project aims to measure and test the performance of a variety of 3D printed propeller designs powered by a submersible electric motor on a 4m boat. You will have an opportunity to develop your skills in field testing and experimental data analysis of light electric vehicles.

The specific project goals include:

- Review and operation of the system to be tested
- Development of competence in electrical measurement systems, GNSS positioning, inertial measurement and data logging
- Planning and running of field tests
- Development of data management, analysis methods and presentation
- Performing, documenting and presenting the analysis results
- Put the tools and measurement results into a larger context of electrification of light marine transports and discuss this in your final report

Prerequisites

Recommended: programming skills (Python, Pandas, Plotly), experience or interest in working with raspberry Pi (Linux), comfortable working with laboratory instruments and test equipment.

Project D3: Statistical analysis and simulation of electric vehicle smart charging in Swedish Market

Supervisors: Dita Anggraini doctoral student, Mikael Amelin lektor, Div. Electric power and energy system KTH

Electric vehicle adoption has grown significantly in recent years and is expected to keep rising. It is estimated that 3.8 million EVs would have an aggregated battery capacity of 114 GWh in Sweden, which theoretically can supply electricity for Sweden for several hours [1]. If not managed properly, EV charging can reduce grid stability and even lead to grid overloading. However, using smart charging, EV batteries can be leveraged as flexible assets to help manage grid congestion and stabilize the grid. A preliminary study and model of EV charging are discussed in [2], where EV charging in residential areas is modeled, and a Monte Carlo Simulation is performed. To improve the study and represent more realistic cases, it is interesting to collect recent statistical data, estimate future scenarios, and simulate the smart charging model based on the Swedish market setup.

This project aims to improve the realism of the previously proposed EV charging model. The following steps are recommended:

1. A review of historical data that will be useful for the EV charging model and optimization, such as the mobility pattern, EV types, quantity of EVs owned by family, travel routes, etc.
2. Estimate the parameter values representing future EV scenarios in Sweden.
3. Apply the estimated data to simulate EV smart charging in the Swedish market.
4. Interpret and explain the obtained findings.

References

[1] Power Circle, “What is V2G - Vehicle to Grid?,” Power Circle, Sweden, Jan. 2024. [Online]. Available: https://powercircle.org/wp-content/uploads/2024/03/240311-V2G-faktablad-uppdatering-jan-2024-Engelsk-version-1.pdf

[2] D. Anggraini, M. Amelin, and L. Söder, “Electric Vehicle Charging Considering Grid Limitation in Residential Areas,” in *2024 IEEE Transportation Electrification Conference and Expo (ITEC)*, Jun. 2024, pp. 1–6. doi: 10.1109/ITEC60657.2024.10598892.

Project D4: PCB with Integrated Busbar for High Voltage Battery in a Formula Student Car

Supervisors: Carl-Mikael Zetterling (bellman@kth.se) together with the powertrain and electronics team at KTH Formula Student

Background:

The KTH Formula Student vehicle, **DeV18**, is an electric racing car featuring a custom-built high-voltage battery pack. The battery comprises **252 Lithium-Ion cells**, divided into **six segments**, which together form a **529.2 V, 13.2 Ah** power source. Under peak performance, the battery is expected to draw up to **150 A**, placing significant thermal stress on the system and necessitating efficient cooling. In the current setup, cells are connected in series using **rectangular copper busbars**, with a separate **measurement PCB** mounted above to monitor cell voltages and temperatures. However, this configuration introduces challenges related to **manufacturing complexity**, **increased contact resistances**, and **potential reliability issues**. To improve the overall system design, it is crucial to explore alternatives that integrate multiple functions into a simpler, more reliable, and compact solution.

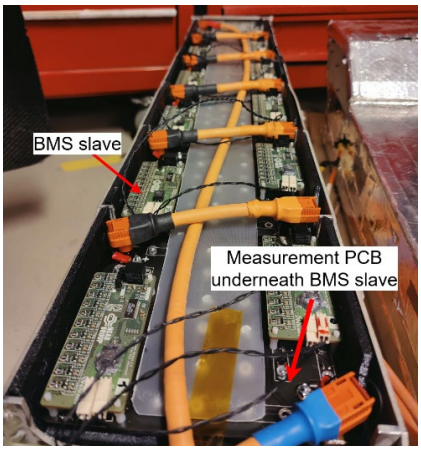


Figure 1: Picture of currently used high voltage battery with the six segments installed

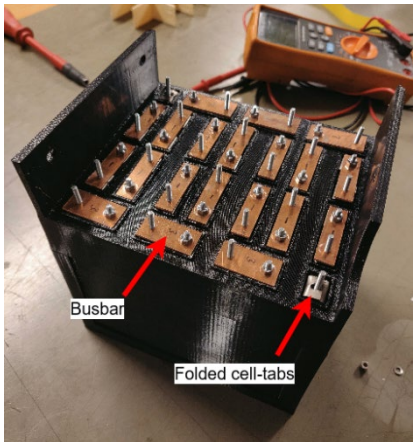


Figure 2: A currently used battery segment without measurement PCB installed, showcasing the busbars to be integrated into the new PCB

Project Proposal:

This project aims to design a **measurement PCB** that integrates the busbars directly into the PCB. The goal is to reduce complexity, improve reliability, and enhance the electrical and thermal performance of the system. Key objectives include:

- **Designing the PCB** using **KiCAD** to integrate busbars for direct cell connection, ensuring robust current handling of up to **150 A**.
- **Thermal analysis** of the PCB to ensure proper heat dissipation under varying conditions.
- **Mechanical integration** to fit within the physical constraints of the **DeV18 battery container**, as well as allocating space for the **BMS slaves** to be mounted on top.
- **Verification** of the design by testing the hardware and comparing to simulations and calculations.

Context E: Kraftsystemstyrning

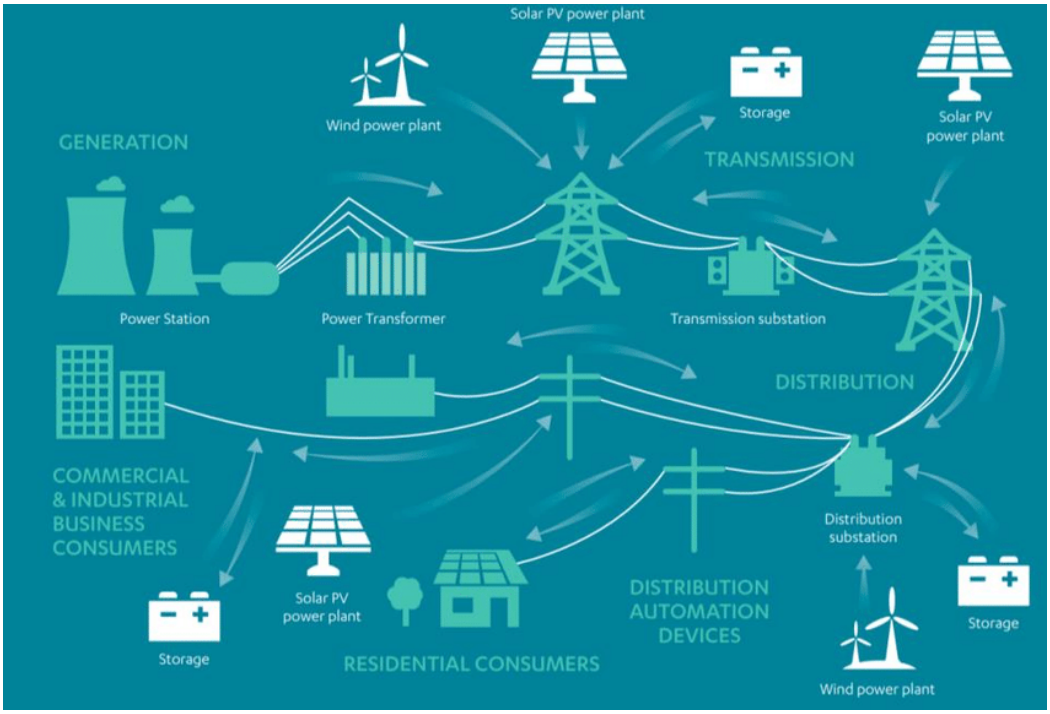


Figure: Future power system

På svenska:

Som ett svar på utmaningen med klimatförändringarna elektrifieras allt fler delar av samhället, och elproduktionen ställs om till att inkludera stora mängder förnybar och delvis distribuerad kraftproduktion. Dessa nya kraftkällor t.ex. vind och solkraft ersätter de större centrala produktionsenheter som tidigare utgjort ryggraden i systemet. Detta ställer nya krav på elkraftsystemet dels eftersom vindkraft och solkraft inte är i lika hög grad styrbart och därför kan påverka systemets stabilitet på nytt sätt. Dessutom är de förnybara kraftkällorna inte lokaliserade i närheten av stora last-centra, exvis. städer, vilket gör att kraven på överföring av elenergi förändras. De senaste åren har dessa frågor blivit alltmer aktualiserat i samhällsdebatten

De nya kraven finns både på transmissions och distributionsnivå. Det inkluderar nya gränser för stabilitet i systemet på grund av minskad roterande massa i generatorer och ökade variationer gällande spänning, effektflöden och frekvens. Dessa nya krav möts effektivast med nya kontroll och automationssystem och även nya styrbara kraftsystemkomponenter, vilka blir allt viktigare för ett välfungerande elkraftsystem. För att dessa kontrollsystem ska fungera krävs mer omfattande mätning och insamling mätvärden från större delar av systemet.

Detta kontext behandlar nya metoder och tekniker för styrning av elkraftsystem med stora mängder förnybar kraftproduktion. Projekten i kontexten inkluderar både traditionella elkrafttekniska frågor såväl som utmaningar inom automation och reglerteknik samt de informations och kommunikationssystem som är nödvändiga för denna automation.

In English:

For several reasons, the power system is currently developing to include large amounts of renewable and distributed generation that in part replaces the large central production units that previously formed the backbone of the system. These new distributed power sources, place new demands on the power system partly because they are not equally controllable - but also because they are not always located in the vicinity of large loads.

These changes place new demands on the power system, both at transmission and distribution level. These new demands include new limits on the stability of the system due to reduced rotating mass of generators and increased variations of voltage, power flow and frequency. These new requirements are in turn met most efficiently with new control and automation systems and new controllable power system components, which are becoming increasingly important for an efficient power systems.

This context deals with new methods and techniques for the control of power systems with large amounts of renewable power generation. The projects in the context includes both the traditional electric power issues as well as challenges in automation and control technology and information and communication systems necessary for this automation.

Project E1: Voltage Control of Renewable Energy Integrated Power System

Supervisors: Qianwen Xu, qianwenx@kth.se, Fei Liu fei7@kth.se Electric Power and Energy Systems

As the penetration of renewable energy sources (RES), such as solar photovoltaics (PV) and wind power, continues to increase in modern power systems, the control of system voltage has become a critical challenge. Traditional voltage control methods cannot handle the variability and intermittency of renewable energy. Voltage fluctuations can lead to power quality issues, equipment malfunctions, and even system instability. To address these challenges, modern power systems must implement advanced control strategies that integrate the reactive power control capabilities of inverter interfaced renewable energy sources, along with other flexible resources such as battery energy storage, electric vehicles, demand response assets.

This project will investigate the impact of high levels of renewable energy integration on voltage stability and propose control strategies to mitigate voltage variations. The study will be conducted using Matlab, and the students will develop voltage control schemes that improve voltage regulation of power system to accommodate a high level of renewable energy. The students will be provided with appropriate literature and software tools as a start.

Project E2: Frequency Control of Renewable Energy Integrated Power System

Supervisors: Qianwen Xu, qianwenx@kth.se, Xuan Jiang xuanj@kth.se Electric Power and Energy Systems

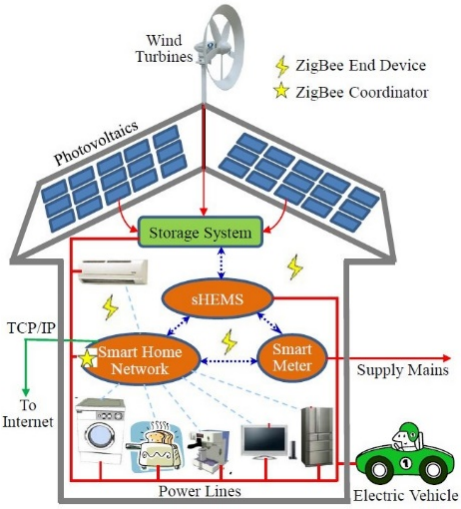
The transition to renewable energy sources (RES) such as solar photovoltaics (PV) and wind power introduces significant challenges for frequency control in power systems. Traditionally, frequency stability has been maintained through the kinetic energy stored in the rotating masses of synchronous generators. However, renewable energy sources, particularly solar

and wind power, do not inherently provide the inertia that conventional thermal and hydro generators offer, which complicates the control of frequency. With the increasing share of renewable energy, the system's overall inertia is reduced, making it more vulnerable to frequency deviations during disturbances. Without adequate control, such deviations can lead to instability, triggering protection systems, load shedding, or even blackouts.

This project aims to investigate the challenges of frequency control in a renewable energy-dominated power system, and explore possible solutions, such as using battery energy storage systems (BESS), and developing advanced control strategies for inverter interfaced RESs. The students will be provided with appropriate literature and software tools as a start.

Project E3: Development of a future residential microgrid

Supervisors: Qianwen Xu, qianwenx@kth.se, Kamil Swiderski kamilsw@kth.se Electric Power and Energy Systems



Driven by environmental concern and sustainable requirement, development of residential microgrids attracts much attention around the world, as a forward step towards future carbon-neutral society. A residential microgrid is a small power system for a house/building, which consists of a solar photovoltaic (PV) source, a battery storage and residential loads, and can operate either in isolation or in connection to the main grid. In the daylight, the solar PV source can generate electricity to supply the loads, and the extra electricity can be stored in the battery to be used in the evening, or even sold back to the main grid. Thus a residential microgrid can reduce the energy cost and reduce CO2 emission. To make it works, each component of the microgrid should be properly designed and they should be controlled in a coordinated manner to provide stable and sustainable electricity

This project will develop a residential microgrid and its control scheme to achieve stable and sustainable electricity supply. The PV converter system will be designed to maximize its power generation in the daylight; the battery converter system will be designed to be charged when there is surplus electricity, and discharged when there is insufficient electricity. A coordinated control scheme will be developed for the whole system with high reliability and stability. The microgrid system will be developed in Matlab/Simulink as a demonstration of this project. The students will be provided with appropriate literature and some basic Matlab/Simulink models as a start. The students also have chance to deploy the solution in the microgrid hardware platform if time allows.

Context F: Hydro power modelling

A fundamental property of a power system is that the generation and consumption of electric power must always be in balance. It is therefore necessary to have enough flexible resources (i.e., generation or demand that can be adjusted to help maintain the balance of the power system) available. The amount of weather dependent, continuously varying generation (for example wind or solar power) is expected to continue increase in the future, which means that the need for flexible resources will also continue to increase.

An individual hydro power plant is very flexible and can very rapidly increase or decrease the generation. However, the operation of multiple hydro power plants in the same river system will be most efficient if coordinated, as water released from an upstream reservoir will eventually reach the next reservoir in the river and if that reservoir is full then water will have to be spilled. The operation planning of a river system can be formulated as an optimisation problem, where the objective is to maximise the value of the total hydro generation in the river system, while taking into account the hydrological coupling between the hydro power plants as well as other operational limitations.

Hydro power has been one of the main sources of flexibility in the Nordic power system. However, to fulfil EU-wide goals for water environment, Sweden has a national plan for revision of the hydro power plant licences, which determine how the owners of the hydro power plants are allowed to schedule generation. The revision of the licenses will need to balance conflicting environment goals and energy goals. For example, requirements on keeping water flows through the natural riverbeds will promote biodiversity and provide ecosystem services, but will result in lower hydro power generation and may influence the flexibility of the concerned hydro power plants.

Large-scale energy system models are necessary to study possible solutions for a future carbon dioxide free energy system in Europe. In such models, it is vital to correctly model the flexibility of hydro power as hydro reservoirs are by far the largest energy storages in the system (for example, the Norwegian hydro power reservoirs can store 80 TWh). It is a large

challenge to build good hydro power models for European energy system models based on public data. Therefore, there is a need to test and verify different methods for data collection of for example inflow.

The aim of this context is to study how hydro power models can be improved and applied in practice. The operation planning of selected river systems will be studied using the open-source energy system modelling tool Spine [1]. Software for collecting data is under development in ongoing research projects and will eventually be integrated in the Spine environment.

Project F1: Updated model of River Ångermanälven

Supervisor: Mikael Amelin, amelin@kth.se, Electric Power and Energy Systems

River Ångermanälven is one of the larger hydro power river systems in Sweden. The aim of this project is to improve an existing model of the system and to add further details (improved power plant data, more detailed inflow data, additional environment restrictions) as well as to run simulations for longer time periods.

Project F2: Equivalent energy storage

Supervisor: Mikael Amelin, amelin@kth.se, Electric Power and Energy Systems

The flexibility of a power plant is generally understood as the capability of the power plant to generate electricity when it is needed by the system. However, there is no common definition of how to estimate the flexibility of a power plant. This project will set up a model of a so-called equivalent energy storage for a small test system and to compare the results to other flexibility measures such as flexibility factors and extreme load following capacity.

Project F3: Estimating inflow using meteorological data in European countries

Supervisor: Mikael Amelin, amelin@kth.se, Electric Power and Energy Systems

Inflow in hydropower systems refers to the amount of water flowing into the reservoir. In hydropower modelling, inflow sometimes is unknown and assumed by an annual average value, which in reality varies spatially and temporally. Thus, to improve the hydropower model performance, it necessary to use the real inflow rather than the average data. Real inflow can be estimated using available energy production data and meteorological datasets. The objective of this project aims to calculate the weekly inflows in European countries by scaling the annual inflow according to the weekly meteorological data from CorRES [2].

[1] https://github.com/Spine-tools

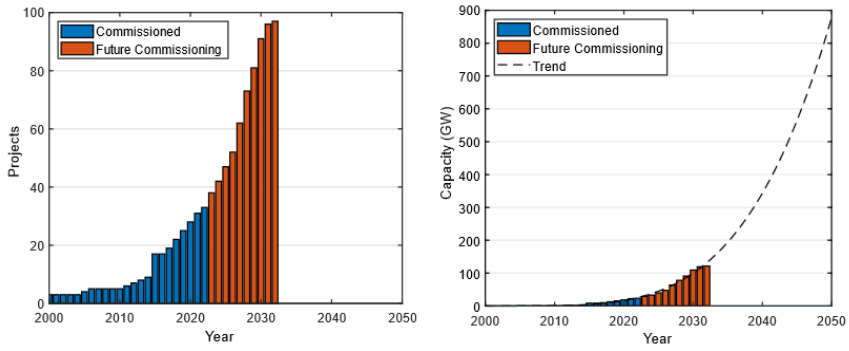
[2] https://corres.windenergy.dtu.dk/

Context G: HVDC Supergrids for Offshore Wind

In Europe, we target the massive integration of offshore wind power into our power system. End of 2022, ca. 30 GW capacity was installed. The EU goal for 2050 is 300 GW [1]. Offshore wind is important to reach our CO2 targets and energy independency. Most offshore windpower will be connected using high-voltage direct-current (HVDC) technology. Today, many point-to-point HVDC connections exist, but no HVDC grids. However, the rapid development of HVDC supergrid technology is ongoing, and the Swedish industry is a world market leader in HVDC technology.

In this context, we will learn about different aspects of a North Sea Supergrid and its underlying technology “HVDC”. The projects can be executed in English or Swedish.

Picture of an offshore HVDC station (source: PROMOTioN/TenneT)



(a) Cumulative projects by year (b) Cumulative installed capacity

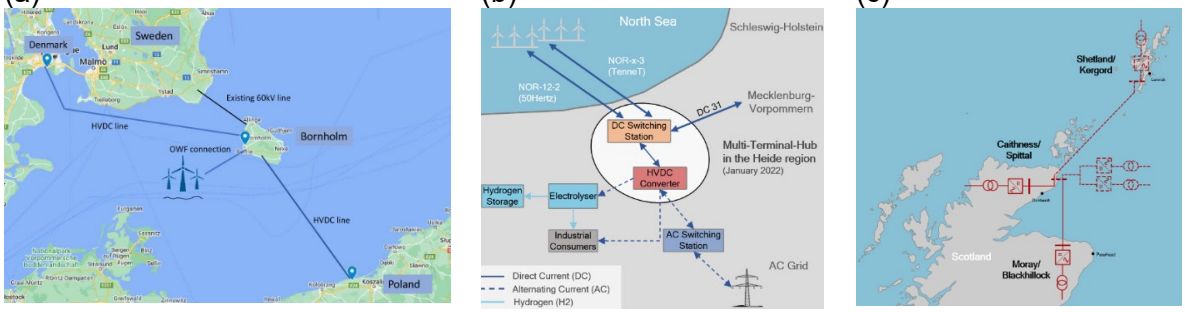
Ongoing and expected HVDC boom [2]

Project G1: Expanding point-to-point HVDC systems into HVDC supergrids

Supervisors: Ilka Jahn, ilka@kth.se (and PhD student), Electric Power and Energy Systems

Today, many point-to-point HVDC systems connect individual offshore wind farms to the onshore electricity grid. This is inflexible and inefficient if more wind energy is produced than can be consumed locally. If, instead, multiterminal HVDC systems or HVDC grids were available, power could be exchanged flexibly between several countries, making the most use of renewables. The first multiterminal HVDC systems are appearing in Europe, but the technology is expensive and new, therefore a smart design is needed. One option is a fall-back-design into point-to-point HVDC connections. In this project, we will investigate how such a fall-back design can look like.

(a) (b) (c)



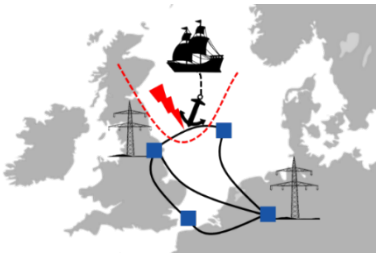
Ongoing HVDC grid developments in (a) Baltic sea, (b) Northern Germany, (c) Scotland.

In this project, the students will learn:

- About concrete ongoing European HVDC projects and how they move towards supergrids
- About commercial and practical challenges in the industry
- How to simulate HVDC technology in MATLAB/Simulink
- How to go about introducing new and expensive technology with smart back-up design options
- How to develop, expand, and investigate HVDC simulation models

Project G2: Protection of HVDC supergrids against blackout

Supervisors: Ilka Jahn, ilka@kth.se (and PhD student), Electric Power and Energy Systems



Example cable fault in an HVDC supergrid

Any electrical system can fail. In the power system, failures can originate from human error or natural disaster, for example a ship anker destroying a subsea cable. HVDC grids need to be designed to handle failures and contain possible damage to a certain grid part. A cascading

blackout affecting several surrounding countries is not an option. In this project, we will investigate ways to protect HVDC grids. This includes the detection of faults with single-ended or double-ended algorithms, and the use of direct current circuit breakers (DCCBs) for which different speed and current handling capabilities exist.

In this project, the students will learn:

- About blackouts and protection in HVDC systems (e.g., anker on cable)
- How to simulate HVDC technology in MATLAB/Simulink
- How to simulate and investigate short circuits in computer simulation
- About Direct Current Circuit Breakers (DCCBs)
- About fault detection algorithms

Project G3: Control of HVDC supergrids

Supervisors: Ilka Jahn, ilka@kth.se (and PhD student), Electric Power and Energy Systems

During normal operation, the control of HVDC supergrids determines where power is flowing. Different control methods have advantages and disadvantages, for example, need for communication, adaptation to grid-restructuring, reaction to events. In this project, we will compare different HVDC grid controllers (with and without communication, voltage vs. power vs. droop) and find the most suitable one.

Future HVDC supergrid in the North Sea supplying surrounding countries with offshore wind energy.

In this project, the students will learn:

- About controlling an HVDC supergrids for stable connection to the surrounding countries
- How to simulate HVDC systems and grids MATLAB/Simulink
- How to simulate and compare different control methods
- About why and how electricity flows between countries

[1] Ostend Declaration of Energy Ministers On The North Seas as Europe's Green Power Plant Apr. 24, 2023. Available online: https://www.government.nl/documents/diplomatic-statements/2023/04/24/ostend-declaration-on-the-north-sea-aseuropes-green-power-plant

[2] J. Cabañas Ramos, M. Moritz, N. Klötzl, C. Nieuwenhout, W. Leon Garcia, I. Jahn, and A. Monti, "Getting ready for multi-vendor and multi-terminal HVDC technology", *MDPI energies*, vol. 17, no.10, pp. 2388-2416, May 2024. https://www.mdpi.com/1996-1073/17/10/2388

Context H: Predicting the Future Sustainable Power System

To help mitigate climate change, it will be necessary to significantly reduce CO_2 emissions. These efforts will in turn have a major influence on power systems and electricity markets, both because power generation is in itself a large source of CO_2 emissions, but also because electricity is necessary to facilitate eliminations of CO_2 emissions in other parts of society. In short, there will be an increased demand for CO_2-free electricity generation in the future. Two main sources of such electricity is of course wind and solar power, which is being introduced in a wide scale across most electric power systems on the planet.

One important characteristic of wind and solar power is that it is non-dispatchable, i.e. the output cannot be controlled but depends on weather. As can be observed on the electricity market recently, the volatility of electricity prices has increased due to the varying inflow of power from these sources[1]. Similarly, the non-disptachable nature of the renewable sources are creating futheer challenges for stable operation of the power system in real-time. To improve functioning of the electricity markets and faciliatate cost-efficient and reliable planning and operation of electric power systems, there is a need for better prediction of the impact of renewable sources on the power grid. This inludes several aspects of this problem including forecasting electricity prices as well as renewable generation but also load, which is also trending towards increased volatility due to new types of consumers e.g. electric vehicles, electrolysers and battery storage systems.

The aim of this context is to explore data science based methods for improved forecasting of electricity price (F1), Renewable generation (F2) and Load (F3)

[1] https://www.di.se/nyheter/svenska-kraftnat-varnar-for-mer-volatila-elpriser-och-okad-risk-for-akut-effektbrist/

Project H1: Forecasting of electricity prices in systems with renewable generation

Supervisor: Mohammad Reza Hesamzadeh, mrhesa@kth.se,
Electric Power and Energy Systems

In this project we focus on estimating and forecasting electricity prices in the wholesale electricity markets. We mainly focus on the electricity spot markets which are day-ahead, intra-day, and real-time markets. Due to competitive forces in the today's electricity markets, electricity-price estimation and forecasting has become a fundamental tool which provides input to the decision-making mechanisms.

The electricity as a tradable commodity is notoriously volatile. This is partly because electricity is not economically storable and what is produced at a moment must be consumed at that moment. Also, electricity demand depends on hard-to-predict parameters such as weather or the intensity of everyday activities. These characteristics of electricity make the electricity prices to have a very complex dynamic. It often depends on several driving factors.

Besides, the current push from governments in many jurisdictions to increase the share of renewable CO2 free generating technology (mainly wind and solar generation) has added extra level of complexity to electricity price estimation and forecasting models. These renewable generation sources are intermittent, and they make the electricity spot prices more volatile than before.

At this background, the area of price estimation and forecasting has been quite active over the last few years. Various estimation-and-forecasting techniques are suggested in the academic literature with various degrees of success. Also, competition events such as Global Energy Forecasting Competition (GEFcom) are organized to attract the innovative forecasting techniques.

Broadly speaking, the estimation-and-forecasting techniques can be categorized as regression models and intelligent models. Linear and nonlinear regression are examples of regression models and the Neural network models are examples of intelligent models. The estimation and forecasting models can be static (without considering time) and dynamic (with time consideration). References [1] and [2] below provide very good information about different estimation-and-farecasting techniques.

At this background, this project has the following aims:

1) A review of different recent techniques developed and suggested in the literature for electricity spot-price estimation and forecasting; In this review, the strengths and weaknesses of these reviewed techniques are clarified.
2) To select three promising forecasting techniques and justify why these technique are suitable for forecasting; These three techniques can be selected between the regression and intelligent techniques.
3) To apply the selected three forecasting techniques to estimate-and-forecast the spot prices in the Nordic electricity market. You can select two markets out of three following markets: day-ahead market, intra-day market, and real-time market. For your application, you may use the following software packages: Julia/Python, R, Eviews or Matlab.
4) To interpret and explain the estimation-and-forecasting results that you have obtained for your selected spot markets and your forecasting technique.

References:
[1] https://en.wikipedia.org/wiki/Electricity_price_forecasting
[2] Bunn, Derek W. "Modelling prices in competitive electricity markets." (2004).

Project H2: Forecasting wind and solar generation in sustainable power systems

Supervisors: Lars Nordström, larsno@kth.se, and Xavier Weiss xavierw@kth.se
Electric Power and Energy Systems

Wind generation in Sweden has gone through an enormous expansion the last 5-10 years and is expected to see even larger expansion with the growth of off-shore wind power [1]. Presently (2022) the total wind energy production amounted to 33TWh, approximately 20% of the total Swedish electric energy generation. Similarly, Solar power is seeing a similar expansion, albeit from lower numbers, both in terms of PV-farms in the MW scale to household level PV on roof-tops. With the size and scale of PV being smaller, and more distributed in the grid, the observability of PV is lower than that of wind generation but can during situations of low load, e.g. a warm day in July, still amount to a large proportion of the total generation.

Given the variability in in-feed from renewable sources both in time and space, there is a need to forecast the production so that planning of the operation of the power grid can be facilitated. As an example, upcoming changes in production from wind may necessitate activation of reserves and systems services. Similarly, the location of generation in the grid may cause congestion if the production is concentrated to specific areas far from load-centers. Overall, the need to predict the production from renewable generation both in space (price area) and time (hours and days) is growing.

At this background, this project has the following aims:

(1) A review of different recent techniques developed and suggested in the literature for renewable generation (wind, solar or both) estimation and forecasting; In this review, the strengths and weaknesses of these reviewed techniques should be clarified. https://transparency.entsoe.eu https://transparency.entsoe.eu
(2) Develop one forecasting application for renewable generation based on suitable approach identified above, using data from the ENTSO-E Transparency portal[1] applied to one or several price areas in the Nordic power system. For your application, you are encouraged to use: Python or Matlab.
(3) To apply the developed forecasting technique to estimate-and-forecast the renewable generation. The forecasts shall be benchmarked with the forecasts available on the ENTSO-E transparency platform.
(4) To interpret and explain the estimation and forecasting results that you have obtained

References:

[1] https://www.energimyndigheten.se/statistik/den-officiella-statistiken/statistikprodukter/vindkraftsstatistik/
[2] https://transparency.entsoe.eu

Project H3: Estimation and forecasting of power system load profiles

Supervisors: Lars Nordström, larsno@kth.se, and Arvid Rolander arvidro@kth.se
Electric Power and Energy Systems

The electric load has in Sweden for a long period remained relatively stable. The share of residential load remaining constant with some changes in industrial and commercial load as society has moved from heavy industry in 1980s to a service based economy centered on larger cities[1]. Present forecasts [2] indicate a doubling of the electricity load, mainly due to electrification of heavy industries in mining and steel manufacturing, but other sectors such as transportation are also contributing to this growth.

Similar to the development within renewables (see project 2) the changes in load happen both in time and space. E.g. data centers are built outside municipalities or steel mills are redesigned to use electricity and Hydrogen instead of fossil fuels. Given this, there is a need to forecast the load so that planning of the operation of the power grid can be facilitated. As an example, the location of loads in the grid may cause congestion if the production is concentrated to specific areas far from these load-centers. Overall, the need to predict the loads both in space (price area) and time (hours and days) is growing.

At this background, this project has the following aims:

(1) A review of different recent techniques developed and suggested in the literature for electricity load both residential, commercial and industrial; In this review, the strengths and weaknesses of these reviewed techniques should be clarified.
(2) Develop one forecasting application based on suitable approach identified above, using data from the ENTSO-E Transparency portal[1] applied to one or several price areas in the Nordic power system. For your application, you are encouraged to use: Python or Matlab.
(3) To apply the developed forecasting technique to estimate-and-forecast the total electricity load. The forecasts shall be benchmarked with the forecasts available on the ENTSO-E transparency platform.
(4) To interpret and explain the estimation and forecasting results that you have obtained

References:

[1] https://www.energimyndigheten.se/statistik/den-officiella-statistiken/statistikprodukter/manatlig-elstatistik-och-byten-av-elleverantor/
[2] https://www.svk.se/siteassets/om-oss/rapporter/2021/langsiktig-marknadsanalys-2021.pdf
[3] https://transparency.entsoe.eu

Context I: Design and testing of novel microwave/antenna technologies

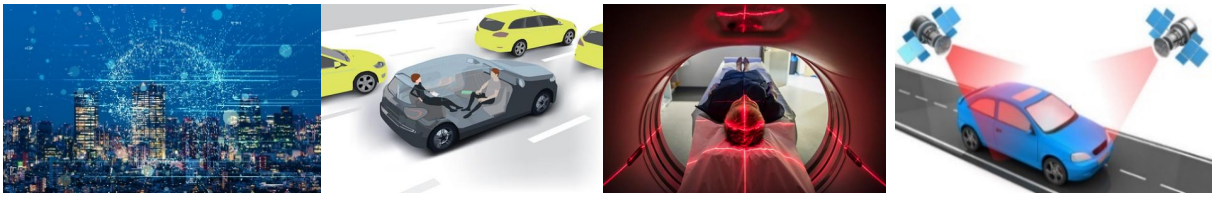
Today, microwave technology is employed in many of our technological devices, and they fulfil an essential function in communication systems, intelligent cities, surveillance, medical diagnosis and space observation.

Innovative microwave designs are required daily in the products of technology-driven companies. These companies require efficient and multi-functional antennas and microwave devices that can enable:

- High data rate communications for present 5G and future 6G networks.
- Efficient satellite communications with the newly deployed low-Earth-orbit satellites.
- High resolution radars to detect people, vehicles and objects in smart cities.
- Non-invasive imaging of patients for early detection of health issues.
- Highly precise airport scanners that maximize the location of concealed objects.
- Precise detection of stars and planets in the outer space.

Within the projects of this Context, you will be able to acquire the fundamental knowledge for designing advanced microwave devices and antennas. You will learn how to use commercial software of simulation, which is commonly employed in the industry. Finally, you will manufacture and measure a proof-of-concept. After the project, you will be able to reproduce the usual steps followed in a microwave or antenna design process.

Examples of challenges that require innovative microwave/antenna technologies:



***Picture 1**. Artistic rendition of future communications.*
***Picture 2.** Autonomous car inter-connected with wireless systems.*
***Picture 3**. Patient inside a high-resolution medical scanner.*
***Picture 4**. Car communicating* with low-Earth-orbit *satellites.*

Project I1: Design of a feeding network for satellite communications using Electromagnetic Bandgap (EBG) periodic structures

Supervisors: Oscar Quevedo-Teruel, oscarqt@kth.se, Jesus Maria Jimenez Suarez jmjs@kth.se

Division of Electromagnetic Engineering and Fusion Science

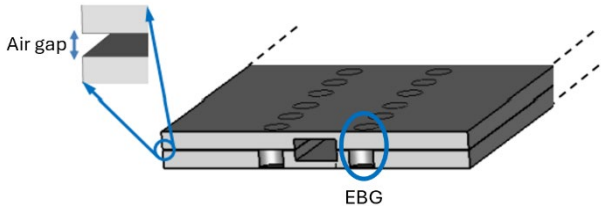
With the development of modern society, there is a high demand for the improvement of high-performance satellite communications. Thus, robust and efficient antenna systems in the satellite payloads are necessary, including the antenna and the feeding network.
Feeding networks are guiding structures intended for power distribution in a system. They are usually manufactured in two separate metallic plates that are joint together using screws. This process is very sensitive at high frequencies resulting in misalignments and a small air gap between the two plates, producing wave leakage, decreasing the transmission and the system performance.

In recent years, periodic structures have been commonly used to design a wide range of microwave devices, such as lenses, leaky-wave antennas and flanges with low leakage. A periodic structure is said to possess a higher symmetry if it is invariant after a transition and additional geometrical operation. A suitable higher symmetry capable of increasing the stopband in periodic structures is glide symmetry, which makes it desirable for the design of Electromagnetic bandgap (EBG) structures.

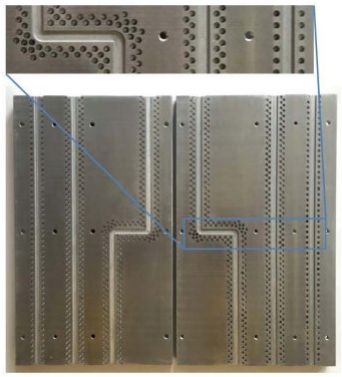
This project aims to study different EBG periodic structures to cut the propagation outside the feeding network waveguide, reducing the leakage due to the manufacturing process. The work will focus on simulate, design and measure a feeding network.

As a student, you will learn:

- The electromagnetic operation of higher-symmetric structures
- How to simulate periodic structures using commercial software.
- How to design and simulate feeding networks in commercial software.
- How to perform measurements of feeding networks.



Holey EBG periodic structure in a feeding network



Feeding network prototype

Project I2: Design of a compact Risley prism for low earth orbit satellite communications

Supervisors: Oscar Quevedo-Teruel, oscarqt@kth.se, Freysteinn Viðar Viðarsson fvvi@kth.se

Division of Electromagnetic Engineering and Fusion Science

On Earth, vast geographical areas lack wireless internet access, particularly in developing countries or regions affected by environmental disasters or conflict. Providing reliable internet connectivity to people in these areas is crucial. When terrestrial infrastructure is unavailable or impractical, satellites can offer a viable solution.

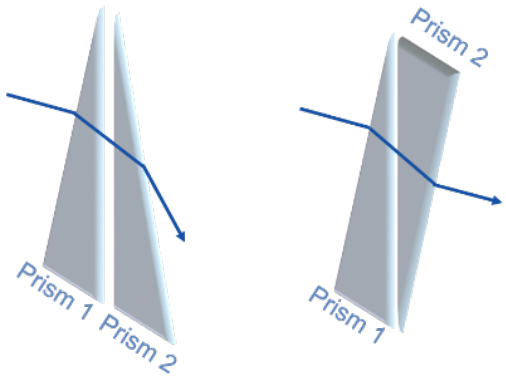
To enable communication with low Earth orbit satellites, antennas with high gain and effective beam steering capabilities are required, while maintaining a low-profile design. This presents a significant design challenge, so new antenna solutions are needed. One method to achieve beam steering is by using a Risley prism.

A Risley prism consists of a pair of dielectric wedges, and by adjusting the orientation of these wedges, different scanning angles can be achieved. However, for large antenna systems, the dielectric wedges required for sufficient beam steering can become too bulky. Therefore, to make the Risley prism concept viable for satellite communications, a more compact design for the prism is required.

In this project, you will design a novel Risley prism concept that is suitable for Earth terminal antennas used in satellite communications.

As a student, you will learn:

- The operation principle of a Risley prism.
- How to simulate antenna structures using commercial software.
- To apply 3D printing techniques for antenna manufacturing.
- How to perform radiation pattern measurements in an anechoic chamber.



Operation of a Risley prism

Satcom on the Move (SOTM) use cases

Project I3: Study of artificial materials for lens antenna design in aerospace applications

Supervisors: Oscar Quevedo-Teruel, oscarqt@kth.se, Moises Tercero, moisestn@kth.se

Division of Electromagnetic Engineering and Fusion Science

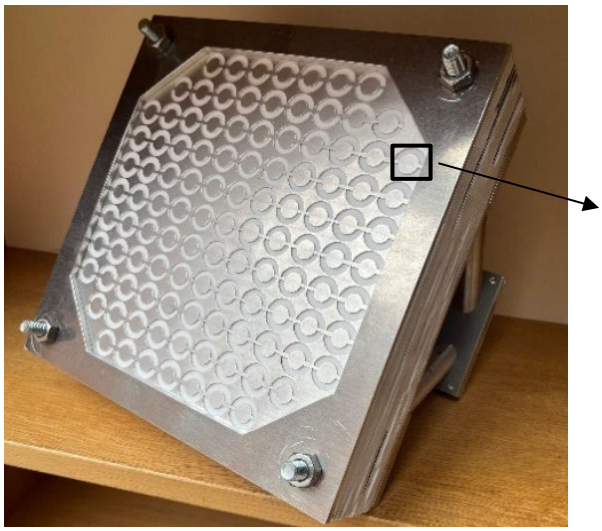
Nowadays, the industry of satellite communications is pushing towards demanding requirements. Lens antennas are a suitable solution because of their collimating capabilities, which allow them to achieve high directivity. Nonetheless, conventional dielectric lens antennas are not optimal, as they can be heavy, bulky and lossy. In recent years, a common approach to design lens antennas and work around these drawbacks is the use of metamaterials. Metamaterials are a structured combination of dielectrics and metals that can achieve unusual electromagnetic properties that cannot be found in nature.

The metamaterials you will study can achieve high permittivity values and therefore attain a high refractive index, which will make for thin and light lenses. You will explore different geometries, extract the value of their properties with an in-house code and run through optimization procedures to attain a suitable performance for the final lens design.

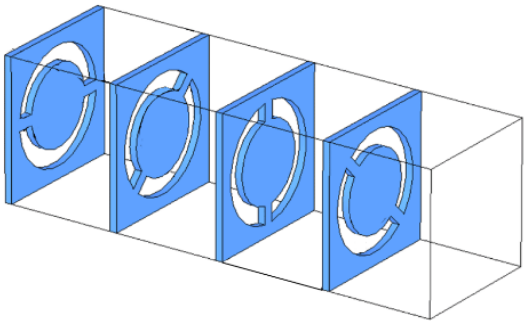
The main goal of this project is to create a library of unit cells and contribute to the development of a flat, light, low-profile lens antenna for satellite communication applications in the ground segment.

As a student, you will learn:

- How lens antennas work and how they are implemented for satellite communications.
- Fundamentals of periodic structures and metamaterials.
- How to simulate periodic structures with commercial software.
- General design guidelines of periodic structures having high permittivity.



Flat lens made with a metamaterial composed of complementary split-ring resonators



Depiction of a stack of unit cells in a simulation setup

Project I4: Study of electromagnetic transparent structures for the design of future 6G multi-band antenna

Supervisors: Oscar Quevedo-Teruel, oscarqt@kth.se, Johan Lundgren, jlu8@kth.se, Freysteinn Viðarsson, fvvi@kth.se

Division of Electromagnetic Engineering and Fusion Science

Multi-band antennas play a key role in modern communication systems since they combine the benefits of low path loss at low-band frequencies with larger bandwidth at high-band frequencies. However, placing antennas that operate at different frequencies close to each other is challenging since they will interfere with each other.

One method for mitigating the interference is to make the antennas electromagnetic transparent to out-of-band signals. This can be achieved by splitting the structure into small sections that are electrically connected at the desired frequencies and disconnected for unwanted frequencies. Different methods for designing such structures have been proposed, such as connecting the sections through LC-filters or integrating quarter-wave chokes that selectively stop out-of-band signals.

This project aims to compare different methods and possibly propose new ones for designing electromagnetic transparent structures. The work will focus on simulation, experimental testing, and comparison between simulation and measurements.

In this project, the student will learn:

- About some of the fundamental challenges of having multiple antennas operating at different frequency bands in close proximity to each other.
- How to use commercial simulation software to analyze different aspects of electromagnetic transparent structures.
- About different manufacturing techniques used in the antenna industry.
- How to perform antenna measurements in the antenna laboratory.

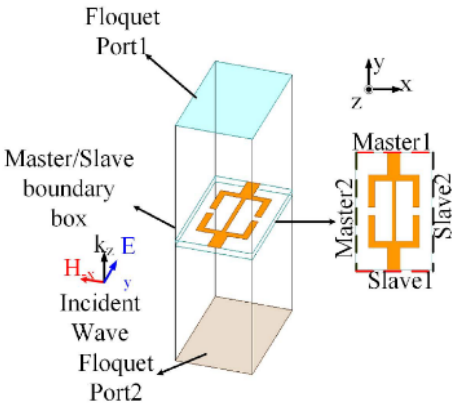
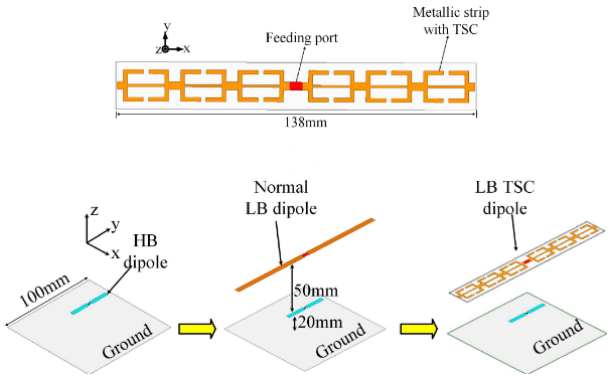


Illustration of a unit-cell for simulation in a periodic environment.



Example of a low-band antenna realized by unit-cells for interference simulation.

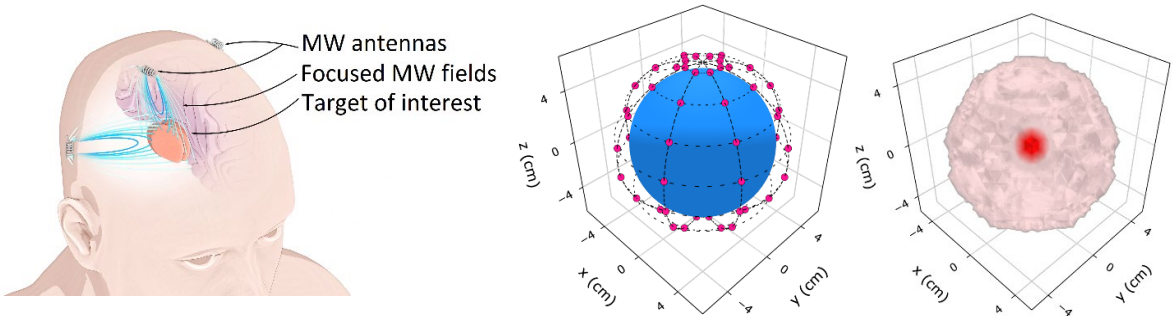
A prototype of a PCB filter.

Project I5: Microwave focusing on a human brain model for deep brain stimulation

Supervisors: Mariana Dalarsson, mardal@kth.se, Mika Söderström, mikaso@kth.se
Division for Electromagnetic Engineering and Fusion Science

Stimulation of biological tissues using electromagnetic (EM) fields is of high interest within the biomedical field. One important application is neuromodulation, used for deep brain stimulation to treat neurological disorders like Parkinson's disease. The currently recognized treatments use intracranial electrodes with an extension wire and pulse generator to directly create intervening electric fields near neural tissues. However, this invasive approach carries risks, including surgical complications and infections. As a result, non-invasive treatments are being proposed with the prospect of achieving similar therapeutic benefits without the associated risks.

The most studied alternative methods use magnetic coils that induce low frequency fields. Low-frequency fields can pass through the skull but cannot achieve the required focus to target a specific area of the brain. Therefore, high frequency fields in the microwave (MW) region have been suggested to be used because of the high degree of spatial focusing. Achieving highly focused electromagnetic fields inside the human body is a complex task. Recent studies utilizing an array antenna system have shown the potential to generate such fields for deep brain stimulation.



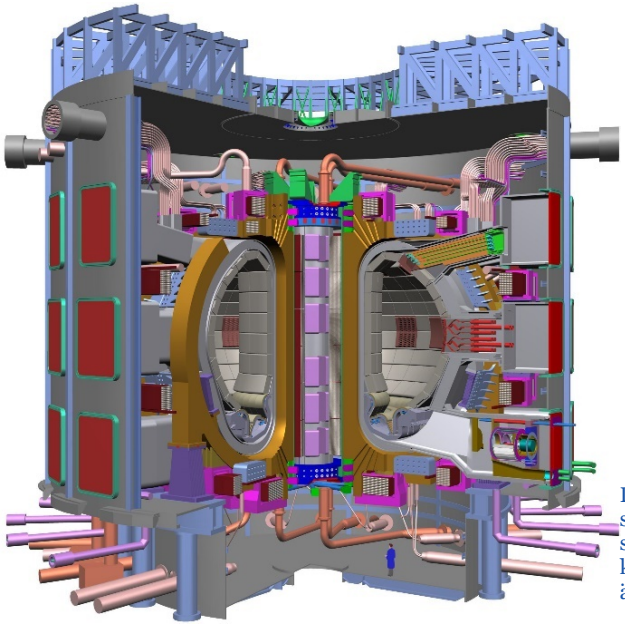
Figures taken from: Harid et al. (2023). A method for non-destructive microwave focusing for deep brain and tissue stimulation. (PLoS ONE, 18(2): e0278765).

The objective of this student project is to obtain an understanding of how EM fields interact with biological tissues in the context of deep brain stimulation, as well as to develop and perform numerical simulations of array antennas in geometries that mimic brain structures. The findings and insights gained from this project will be of significance for further research within the emerging field of deep brain stimulation using MW fields.

In this project, the students will learn:

- About deep brain stimulation and the mechanisms behind neuromodulation
- How to model the EM properties of relevant biological tissues
- How to evaluate EM fields created by antenna elements in an array to achieve some desired radiation pattern
- How to develop relevant numerical simulation models using a commercial software (COMSOL)
- If time allows, implement gold nanoparticles (GNPs) in the brain tissue to evaluate their effect on focusing of the fields

Context J: Fusion, solens energikälla på jorden



Den 73m höga fusionsreaktorn ITER som nu byggs i södra Frankrike och som ska stå klar 2020. ITER väntas kunna producera 10 gånger mer energi än den förbrukar.

Introduktion

Fusionsforskningen arbetar för att kunna konstruera ett kraftverk som genererar energi från kärnreaktioner mellan olika väteisotoper. Dessa fusionsreaktioner avger ungefär en miljon gånger mer energi än kemiska reaktioner och är den process som värmer solen. Om fusionskraften kan bemästras på jorden har vi en i princip i outtömlig energikälla utan växthuseffekter och med relativt lite radioaktiva restprodukter. Dessa reaktioner sker dagligen i fusionsexperiment världen över, men man har aldrig lyckats producera mer än 65% av den inmatade effekten. För att producera nettoeffekt krävs större experiment och just nu byggs en experimentanläggning, ITER, i södra Frankrike som väntas producera tio gånger högre effekt än vad man stoppar in. ITER är det andra mest påkostade vetenskapliga projektet i mänsklighetens historia, efter den internationella rymdstationen (ISS). Om fusion fungerar, som många forskare tror, kan det ha stor betydelse för vår framtida energiförsörjning.

Varför behövs så stora experiment? För att fusionsreaktionen ska komma i gång måste man uppnå en temperatur på över 200 miljoner grader, samtidigt som man behöver en tillräckligt hög täthet (~10^{20} m^{-3}), vilket är svårt att åstadkomma i mindre maskiner. Så hur kan man bygga en reaktor som innesluter en 200 miljoner grader varm gas (eller plasma som gasen kallas vid dessa temperaturer)? Det finns inga material som klarar att värmas till över 3 000 grader utan att smälta, så i en fusionsreaktor måste det varma plasmat hållas borta från väggarna. Detta sker med hjälp av magnetfält. Men även med starka magnetfält "läcker" värmen ut, och väggarna i en fusionsreaktor utsätts för stora påfrestningar. Dessutom måste plasmat ständigt värmas upp för att kompensera för värmeförluster till väggen. Denna uppvärmning kommer dels från fusionsreaktionerna, dels från injektion av radiovågor och av högenergetiska partiklar, samt resistiv uppvärmning.

Projekten i den här kontexten ingår både experimentella och teoretiska projekt. Här får man möta forskning vid frontlinjen och man får en inblick i möjligheterna och utmaningarna kring fusionskraften. Dessutom ska vi besöka fusionsexperimentet Extrap-T2R på KTH, samt diskutera etiska och politiska frågor kring vår framtida elförsörjning.

Project J1: Numerical analysis of fusion reactor emergency shutdown experiments

Supervisors: Mathias Hoppe, mhop@kth.se, EMF, Lorenzo Votta, votta@kth.se, EMF

Future fusion reactors of the tokamak type – the currently most promising type of fusion device – faces a major challenge. If the difficult-to-control plasma which makes up the fuel of the fusion reactor suddenly experiences an instability and cools in what is known as a *disruption*, the electrons of the plasma can be accelerated to relativistic energies and become so-called *runaway electrons* (REs), which risk causing severe damage to the reactor wall and other plasma-facing components. Since runaway electrons could potentially damage a tokamak reactor beyond repair, techniques for mitigating the damage done is one of the most highly prioritized areas of research for next-generation fusion devices such as ITER and SPARC.

One of the techniques utilized to mitigate the damage done in disruptions is called *Massive Gas Injection* (MGI), whereby the plasma discharge is deliberately stopped via injection of noble gases into the plasma in a kind of emergency shutdown. Experiments for this type of emergency shutdown have been conducted at many facilities, and in particular on one of the world's largest fusion devices, JET. Those experiments have revealed that the acceleration of REs depends non-trivially on the amount of injected gas and the strength of the tokamak magnetic field.

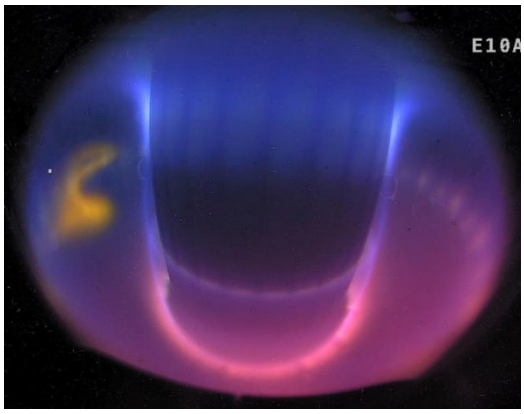


Figure 1: *Photo of a plasma in the TCV tokamak, where the runaway electrons can be seen in orange.*

The goal of this project will be to run simulations with the state-of-the-art disruption simulation tool DREAM to try to explain experimental measurements and better understand how runaway electrons are generated in tokamak disruptions. The project aims to give you a better understanding of the physics involved in operating a fusion plasma while allowing you to contribute to the forefront of the fusion research.

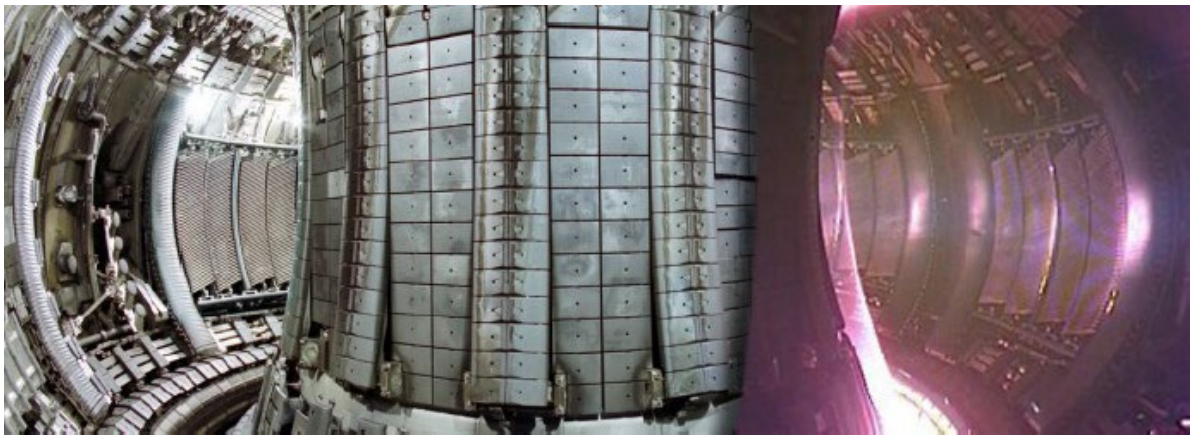
The project will be executed in the following steps:

1. Survey the relevant literature about runaway electrons and tokamak disruptions.
2. Obtain JET experimental data, analyse it and prepare a simulation strategy.
3. Write a Python script for running simulations with the DREAM code. Execute a range of simulations to test the hypotheses formulated in 2.
4. Write a report and present the method and results of the project.

Project J2: Improved calibration of detectors for material analysis

Supervisor: Per Petersson, ppeter@kth.se, EMF

Despite the magnetic confinement used in tokamaks the walls facing the plasma get eroded and have material deposited on top of it. These deposits contain most elements present in the machine and is sometimes referred to as “tokamakium”. It can have very different content and properties depending on where and how it is formed. In future reactor devices, such as the International Thermonuclear Experimental Reactor (ITER), the interaction of the plasma with surrounding materials in the vacuum vessel constitutes one of the main remaining engineering problems.



JET tokamak in Culham, England - with and without plasma that interacts with the wall.

An important tool that we frequently use for looking at tokamakium is Time of Flight Elastic Recoil Detection Analysis (ToF-ERDA) that gives information about all elements that are present in the surface of a material. ToF-ERDA is a type ion-beam analysis that uses MeV ions from an accelerator that interacts with the sample and knocks out some atoms from the target.

The main goal in this project will be to improve of the calibration method of the spectrums that are recorded. With the improved calibration we hope to increase the reliability by with we can determine the identity of unexpected elements and use clustering methods for determining depth profiles and separate similar elements.
For testing the results both existing data as well as data produced in this project can be used.

Introductory Part
Visit to the Tandem Accelerator Laboratory of Uppsala University and introduction to accelerator-based material analysis techniques.

Main Tasks
- Importing data from existing tools.
- Setting up several models for calibration of the data, both existing and new.
- Analysis of experimental data using the developed calibrations.
- Comparison of different methods for advances and weaknesses.
- Writing report

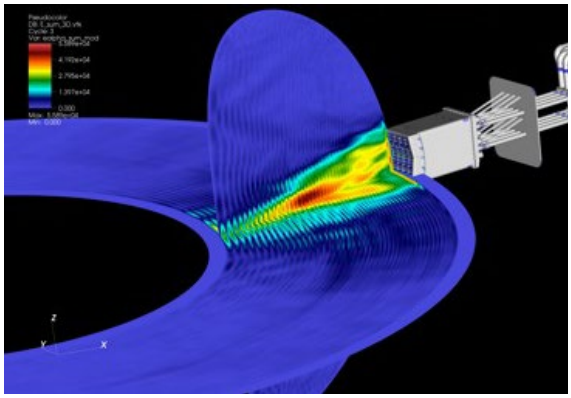
The main part of the work will consist of data handling using e.g. python and analysis of the results but there will also some laboratory visits and work. The project is part of larger program of experimental investigation and production of material and can be adjusted in cooperation with the student.

Projekt J3: Modellering av radiovågsuppvärmning i SPARC

Supervisor: Thomas Jonsson, johnso@kth.se, EMF; Lukas Bähner, bahner@kth.se, EMF

Fusionsreaktioner kräver mycket höga temperaturer. För att producera stora mängder energi i ett fusionskraftverk krävs cirka 200 miljoner grader, vilket vanligtvis kräver mycket stora och därmed dyra anläggningar. Men, med hjälp av ny supraledande teknologi hoppas man nu kunna bygga mindre och därmed mer ekonomiska reaktorer. I USA byggs nu fusionsexperimentet SPARC som förväntas visa på denna potential. För att nå de relevanta temperaturerna kommer SPARC använda uppvärmning med hjälp av radiovågor, och i denna studie kommer vi att undersöka hur dessa vågor kan accelerera snabba joner, som i sin tur överför sin energi till bränslet i form av värme.

SPARC skiljer sig mot tidigare experiment genom att man använder starkare magnetfält, vilket påverkar flera egenskaper hos plasmat (den varma joniserade gas i vilken reaktionerna ska ske). Framför allt kan man skapa plasma med högre täthet än vad som använts i tidigare fusionsexperiment. Detta påverkar i sin tur de radiovågor som används för att värma plasmat, samt hur dessa vågor accelererar snabba joner. Huvudmålet med det här projektet är att undersöka hur accelerationen av snabba joner i SPARC skiljer sig i jämförelse med existerande experiment, framför allt i jämförelse mot experimentet JET i England.



Elektrisk fältstyrka från en numerisk simulering av radiovågsuppvärmning i ett fusionsplasma.

För att studera hur snabba joner accelereras måste man först lösa en vågekvation och därefter lösa så kallade kinetiska ekvationer som beskriver accelerationen av jonerna och hur de kolliderar med elektroner och andra joner. På KTH har vi utvecklat både en vågkod, FEMIC, och en kinetisk kod, Foppler, som ska användas i detta arbete.

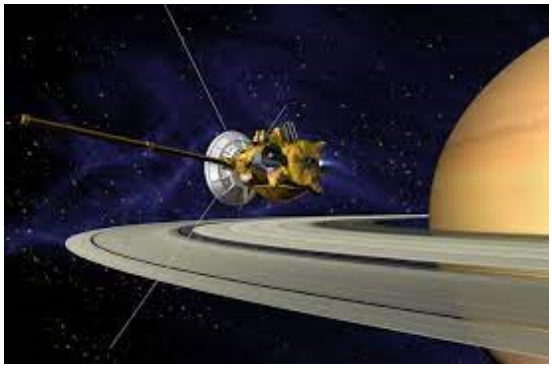
I detta projekt kommer man lära sig mycket fysik. Man kommer få prova på att göra ett forskningsprojekt och dessutom göra att viktigt bidrag till forskningen om radiovågor i SPARC! I projektet kommer vi att arbeta med både COMSOL Multiphysics och MATLAB.

Målen med detta projekt är:

1. Läsa relevant litteratur om fusionsplasmafysik och radiovågsuppvärmning.
2. Lära sig den grundläggande fysiken som finns beskriven i FEMIC och Foppler, samt att lära sig köra koderna och analysera resultaten.
3. Identifiera mått som beskriver de snabba jonerna. Dessa mått ska användas för att jämföra resultaten från SPARC och JET.
4. Ta fram parametrar som är representativa för SPARC och JET. Skapa inputfiler för simuleringar med FEMIC och Foppler.
5. Göra en kvalitativ och kvantitativ analys av simuleringsresultaten som besvarar frågorna;
    a. Hur skiljer sig fördelningarna av snabba joner mellan SPARC och JET?
    b. Hur påverkas uppvärmningen av joner och elektroner av dessa skillnader?
6. Skriva en rapport och hålla en presentation.

Context K: Solar Wind and Planetary Environments

Context responsible: Lorenz Roth (lorenzr@kth.se)



INTRODUCTION

Space Physics encompasses the physics of the open space in our solar system, mainly the environments of the Earth, other planets, and the Sun. The neutral gas and plasma (charged gas) environments of the Sun, the planets (including Earth's magnetosphere) and smaller bodies like moons and asteroids are studied with help of space probes that are in high-altitude orbit around the Earth or visit other planets. Observations are also made by space-based telescopes Hubble and the James Webb observatory. The space plasma physics research group SPP at KTH is involved in various projects that utilize direct in-situ measurement by space probes from both, NASA and ESA space missions as well as the observatories mentions. In this context, students have the possibility to participate in real research projects within observational space physics.

The first project of this context is about Mercury the planet closest to the Sun. The focus is on the bow shock region created by the interaction between the solar wind and Mercury's small magnetosphere. It uses data from the NASA MESSENGER spacecraft mission.

In projects 2 and 3, the fascinating behavior in turbulent flows is studies in the solar wind (a stream of charged particles continuously emitted by our sun). Turbulence can be studied using measurements in space of electromagnetic fields like used from the NASA and ESA spacecraft *Parker Solar Probe* and *Solar Orbiter*.

Projects 4 and 5 use observations from the most famous space telescopes: the NASA/ESA Hubble Space Telescope and the new NASA James Webb Space Telescope. With data from these telescopes the outermost part of the Earth atmosphere and the environments of icy moons of Saturn will be studied.

Project K1: Ultralow frequency electromagnetic waves at and behind the Saturn bow shock

Supervisor: Tomas Karlsson, tomask@kth.se, Space and Plasma Physics

The sun continuously emits a not only light, but also a plasma, containing electrons and protons. This solar wind is highly supersonic, and interacts strongly with planets in the solar system, and their magnetic fields. In this interaction, the solar wind is braked down and forms a shock, similar to that in front of a supersonic airplane. Mercury the innermost planet in the solar system has such a bow shock. During some circumstances strong ultra-low frequency (ULF) electromagnetic waves are formed in front of the bow shock. Figure 2 shows such waves in front of Earth's bow shock. For Mercury this type of ULF waves have been detected, but many of their properties are unknown.

You will use magnetic field measurements from the MESSENGER spacecraft (https://science.nasa.gov/mission/messenger/), which orbited Mercury for over four years, to identify such ULF waves.

In this project we are primarily interested in answering the following question: can these ULF waves cross the bow shock and also be observed behind it?

In this project you will acquire knowledge about the solar wind and how it interacts with planets. The data analysis will take place in Matlab, partially by using existing programs. The data is readily available from KTH or directly from an international repository (The Planetary Data System). The results will be very useful for future scientific investigations by researchers at KTH and elsewhere in the world, in particular in light of the upcoming BepiColombo mission to Mercury (https://www.esa.int/Science_Exploration/Space_Science/BepiColombo).

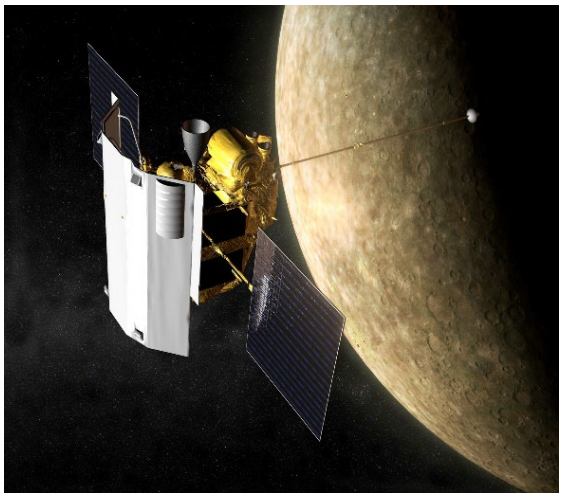


Figure 1. The MESSENGER spacecraft in front of Saturns's bow shock (Image: NASA).

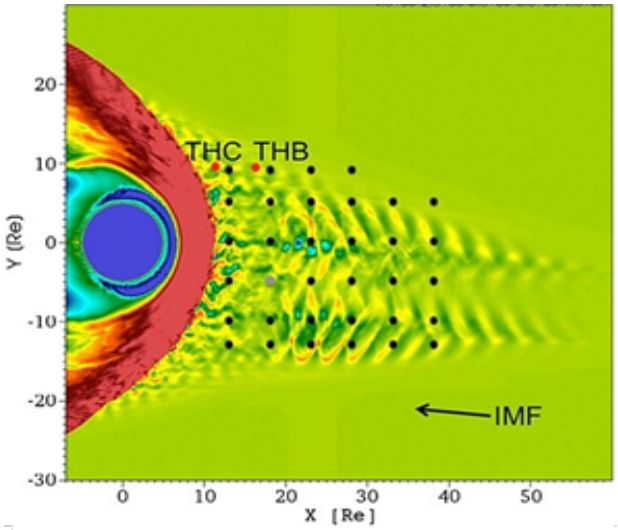


Figure 2. Simulation of ULF waves in front of Earth's bow shock [Turc, 2020]. Also here Earth is at the origin of the plot.

Project K2: Radial evolution of solar wind turbulence using multi-spacecraft alignments in the inner heliosphere

Supervisor: Luca Sorriso-Valvo, lucsv@kth.se, Space and Plasma Physics

The inner heliosphere is currently sampled by several spacecraft, whose orbits occasionally result in the alignment of two or more of them along the radial direction from the Sun. Such configurations provide samples of expanding solar wind at different distances from the Sun, enabling us to evaluate the radial evolution of various properties. For this project, the student will use measurements collected during one or more radial alignments of spacecraft in the inner heliosphere, such as Solar Orbiter, Parker Solar Probe, BepiColombo or missions near the Earth (Wind). The accurate determination of the solar source region will be used to convalidate the effective radial alignment.

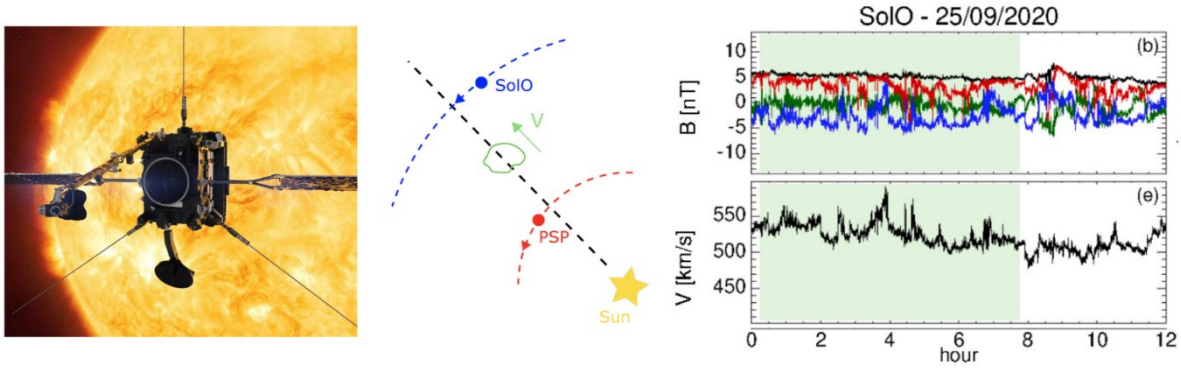


Figure 1. Left: representation of Solar Orbiter facing the Sun. Center: schematics of radial alignment between Solar Orbiter and Parker Solar Probe measuring the same wind parcel. Right: velocity (bottom) and magnetic field (top) by Solar Orbiter.

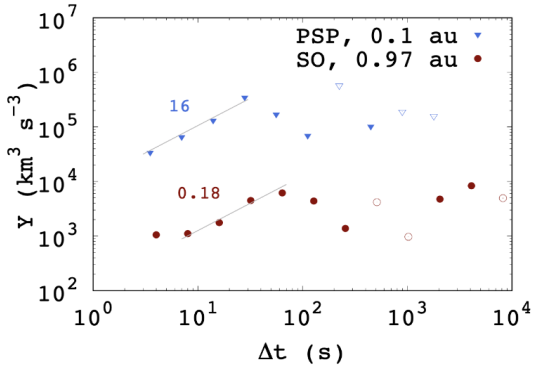


Figure 2. Scaling laws for the total energy at Solar Orbiter and at Parker Solar Probe during a radial alignment

A comprehensive analysis of the turbulent statistical properties of the fields and plasma fluctuations will be complemented with estimates of the turbulent energy transfer rate, based on different versions of the third-order moment scaling laws. The radial decay of the turbulent energy will be thus determined and compared with the measured solar wind heating, providing crucial information about the global energy budget of the solar wind in its expansion in the heliosphere.

Possible questions to be addressed include:

1. Do the selected intervals show typical and measurable characteristics of turbulence?
2. Does the solar wind turbulence evolve as it expands from the Sun?
3. Is the energy dissipated by the turbulence sufficient to heat the solar wind to the observed temperature?

In this project, the students will learn basic concepts of space plasma turbulence. They will acquire competences in obtaining, managing and analyzing spacecraft data, and interpreting the observations of statistical analysis. The analysis will be performed using a programming language of choice. The work will be a preliminary study for further research by KTH scientists.

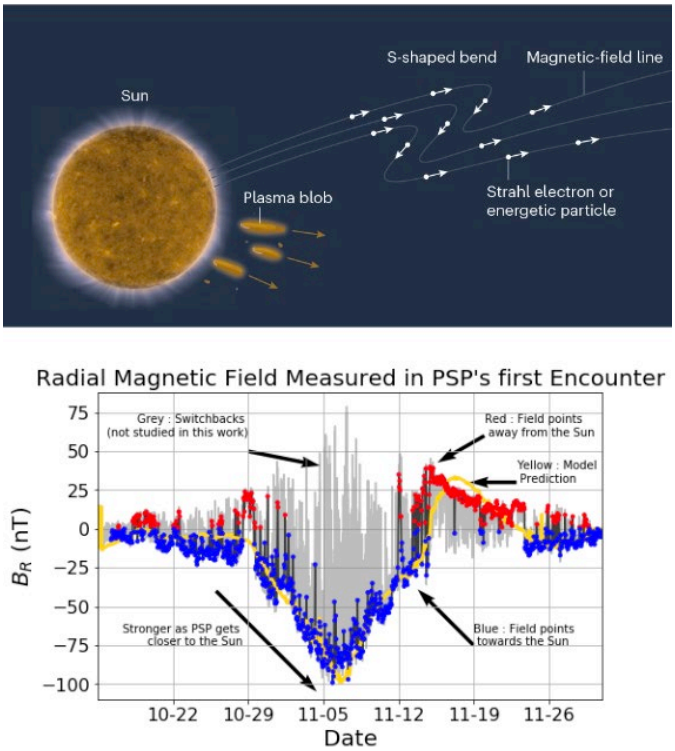
Project K3: Switchbacks and turbulence in the young solar wind

Supervisor: Luca Sorriso-Valvo, lucsv@kth.se, Space and Plasma Physics

Recent measurements collected by the NASA spacecraft Parker Solar Probe (PSP) in the near-Sun solar wind revealed the presence of clusters of sharp jets of accelerated plasma associated with large rotations of the magnetic field. The nature of such structures is currently under investigation.

It is not clear if and how they interact with other phenomena such as turbulence, waves and magnetic reconnection, and their role in the dynamics, acceleration and heating of the expanding solar wind is a major open issue in the community.
The amount of data collected by PSP and the ESA mission Solar Orbiter requires a massive statistical study, also using AI-based classification tools. Such study could help understanding how switchbacks are formed and interact with the plasma in which they are embedded.

For this project, the students will use intervals of solar wind parameters measurements from the two cited to identify switchbacks, classify their properties, and compare samples with different ambient solar wind characteristics (in particular, the wind speed, the angle between velocity and magnetic field, the degree of correlation between magnetic field and velocity fluctuations), and perform statistical analysis of the data. AI techniques might be used to create accurate identification tools, and clustering or neural network techniques could be used to establish possible correlations between switchbacks and solar wind parameters.



Top: Schematics of a switchback. Bottom: PSP magnetic field measurements near the Sun

The main questions that will be addressed are:

1).Is the cross-helicity scaling law valid in solar wind plasmas?
2) What is the cross-helicity dissipation rate in the solar wind?
3) How does the cross-helicity scaling and dissipation depend on the solar wind parameters?

In this project, the students will learn basic concepts of space plasma turbulence. They will acquire competences in obtaining, managing and analyzing spacecraft data, and interpreting the observations of statistical analysis. The analysis will be performed using a programming language of choice. The work will be a preliminary study for further research by KTH scientists.

Projekt K4: Earth's hydrogen exosphere observed by HST

Supervisors: Nickolay Ivchenko, nickolay@kth.se / Lorenz Roth, lorenzr@kth.se, Space and Plasma Physics

The exosphere is the outermost layer of the neutral atmosphere of Earth (Figure 1). It consists of hydrogen atoms, the lightest of all elements. A recent study has claimed that the top of this outermost layer contains extremely hot hydrogen atoms that populate an even wider space around Earth than thought before. The existence of this hot outer exosphere has however not been independently confirmed yet.

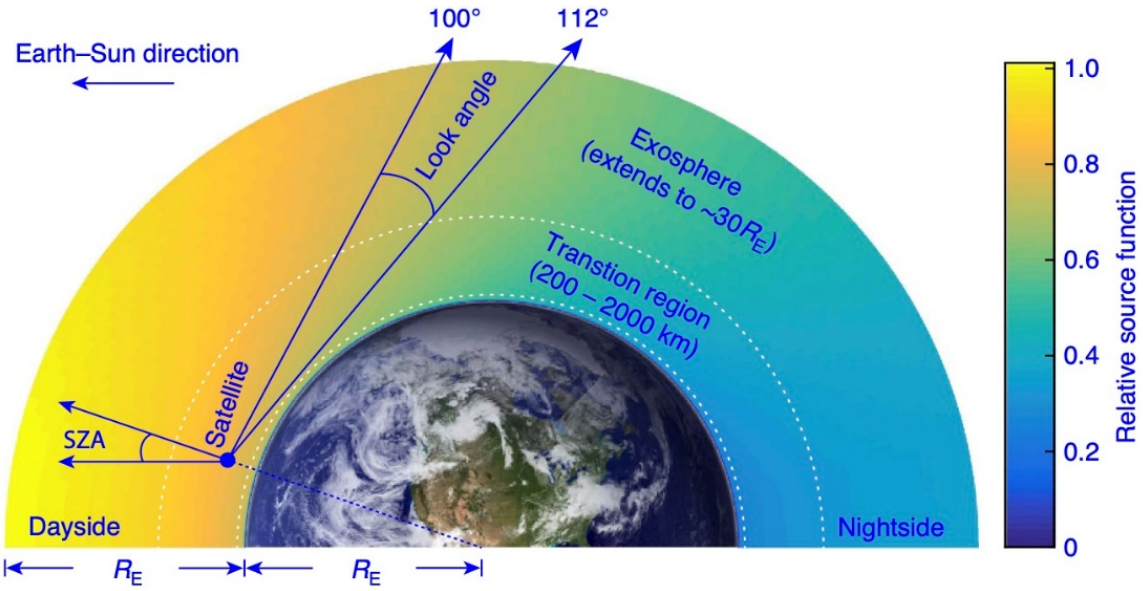


Figure 1: Sketch of the Earth's upper atmosphere as observed from a space telescope

The Hubble Space Telescope is orbiting the Earth at about 600 km for over 30 years now. In every single observation, HST is looking through the hydrogen exosphere of Earth. The Earth's hydrogen is therefore automatically measured in all far-UV spectral observations that include the wavelength 121.6 nm.

In this project, you will systematically go through the archive of the Hubble Space Telescope and identify observations that are suitable to search for the hydrogen signatures. You will then process the identified observations to extract the relevant signals. Finally, you convert the signal to the values of density and temperature of hydrogen.

Steps include:

- Search the HST archive, identify and download the HST data containing exosphere emissions.
- Process the data and extract the hydrogen exosphere signal.
- Convert the signal to hydrogen densities and temperature and compare to the previous detections of the hot outer exosphere.

The project deals with the acclaimed but debated existence of a very hot outer part of our atmosphere. If the hot exosphere is detectable in the HST data, it would constitute an important confirmation of this phenomenon.

Projekt K5: James Webb Space Telescope observations of Saturn's moons

Supervisor: Lorenz Roth, lorenzr@kth.se, Space and Plasma Physics

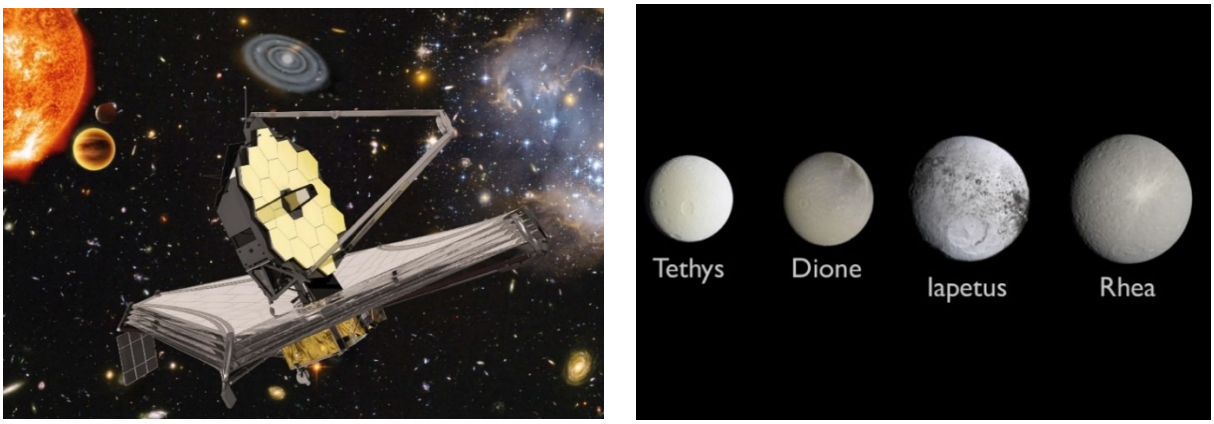


Figure 2. (Left) Illuastration of the James Webb Space Telescope. (Right) Icy moons of Saturn.

The NASA/ESA James Webb Space Telescope (JWST) was successfully launched on Christmas Day last year (2021). After commissioning of the telescope, science observations are taken since July 2022 and the moons of Jupiter and Saturn were among the first targets for JWST.

JWST has the unique capabilities to take spectral images with information on wavelength (color) in infrared light (IR) in each pixel (Figure 2). Observations of Jupiter moons Ganymede and Callisto provided resolved images of the moons with information on the light's wavelength in each pixel. The data revealed exciting insights into the material in the moons' atmospheres and surfaces in different specific places. In this project, you will search for atmosphere signals in the JWST data of different moon of Saturn. Most of Saturn's moons are icy bodies and some might have oceans with liquid water below the icy crust. Atmospheres around the moons have been found by the NASA Cassini spacecraft but never seen in telescope observations before.

The tasks in this project include:

- Download JWST observations from one of the moons from the NASA data archive
- Read and process the data "cubes" extract infrared spectra and images of moons
- Interpret the spectra using reference spectra and simple models
- Compare the spectra to previous observations from spacecraft

Doing this project, you will be among the first people actively working with this milestone telescope in the world.

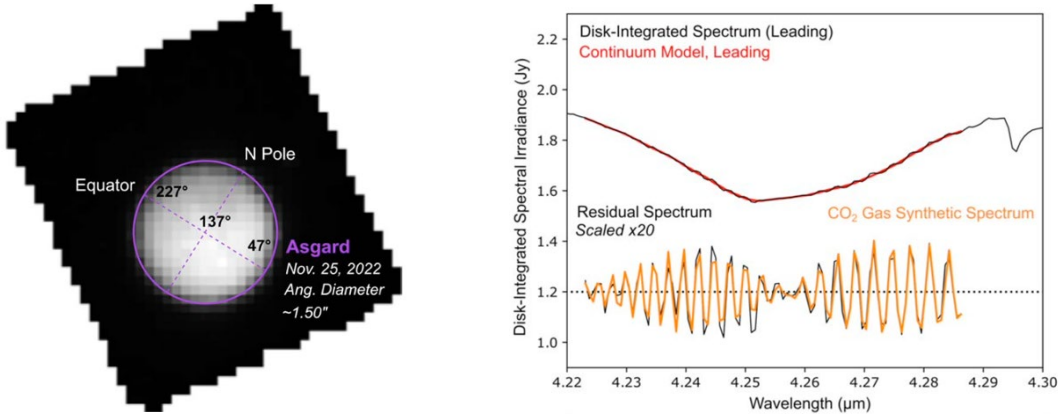


Figure 2. Example JWST observations of showing emissions from CO_2 gas at Callisto

Context L: Aerospace Systems Testing

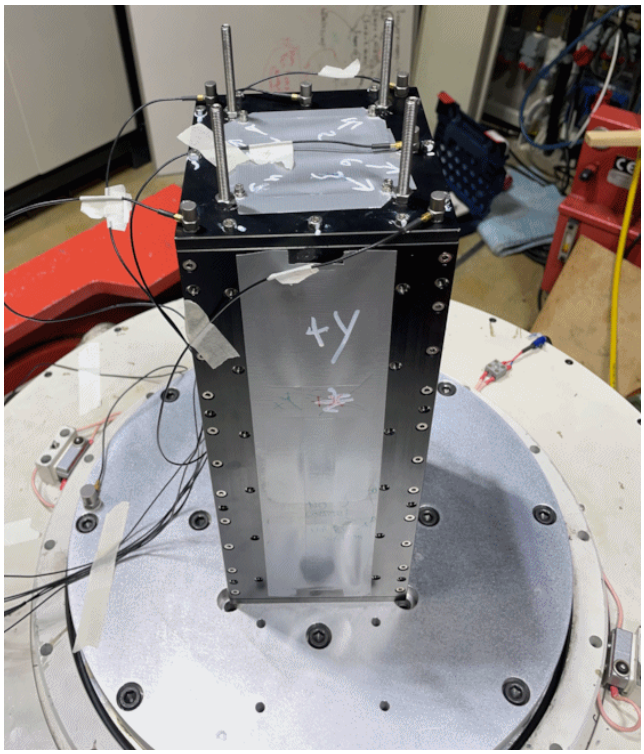


Figure: Vibration test of Cubesat structure.

Introduction

Our understanding of the environment of the Earth, with its upper atmosphere and the space beyond, comes from observations from the ground, satellites, sounding rockets and, more recently, unmanned vehicles (UAVs). Several projects aimed at testing and validation of custom-designed fixed wing UAVs and small satellites are ongoing at KTH. This context offers four engineering projects related to the testing of aerospace systems. Testing aerospace vehicles present design challenges and ingenuity on par with the design of the actual flight hardware. Remember this formulation of “Murphy’s Law”, “if it is not tested, it will fail”!

Projekt L1: Flight testing of fixed wing UAVs

Supervisors: Nickolay Ivchenko, nickolay@kth.se, Space and Plasma Physics
Raffaello Mariani, rmariani@kth.se, Aeronautics and Vehicle Engineering.

In this project you will focus on the autonomous flight control system for the fixed wing UAVs. Today a number of open source “autopilot” software solutions are available, that use multiple sensors onboard the UAV together with a control loop to steer the main engines and control surfaces. This way a “stabilized” flight – or even fully autonomous mission – can be achieved. In order to reliably use the UAVs a substantial amount of flight testing is required, to characterize the aerodynamical performance of UAV and validate the function of the autopilot (including response to non-nominal situations). Several different UAVs at KTH use similar approach, with Ardupilot used as the flight software. This project aims at developing a systematic process of flight testing of the UAVs, that can be applied across the platforms.

The tasks in this project include:

- Getting familiar with the basics of flight
- Understanding the basics of the fixed wing UAV control
- Getting familiar with the open source autopilot (Ardupilot)
- Flying the UAVs in various modes
- Analyzing the flight data to determine the performance of the UAV.

Figure 1. Early flight testing of a fixed wing UAV by KTH students.

Projekt L2: Detecting smoke plumes from forest fires

Supervisor: Nickolay Ivchenko, nickolay@kth.se, Space and Plasma Physics

This project focuses on the analysis of the images acquired from forest fire monitoring systems. The detection of the smoke plumes relies both on the morphology/appearance and the motion of the plume between subsequent images. The partner company, EVSolutions, has an extensive experience with the stationary vantage point imaging, and is interested in exploring the AI solution for detecting smoke plumes, and, in the future, using UAVs for fire monitoring. Imaging from an UAV poses a number of challenges. Due to the motion of the UAV, the view of the scene is changing related to the perspective change, which adds complexity to the analysis.

The tasks in this project include:

- Getting familiar with modern pattern detection methods in imaging, and their application to fire detection
- Applying the methods to difference images, i.e. images produced by taking the difference between two consecutive images separated by several seconds.
- Investigating how the methods would work for an UAV platform.

The EVSolution can provide sample imaging from their systems for training and evaluating the algorithms.

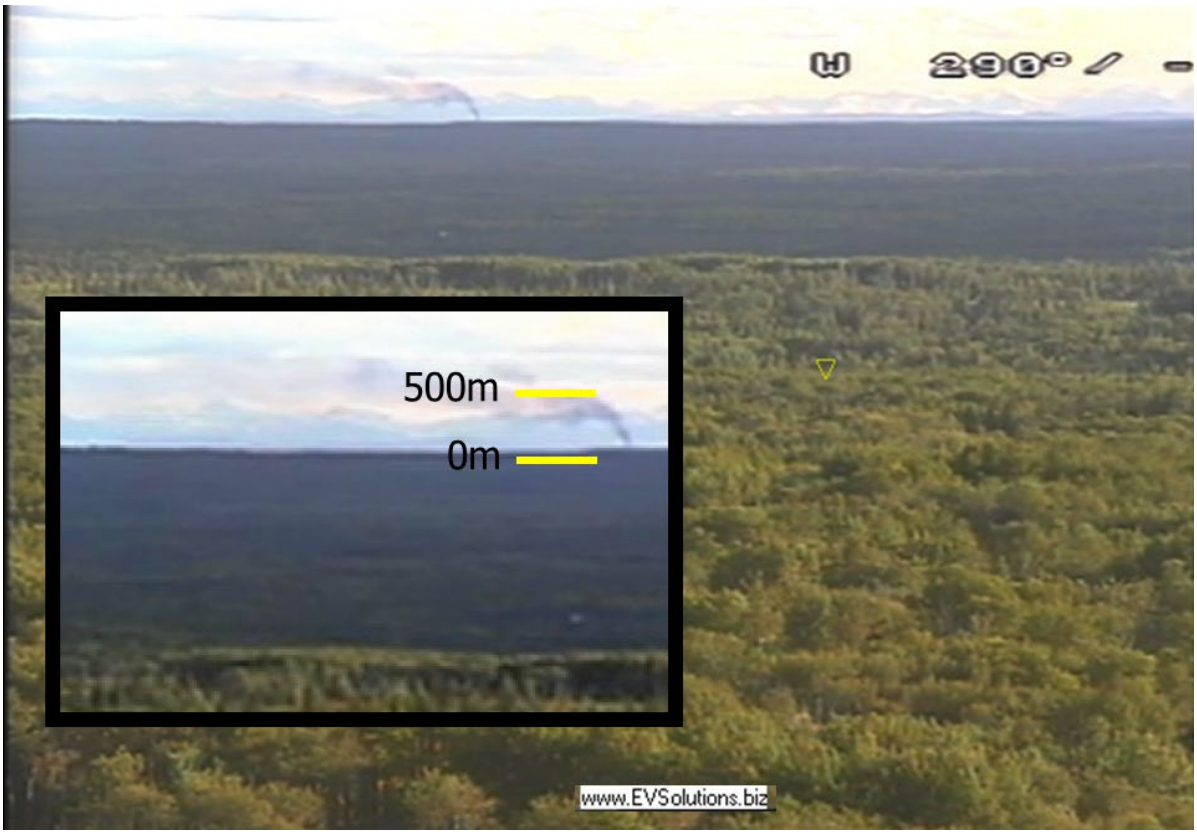


Figure 2 . An example of the smoke plume from a forest fire [EVSolutions].

Projekt L3: Universal jig for safe handling of a CubeSat

Supervisor: Sven Grahn, sveng@kth.se, Space and Plasma Physics

During assembling and testing of a CubeSat, it is common to use many different jigs in different situations to hold the CubeSat in different positions or to lift or transport it.

In this thesis project, you will:

- Perform a literature review to find different types of jigs used for CubeSats and relevant requirements (ECSS, NASA, ISO, etc)
- Identify design requirements for jigs in different stages of the development and testing of the MIST satellite. The jig shall facilitate lifting, raising/lowering, and rotation of the MIST satellite.
- Design a universal jig that fulfils the relevant design requirements
- Manufacture the jig
- Test the jig with a structural model of the MIST satellite

If time allows, several design iterations of the jig may be necessary. If testing with the structural model is successful, the jig will be used during assembling and testing of the MIST satellite.

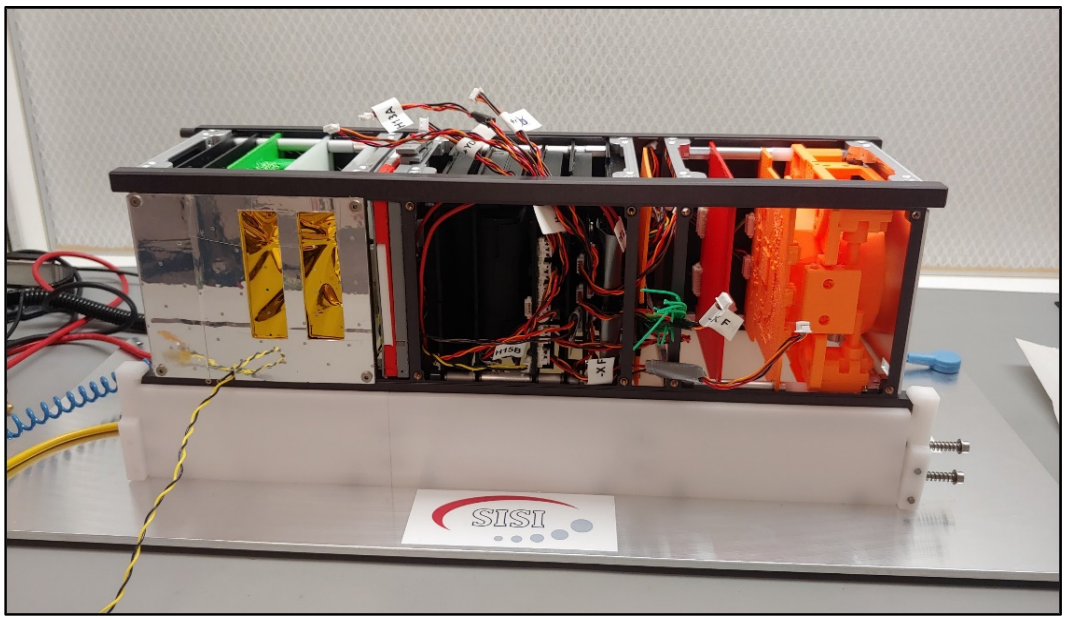


Figure 3The MIST flight structure with simulated subsystems.

Projekt L4: Testing of CubeSat solar panels

Supervisor: Nickolay Ivchenko, nickolay@kth.se, Space and Plasma Physics

This project focuses Most satellites are equipped with solar panels to power the satellite. This is also the case with the MIST satellite. To ensure that the solar panels are working, they have to be tested before the satellite is sent to space.

In this thesis project, you will:

- Perform a literature review of different ways to test the solar panels of a satellite
- Design and manufacture a test setup for testing of the MIST solar panels
- Prepare a test procedure
- Perform testing of a solar panel

If testing is successful, the test setup will be used for testing of the MIST flight solar panels.

Figure 4 The MIST test lab.

Context M: Machine Learning over Networks

Over the past decades, we have experienced a series of revolutions in computing, information, and communication technologies—starting with the invention of computers, followed by networking, and then wireless communication. Now, we stand on the brink of the next great leap: the "all-connected and digitalized world," where networks of interconnected devices will drive automatic data analysis and decision-making, transforming everyday objects into intelligent systems.

By 2030, it is predicted that the number of connected devices will reach 100 billion, ushering in a multi-trillion-dollar economy. One defining feature of this fourth revolution is the massive volume of data being generated, particularly by Internet of Things (IoT) devices, smartphones, and social networks. In fact, 90% of the world's data has been produced in just the last few years, creating an urgent need for advanced data analysis methods like **Machine Learning (ML)** and **Artificial Intelligence (AI)**.

While ML has already achieved remarkable feats—such as Google's AlphaGo, which trained on 30 million possible moves to defeat a Go grandmaster—these accomplishments rely heavily on centralized data processing in high-powered environments like data centers. However, the reality of the fourth revolution is different: data will be distributed across millions of nodes, from smartphones to sensors, each with limited computing power and bandwidth. Traditional ML methods, designed for centralized systems, struggle in this new landscape, particularly in networks like IoT or 5G, where bandwidth is scarce, and communication protocols are diverse.

This is where **Machine Learning over Networks** comes into play. The challenge is to design ML algorithms that can function efficiently across distributed systems. Instead of relying on central servers, these algorithms need to operate collaboratively across many devices, each making decisions based on its local data and only exchanging essential information with others. This requires addressing key technical hurdles, such as communication delays, bandwidth constraints, and the need for coordination between nodes with different computational capacities.

One major challenge is the fundamental bandwidth limitation. As more devices transmit data, congestion becomes a significant concern in a shared wireless medium. Emerging low-latency communication technologies rely on short packets with limited data capacity, further complicating ML over networks. IoT systems, such as smart grids or smart cities, will often operate in environments with unreliable links, low data rates, and transmission delays—whether it is underwater IoT sensors or communication networks within the human body, which transmit only a few bits per second.

This bachelor thesis context offers you the opportunity to work at the forefront of this exciting field. You will explore cutting-edge techniques for **Machine Learning over Networks**, studying the latest advancements in distributed optimization and investigating how to train ML models across a network of devices. Nodes will collaborate by learning from their local data and sharing only essential information with others using wireless communications. Using the latest tools, simulations, and theoretical models, you will develop solutions that could shape the future of intelligent, distributed networks.

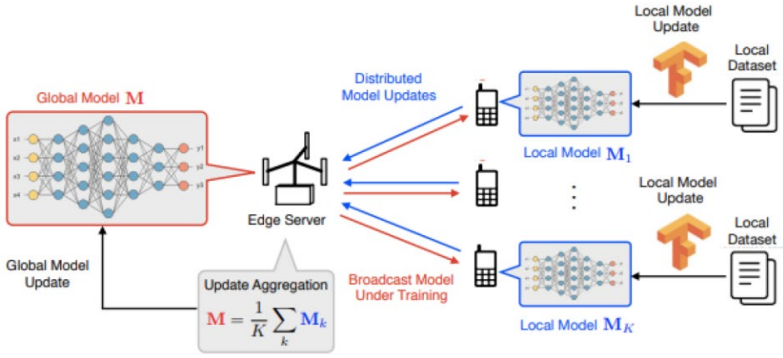
If you are passionate about AI, data science, and networking, this is your chance to be part of a transformative technological revolution through one of the following exciting projects:

- Over-the-Air Federated Learning
- An Introduction to Graph Neural Networks and Their Applications
- Predicting Network Latency Using Machine Learning
- Machine Learning Algorithms in Neural Networks
- Meta-Learning for AI-Aided IoT Networks
- Intelligent Over-the-Air Computation: Machine Learning Solutions for Edge Computing in IoT
- Distributed Optimization in Machine Learning
- Alternating Direction Method of Multipliers for Distributed Optimization
- Human Activity Recognition Using Machine Learning Through Wi-Fi Sensing

We describe the projects in detail on the following pages.

Project M1: Over-the-Air Federated Learning

Supervisors: Seyedmohammad Azimi (seyaa@kth.se), Carlo Fischione (carlofi@kth.se)



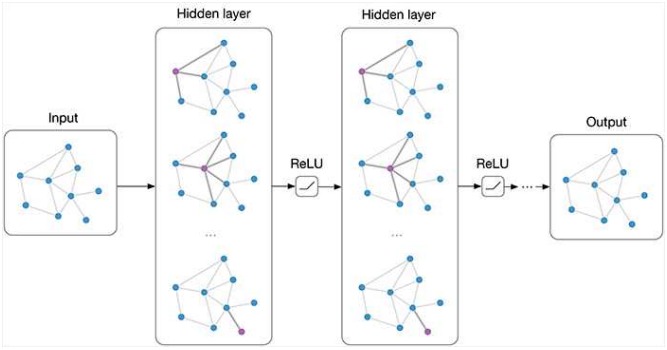
Federated Learning (FL) is a method where several devices (nodes) work together to train a shared machine learning model without sending their data to a central server. Instead, each device sends updates based on its local data, which are combined to improve the overall model. Over-the-Air Computation (OAC) is a technique that allows these updates to be sent over a wireless network, where the signals are combined as they travel, like adding numbers together. In this case, we can think of OAC as adding a bit of extra noise during communication.

This project aims to understand the basics of FL and how OAC, along with wireless communication, affects the system. The main objectives are as follows:

- Conduct a literature review of FL algorithms and OAC techniques.
- Build and simulate a simple FL system with perfect, noise-free communication between nodes and the server.
- Model OAC with the introduction of additional noise during communication.
- Simulate the impact of noise on the FL system's performance.
- Analyze how the extra noise influences the overall performance of the system.

Project M2: An Introduction to Graph Neural Networks and Their Applications

Supervisors: Xinyu Huang (xinyh@kth.se), Carlo Fischione (carlofi@kth.se)



Graph Neural Networks (GNNs) are a type of machine learning model designed to work with data that is structured as graphs. Graphs are used to represent relationships between objects, such as social networks, communication networks, and biological structures. This project aims to explore the basic concepts behind GNNs and apply them to a simple real-world problem.

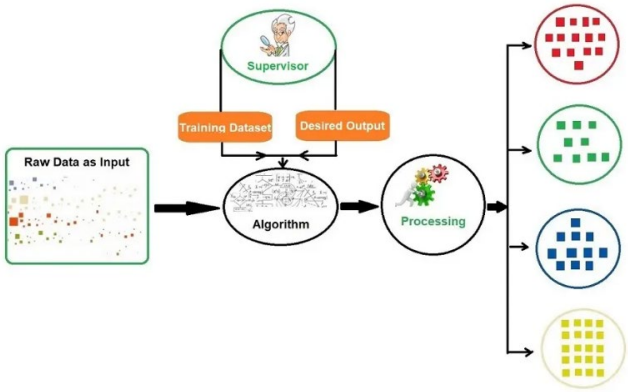
The objective of this thesis is to provide an introduction to Graph Neural Networks, understand their structure and operation, and apply them to a basic example, such as predicting relationships in a social network or analyzing traffic flow in a simple communication network.

The followings are tasks required in this project:

- Literature Review:
    1) Study basic concepts of Graph Neural Networks.
    2) Understand graphs and how they are represented in machine learning.
- Model Development
    1) Implement a simple GNN model using available libraries such as PyTorch Geometric or TensorFlow.
    2) Apply the model to a small dataset (e.g., a social network or road network) to predict relationships between nodes.
- Performance Evaluation:
    1) Test the model's performance on the chosen dataset.
    2) Compare GNN results with traditional methods or algorithms.

Project M3: Predicting Network Latency Using Machine Learning

Supervisors: Niloofar Mehrnia (nilome@kth.se), Carlo Fischione (carlofi@kth.se)



As the demand for faster and more reliable network connectivity continues to grow, there is an urgent need for effective methods to predict and optimize network latency. Recent advancements in machine learning algorithms have shown great potential in accurately forecasting latency within network infrastructures, enabling proactive resource allocation.

This bachelor thesis proposal seeks to investigate the application of machine learning algorithms for predicting latency in network systems. The main goal of this research is to establish a proactive framework that compares the effectiveness of existing machine learning algorithms in latency prediction, ultimately enhancing network performance and reliability.

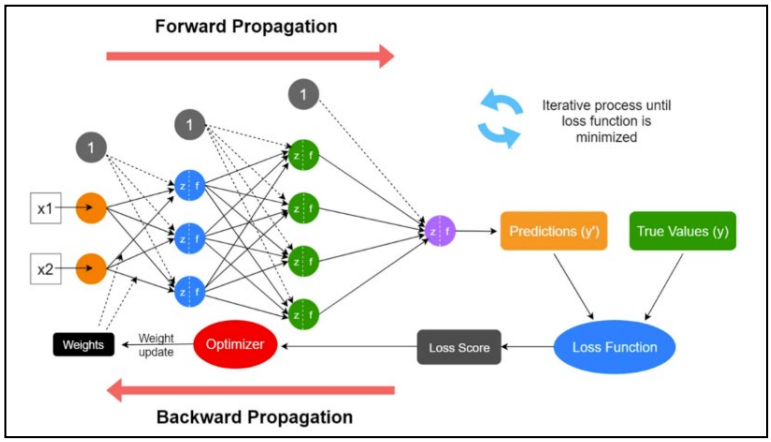
The main objectives are as follows:

- Explore and study at least three machine learning algorithms suitable for predicting network latency, assessing their strengths and weaknesses. For instance, you can choose among the following machine learning techniques for the latency prediction: Linear Regression, Decision Trees, K-Nearest Neighbors (KNN), Support Vector Machines (SVM), and Random Forests.

- Create a predictive model that utilizes the selected machine learning algorithms to forecast latency.
- Compare the performance of different machine learning algorithms in terms of accuracy of latency predictions.

Project M4: Machine Learning Algorithms in Neural Networks

Supervisors: Seyedamirreza Kazemi (seykaz@kth.se), Carlo Fischione (carlofi@kth.se)



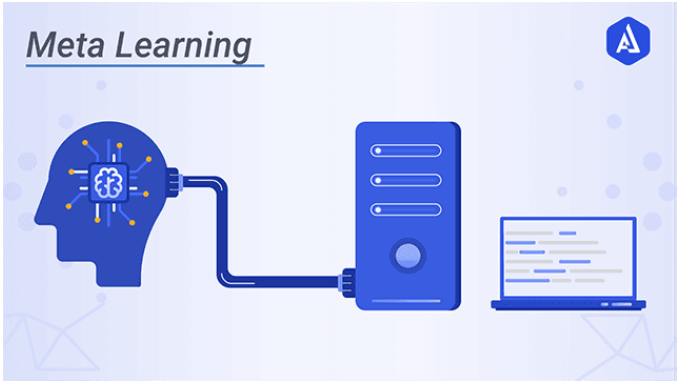
Machine learning (ML), particularly **neural networks (NNs)**, has become a cornerstone of modern artificial intelligence, driving advancements in areas such as healthcare, finance, autonomous systems, and more. As these models evolve, the way they are trained and deployed is also transforming. One major area of research is **distributed machine learning over communication networks**, where neural networks are trained across multiple devices and locations, communicating over a **network** infrastructure. This is particularly relevant in fields such as edge computing, sensor networks, and 5G/6G systems, where data is generated and processed across geographically distributed devices. The **intersection of machine learning and communication networks** is critical to enabling distributed intelligence in real-time applications. For instance, a neural network can be trained collaboratively across a network of IoT devices, mobile phones, or autonomous vehicles without requiring the transmission of massive datasets to a centralized server.

This proposal outlines a bachelor thesis project focused on exploring the **structure of neural networks and their learning algorithms**. The primary objectives are:

1. Study the core concepts of machine learning (ML), including supervised and unsupervised learning, and understand how neural networks fit into the broader context of ML.
2. Describe the learning process of a neural network, focusing on how data is processed and used to improve the model's performance over time (training and backpropagation).
3. Focus on gradient descent as the primary optimization algorithm in NNs.
4. (Optional) Provide simple demonstrations or simulations of neural networks using basic tools and programming libraries.

Project M5: Meta-Learning for AI-Aided IoT Networks

Superviors: Xiangnan Liu (xiangliu@kth.se), Carlo Fischione (carlofi@kth.se)



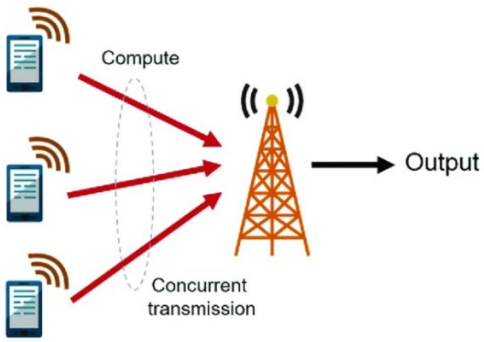
Nowadays, different models of data in IoT networks require to be incorporate together. However, the data fusion operates in highly dynamic environments, resulting in signal quality changes vary rapidly. Meta-learning algorithms enable current IoT networks to quickly adapt to new environments by leveraging prior knowledge gained from a set of related tasks. Instead of training from scratch every time new conditions arise, meta-learning allows IoT networks to generalize from past experiences and fine-tune its models with minimal data.

This project aims at understanding the concept of meta learning, applying to meta learning algorithms in AI-aided IoT networks. Specifically, the main objectives of this study are as follows:

- Learn about the existing models of data used in AI-aided IoT networks.
- Implement meta-learning algorithms in these the existing models to serve the IoT networks.

Project M6: Intelligent Over-the-Air Computation: Machine Learning Solutions for Edge Computing in IoT

Supervisors: Xiaojing Yan (xiay@kth.se), Carlo Fischione (carlofi@kth.se)



With the rapid growth of IoT and increasing reliance on edge computing, efficient resource management at the network edge is critical. Over-the-air computation (OAC) offers a promising approach by enabling simultaneous transmission and computation, allowing the overall efficiency of data aggregation in distributed networks.

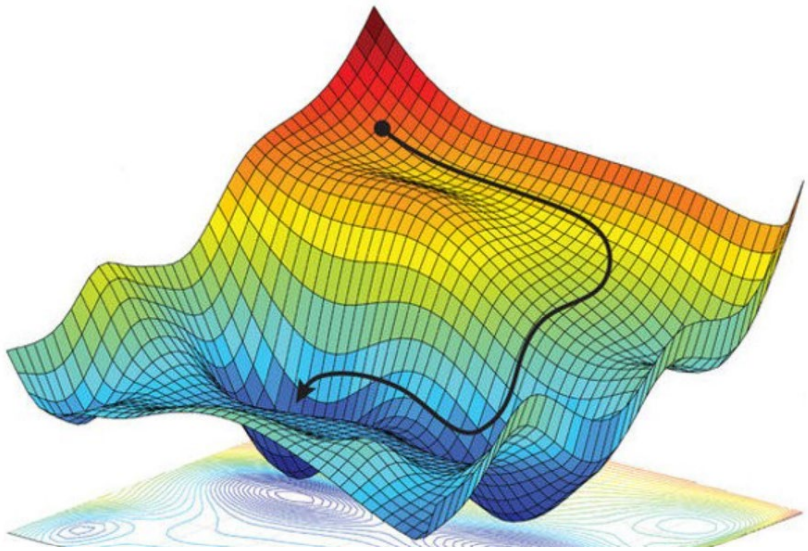
However, optimizing OAC performance in IoT environments poses challenges such as wireless interference, signal design, and dynamic resource allocation. Machine learning algorithms provide a powerful solution by leveraging data-driven insights for real-time optimization.

This project aims to apply machine learning algorithms to address these OAC challenges, with the following objectives:

- Analyze current OAC challenges in IoT and edge computing, identifying areas where machine learning can drive efficiency and performance improvements.
- Develop machine learning models to optimize resource allocation, reduce interference, and enhance overall system performance.
- Evaluate the effectiveness of machine learning solutions through simulations, comparing them with traditional methods in terms of efficiency, accuracy, and scalability.

Project M7: Distributed Optimization in Machine Learning

Supervisors: Seif Hussein (seifh@kth.se), Carlo Fischione (carlofi@kth.se)



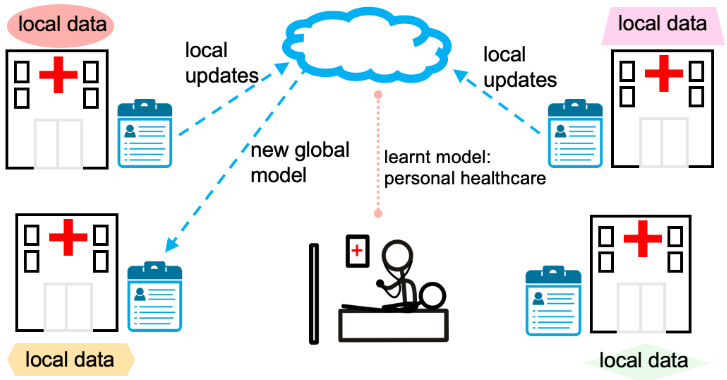
In the era of big data, the processing of high-dimensional datasets has become practically infeasible for traditional centralized computing systems. Machine learning models require immense computational resources to process and analyse this data, leading to significant challenges in scalability and efficiency. Distributed and decentralized optimization algorithms have thus emerged to address these challenges, enabling the processing of large-scale data across multiple computing nodes or networks.

This project aims to explore various distributed and decentralized optimization algorithms proposed in the literature. In particular, the expected outcomes of the project are the following:

- Analyze optimization algorithms commonly used in various machine learning settings
- A categorization of some state-of-the-art distributed/decentralized optimization algorithms based on mathematical properties and application areas
- Simulations to highlight differences between algorithms

Project M8: Alternating Direction Method of Multipliers for Distributed Optimization

Supervisors: Hansi Abeynanda (hkab@kth.se), Carlo Fischione (carlofi@kth.se)



Optimization problems in machine learning typically involve extremely large, high-dimensional datasets, often stored in a distributed manner. Consequently, developing distributed algorithms for solving such large-scale problems has become crucial. The alternating direction method of multipliers (ADMM) is particularly well-suited for distributed optimization in this context.

This project aims to analyze ADMM for solving distributed optimization problems commonly encountered in many machine learning applications. Specifically, the main objectives of this study are as follows:

- Analyze existing ADMM techniques widely used in distributed optimization settings.
- Implement these techniques in commonly used machine learning problems.

Project M9: Human Activity Recognition Using Machine Learning Through Wi-Fi Sensing

Supervisors: Zeyang Li (lizeyang321@gmail.com), Carlo Fischione (carlofi@kth.se)

The widespread use of Wi-Fi devices has not only transformed connectivity but has also opened up new possibilities for applications like sensing and activity recognition within wireless networks. Unlike traditional sensing methods that rely heavily on cameras, Wi-Fi sensing presents unique benefits. Camera-based systems can be hindered by obstacles and often raise privacy concerns. Wi-Fi sensing, on the other hand, can overcome many of these challenges. Given its global adoption, Wi-Fi technology is now ubiquitous, with countless devices present in homes and offices, significantly reducing deployment costs.

This project aims to employ machine learning algorithms to recognize different human activities based on measured Wi-Fi signal. Specifically, the main objectives of this study are as follows:

- Gain a foundational understanding of wireless signals and channels.
- Learn how to apply machine learning for classification tasks.
- Implement machine learning algorithms to classify different human activities based on Wi-Fi signal data.

Context N: Cyber Security

Cybersecurity includes a collection of methods designed to protect systems, networks, and services from external threats. Businesses and organizations employ cybersecurity professionals to protect their confidential information, maintain employee productivity, and enhance confidence in products and services.

Key properties of cybersecurity are privacy, integrity, and availability. Privacy means data can be accessed only by authorized parties; integrity means information can be added, altered, or removed only by authorized users; and availability means systems, functions, and data must be available on-demand according to agreed-upon parameters. An important element of cybersecurity is the use of authentication mechanisms, which allow to securely identify users or processes.

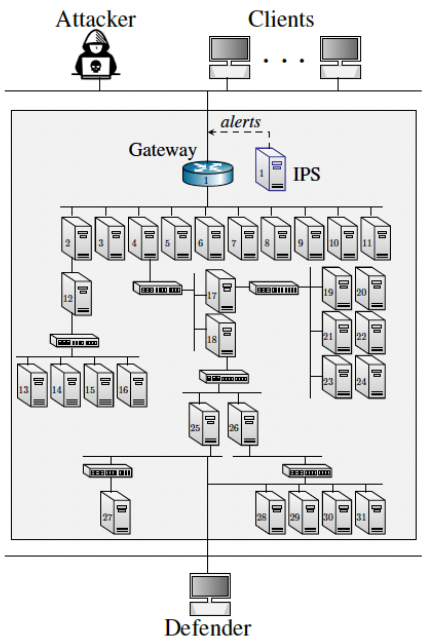
Well-known attacks that compromise the protect systems, networks, and services of an organization include Denial of Service (DOS), installation of malware, man-in-the-middle attack, and phishing. Other types of cyberattacks include cross-site scripting attacks, password attacks, eavesdropping attacks (which can also be physical), SQL-injection attacks, and birthday attacks.

From an engineering point of view, a variety of scientific methods can be used to protect a system or to identify and repel an attack. These include cryptography, formal methods, statistical techniques, and AI. We offer projects where students develop and evaluate state-of-the art approaches to securing systems and preventing attacks:

1. Intrusion detection and intrusion prevention
2. Active learning for intrusion detection and response
3. Trustworthy Autonomy in Cyber-physical Systems

Project N1: Intrusion Response Against IT System Attacks Using Markov Decision Process and Reinforcement Learning

Supervisor: Rolf Stadler (stadler@kth.se)



We consider an intrusion prevention use case which involves the IT infrastructure of an organization (see figure). The infrastructure includes a set of servers that run client applications and an Intrusion Prevention System (IPS), which logs events in real-time. Clients access the applications through a public gateway, which also is open to an attacker. The attacker intrudes on the infrastructure and compromises a set of its servers. The defender continuously monitors the infrastructure through accessing IPS and other statistics.

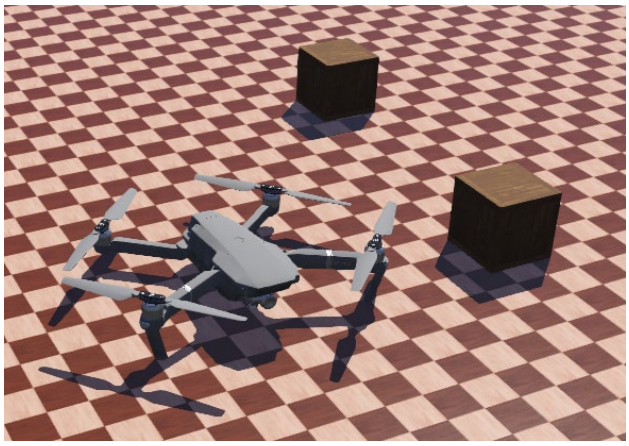
In this project, the students study and evaluate intrusion response methods of a defender against a multi-stage attack strategy. They model the intrusion response with a Markov Decision Process (MDP), formulate the problem of an optimal response strategy, and find that strategy using a Reinforcement Learning technique in a simulation environment.

Prerequisites: statistics, applied probability, basic programming skills in Python; basic concepts of machine learning.

Literature: will be made available at the beginning of the project.

Project N2: Designing and Simulating Cyber Attacks Against Autonomous Vehicles

Supervisors: Axel Andersson (axander@kth.se), György Dán (gyuri@kth.se)



The objective of this project is to design and implement various cyber attacks against autonomous vehicles (AV) such as drones or rovers. This could be done by leveraging open source simulation software such as Webots or PX4 Simulator. The aim of the project is to understand the vulnerabilities of autonomous vehicles control systems and understand the impact of these attacks on systems behavior.

Autonomous Vehicles rely on sensors, control algorithms and communication networks to navigate and perform other tasks. All of these components are vulnerable to cyber attacks that can compromise the safety and security of these systems.

Main components of the Project

1. Set up simulation environment. Get comfortable with a simulation software such as Webots.
    - Simulating an AV for some simple mission and controlling it, for instance with a PID controller.
    - Implement various sensor inputs such as GPS or LiDAR.
2. Attack Design. Develop different types of attacks such as:
    - False Data Injection (FDI). Different attacks could be contructed by injecting false data to certain sensors.
    - Communication Intercepting. Manipulate data that is exchanged between the AV and a central control system or data exchanged between AV's.
3. Attack Implementation. Implement the attacks by writing scripts in e.g Python or C++ in Webots. Then run simulations when the AV is being attacked.
4. Analysis. Analyze the outcome of the attack. What effect does the attacks have on the AV, do they cause the AV to fail its mission? Reason about potential countermeasures for the attacks.

If you are interested in cyber security for control systems and autonomous vehicles and learning a new simulation tool then this project could be of interest to you!

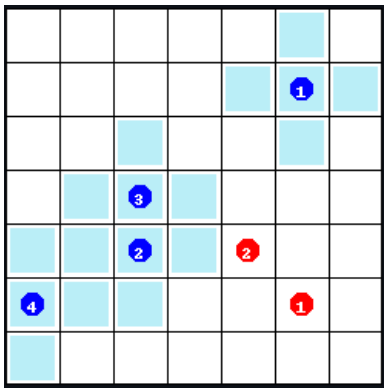
Related Work

[1] W. Duo, M. Zhou and A. Abusorrah, "A Survey of Cyber Attacks on Cyber Physical Systems: Recent Advances and Challenges," in IEEE/CAA Journal of Automatica Sinica, vol. 9, no. 5, pp. 784-800, May 2022

[2] H. Kim, et al., "A Systematic Study of Physical Sensor Attack Hardness," in 2024 IEEE Symposium on Security and Privacy (SP), San Francisco, CA, USA, 2024 pp. 2328-2347.

Project N3: Adversarial Attacks on Multi-Agent Reinforcement Learning Systems

Supervisors: Axel Andersson (axander@kth.se), György Dán (gyuri@kth.se)



In this project, the goal is to find effective attacks against multi-agent reinforcement learning (MARL) systems. A MARL system is a system where multiple autonomous agents operate in the same environment and wants to accomplish some goal. If the agents work together, as a team, it is called cooperative MARL (c-MARL). An example of this is a search-and-rescue task where multiple autonomous agents (e.g., drones) are searching for a target.

In the project we will study how robust MARL algorithms are by trying to construct attacks that causes the team of autonomous agent to fail their mission. A possible avenue could be to perturb the agents observations in some clever way, causing it to take bad decisions. One could consider both training and inference time attacks, that is, is the attacker present during the training of these algorithms or when the agent is actually used?

Main Tasks of this Project

1. Choose an interesting and not too complex c-MARL task.
2. Design a simple and effective attack strategy against the MARL system that causes the system to fail the mission or decrease the general performance. This could be:
    - Perturbation Attacks: Introduce small changes in one or several of the agents observations, affecting decision making at inference-time or during training.
    - Behavioral Attacks: Introduce a malicious agent whose goal is to minimize the overall team reward.
3. Interact with open-source environments commonly used in RL and MARL research such as OpenAI's Gym or PettingZoo.
4. Train a MARL system to understand the baseline performance.
5. Implement the Attack Strategy.
6. Evaluation. Measure how the attacks affect the overall performance of the MARL system.
7. Report and Presentation: Document your findings and the process. Reason about potential countermeasures.

Tools we will use

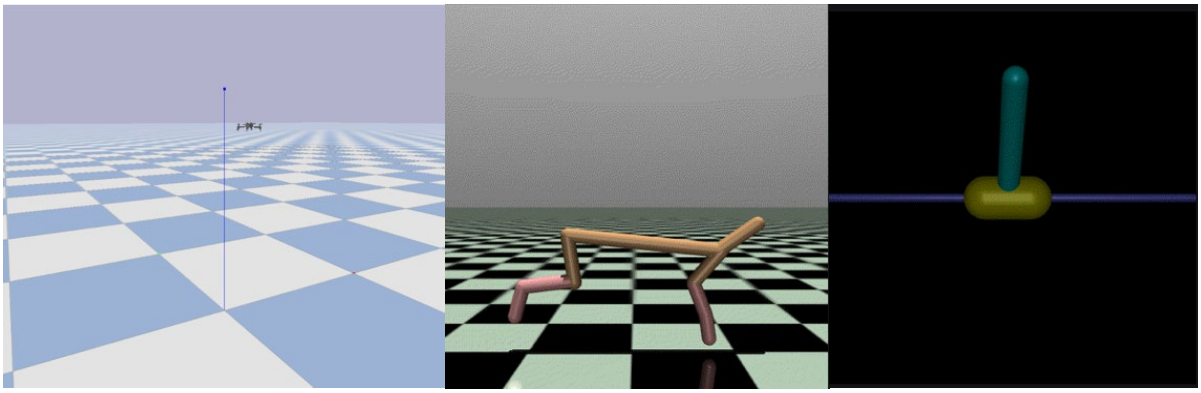
Python and some automatic differentiation library like PyTorch, TensorFlow or Jax. OpenAI's Gym or PettingZoo for simulating an environment.

Related Work

[1] Lin, Jieyu & Dzeparoska, Kristina & Zhang, Sai & Leon-Garcia, A. & Papernot, Nicolas. On the Robustness of Cooperative Multi-Agent Reinforcement Learning. SPW 2020, 62-68.
[2] Pinto, Lerrel & Davidson, James & Sukthankar, Rahul & Gupta, Abhinav. Robust Adversarial Reinforcement Learning. ICML 2017.

Project N4: Adversarial Robustness in Reinforcement Learning

Supervisors: Arshad Javeed (ajaveed@kth.se), György Dán (gyuri@kth.se)



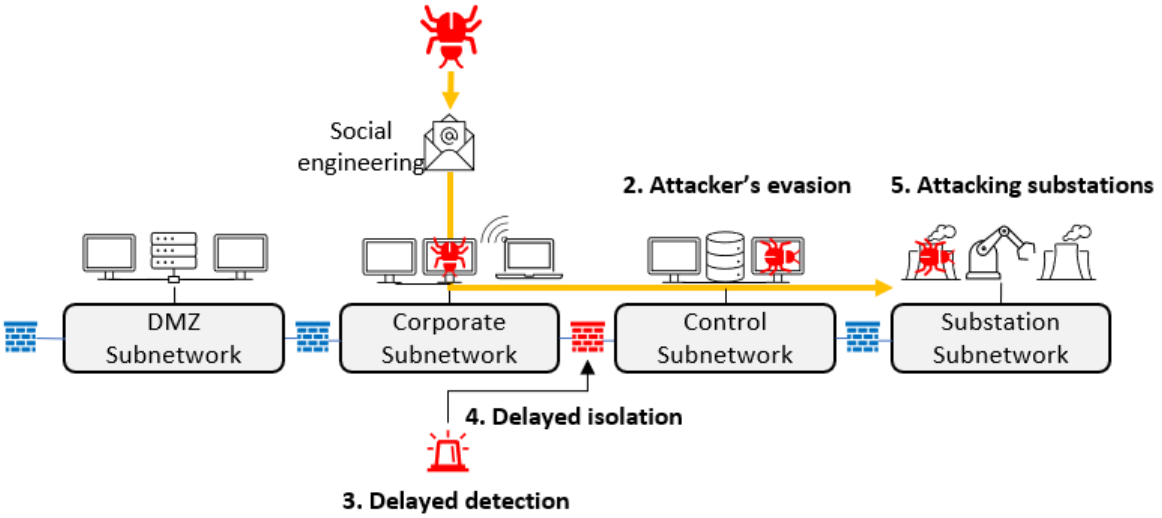
Reinforcement learning (RL) is widely used for obtaining near-optimal policies for Markov decision processes (MDPs), in which an agent interacts with an environment sequentially to maximize its objective [1]. An important area of research within RL is to learn policies that are robust to adversarial perturbations, e.g., learning policies that are robust to wind disturbances in a quadrotor or external perturbations in balancing an inverted pendulum. An approach to improving robustness is to introduce an adversary that tries to inhibit the agent by emulating disturbances or attacks, forcing the agent to learn better strategies [2]. However, [3][4] report that in the case of continuous control tasks, adversarial algorithms do not necessarily outperform the RL agents that were not exposed to any kind of adversaries during training, i.e. RL agents have inherent robustness. To refute this, [5] have proposed a methodology that attempts to incorporate action execution errors (the difference between the expected consequence of the action vs. executed action), thereby letting the agent adapt to perturbations in real-time.

The scope of the proposed project would be to replicate the findings from [5] on continuous control tasks, such as an inverted pendulum. As a first step, you would develop a model of the inverted pendulum to get acquainted with the dynamics and train a model-free RL algorithm to stabilize the inverted pendulum. Along the lines of [5], you would try to incorporate action errors for the inverted pendulum and carry out rigorous performance analysis. The project would empirically evaluate the adversarial robustness of RL and reveal potential research directions in the active field of RL.

[1] L. P. Kaelbling, M. L. Littman, & A. W. Moore. (1996). Reinforcement Learning: A Survey.
[2] Lerrel Pinto, James Davidson, Rahul Sukthankar, & Abhinav Gupta (2017). Robust Adversarial Reinforcement Learning. In Proceedings of the 34th International Conference on Machine Learning (pp. 2817–2826). PMLR.
[3] Catherine Glossop, et al. Characterising the Robustness of Reinforcement Learning for Continuous Control using Disturbance Injection. In Progress and Challenges in Building Trustworthy Embodied AI.
[4] Arshad Javeed, & Valentín López Jiménez. (2023). Reinforcement Learning-Based Control of CrazyFlie 2.X Quadrotor.
[5] Arshad Javeed. (2023). Model-assisted Reinforcement Learning of a Quadrotor.

Project N5: Semi-Autonomous Cyber Defense (APTs)

Supervisors: Yeongwoo Kim (yeongwoo@kth.se), György Dán (gyuri@kth.se)



Advanced Persistent Threats (APTs) utilize a variety of sophisticated techniques and tools to exploit system vulnerabilities, allowing them to gain unauthorized access to networked infrastructures while remaining undetected for extended periods of time. Numerous APT attacks have been observed across critical sectors such as financial institutions, government agencies, healthcare, and energy, causing significant financial losses and societal disruptions.

Defending against APTs poses a major challenge due to their stealthy nature and the large volume of false alerts generated by intrusion detection systems. These false alerts often lead to "alert fatigue," where security analysts become desensitized to the flood of notifications, which can result in delayed responses, such as isolating compromised network segments too late. Additionally, these delays allow attackers to move laterally across the network, transitioning to other devices and further compromising the system.

For effective and timely incident response, it is crucial to automate the detection process and predict the potential movement of attackers within the system. A promising approach is to analyze sequences of alerts over time [1], enabling accurate detection of ongoing attacks and the proactive isolation of suspicious network segments. However, the challenge lies in deciding which network segment to isolate based on historical alert data. One potential solution is to model the problem as a partially observable Markov decision process and use reinforcement learning (RL) for obtaining a solution, where the system learns to anticipate the attacker's progression and isolates potentially compromised segments in real-time. In this project we explore this problem using a combination of model-based and model-free RL algorithms with a focus on obtaining auditable and explainable policies.

[1] Yeongwoo Kim and György Dán, and Quanyan Zhu. "Human-in-the-loop Cyber Intrusion Detection Using Active Learning." IEEE Transactions on Information Forensics and Security (2024).

Project N6: Trustworthy Autonomy in Cyber-Physical Systems

Supervisors: Mauricio Byrd Victorica (mbv@kth.se) , György Dán (gyuri@kth.se)

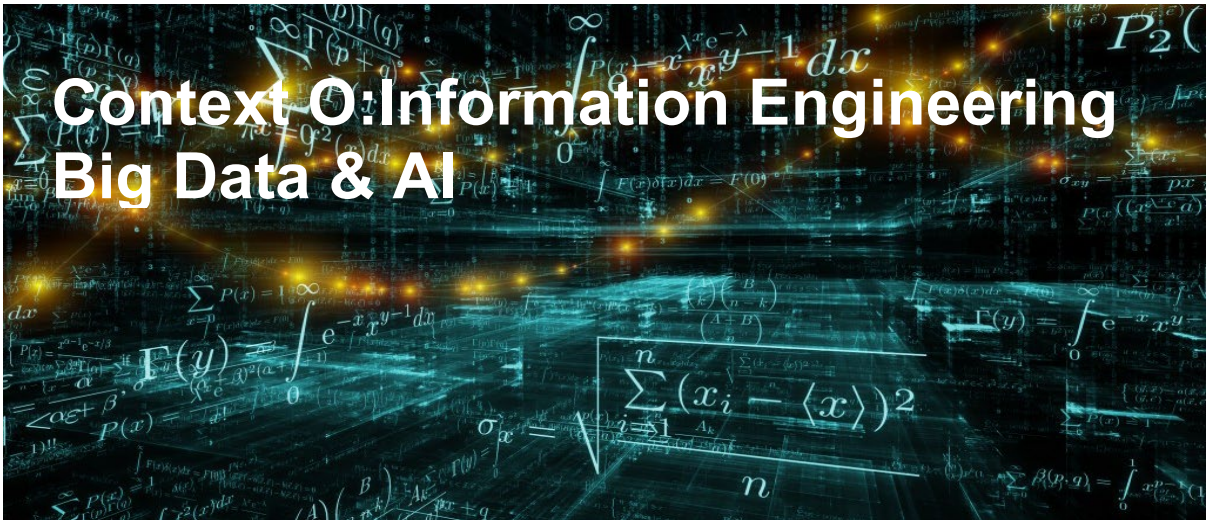
The performance and reliability of autonomous Cyber-Physical Systems (CPS) depend on the accuracy of both the sensory information they acquire (e.g., camera) and the AI/ML algorithms they use to process it (e.g., object detection models). Adversarial attacks are sensory perturbations designed to mislead ML models, and thus pose a safety risk to autonomous CPS [1, 2].

While early research mainly focused on exploring attacks and defenses against ML-models in isolation, recent works have proposed adversarial attacks which are both physically-realizable and capable of decision-level impact on full-fledged systems where the ML-model under attack is only a component of the system's perception pipeline [3] (e.g., autonomous cars, autonomous surveillance systems). In turn, defense mechanisms to handle attacks with system-level impact have also been proposed [4].

In this project we explore this fundamental issue with the objective of developing algorithms for improving the trustworthiness of CPS that rely on ML components for data processing and inference. This might involve, among other tasks:

- Creating adversarial perturbations, i.e., attacks.
- Designing mechanisms to defend ML models from adversarial attacks.
- Modifying and/or integrating complex simulation environments to evaluate attack and defense methods in realistic scenarios (e.g., autonomous driving).

[1] Eykholt et al, "Physical Adversarial Examples for Object Detectors," in Proc. of WEET, 2018.
[2] Tu et al, "Physically Realizable Adversarial Examples for LiDAR Object Detection", in Proc. of CVPR 2020.
[3] Yi Zhu et al. "Malicious Attacks against Multi-Sensor Fusion in Autonomous Driving", in ACM MobiCom, 2024.
[4] Raymond Muller et al. "VOGUES: Validation of Object Guise using Estimated Components", in USENIX Security, 2024.



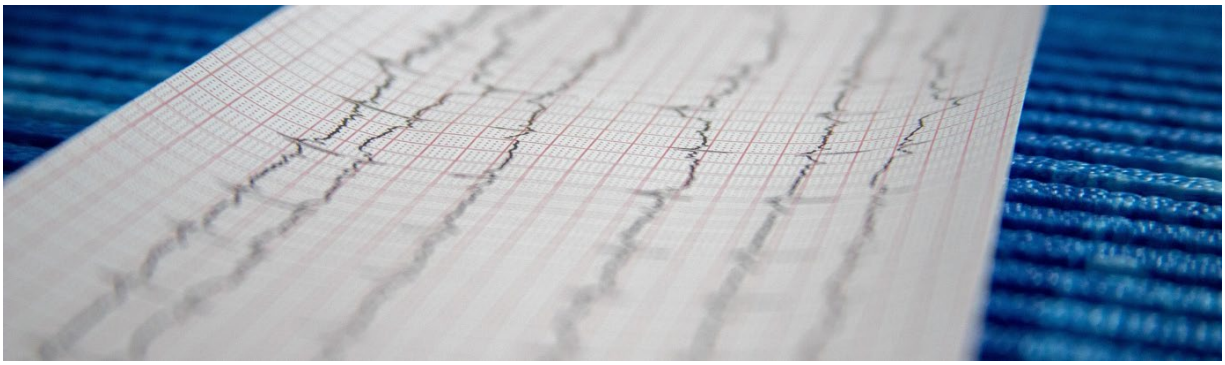
Big Data and artificial intelligence are broad topics with huge technological and economical potentials and therefore is of interest in many areas. From an engineering point of view, it is mostly related on how to process data. Currently, information and communication technology is penetrating all systems to make them *smart,* e.g. we envision smart cities, smart homes, smart grids, etc. or Internet of things in general. The smartness of the systems is built on the principle to sense the system environment and then draw smart decisions on it. However without algorithms that extract information from the data, the information is buried in the data and cannot be exploited. Thus, the process of extracting information will be the key ingredient of many future technologies and is the main objective of technologies nowadays known as artificial intelligence (AI), machine learning, data mining, pattern recognition, data analytics, adaptive signal processing etc. which are all instances of information engineering.

In general, we can say that the more data we have, the smarter the system will be. Thus, advanced smart systems sooner or later face the big data problem, which commonly means that the amount of the data is *too big* to be processed e.g. with standard tools. Therefore, there are huge research efforts developing novel information processing and data analytic methods, which enable future systems to deal with larger and larger data sets.

Innovative information processing and data analytic methods are traditional topics of the Information Science and Engineering Division. Thus, the sub-projects offered in this course will address fundamental topics and problems in the area with a strong engagement of the department's teachers. Accordingly, all offered Bachelor projects are closely related to some of the on-going research projects in the division. In particular, we offer project that deal with data augmentation for ECG training data, algorithms for contactless heart-beat sensing, assessment of data pre-processing methods, tuning of GPT model of a chess bot, machine learning based FM radio receiver, and model inversion attack-based assessment of privacy-enhancing subsampling. Since information processing is quite abstract, all projects require a good mathematical background and solid programming skills.

Project O1: ECG data augmentation for training deep learning classifiers

Contact: Joakim Jaldén, jalden@kth.se, Information Science and Engineering Division



Problem Statement:
The electrocardiogram (ECG) is vital for identifying heart issues like heart attacks and irregular heartbeats. Its non-intrusive nature makes it an ideal early screening tool for guiding medical decisions. Nowadays, ECGs are predominantly digital, enabling automated data analysis. The realm of computerized ECG analysis is rapidly progressing.

KTH is collaborating on a novel project with Region Stockholm, AISAB (Ambulanssjukvården i Storstockholm AB – The ambulance service in Stockholm), and Karolinska Institutet (KI). This endeavor will explore the effectiveness of automated ECG analysis within a decision support system. This system, in turn, could aid ambulance staff in making challenging decisions about patient care. Within this project, we are now developing in-house expertise in designing optimal automated ECG classification algorithms. This is where the proposed bachelor project comes into play.

Your project's specific task involves studying the use of physically realistic data augmentation strategies when training deep neural networks for categorizing 12-lead, 10-second digital ECG traces of the same form as those collected in Stockholm's ambulances. The bachelor thesis will work with a common publicly available ECG datasets (PTB-XL) and make use of a previously published deep neural network structure, which was further improved during a bachelor thesis project in 2023.

Prior experience working with deep neural networks isn't necessary, but proficiency in Python programming is essential. Basic familiarity with the Unix shell environment will also be advantageous, especially if you wish to use our computational infrastructure to train the neural networks.

Project O2: Contactless Heart Rate Sensing using Camera, Signal Processing, and Machine Learning

Contact: Magnus Jansson, janssonm@kth.se, Division of Information Science and Engineering

Problem Statement:
Remote vital sign (like body temperature, heart rate, respiration rate, blood pressure) detection may be desirable in health care, for driver alertness detection in traffic, or in sports (see e.g. [1] and Figure 1). One technology for accomplishing parts of this may be to use Radar sensors. Another possibility is to use video cameras to try to detect subtle changes in skin color or body part movements. In this project you should implement a contactless remote heart rate sensor using video data and clever signal/image processing or machine learning. For some background information, see e.g. [1, 2, 3].

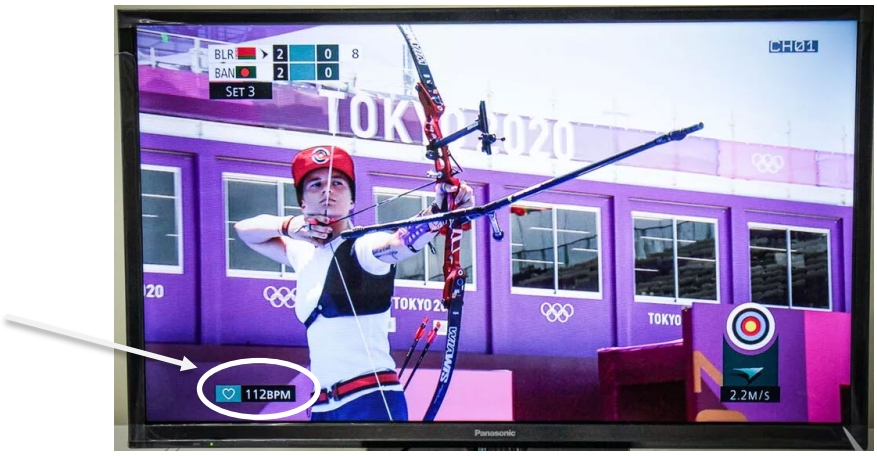


Figure 1: Remote heart rate monitoring during archery competitions at the Olympic Games in Tokyo 2020 (2021).

Aim of the thesis project:
As mentioned above, in this project you should implement a contactless remote heart rate sensor using video data. The required algorithms for processing the data can run in an offline mode, at least in a first step of the project. This means you can collect video data first and then process this in a batch mode. The results do not need to be produced in real time. The accuracy of the results and its dependency of the required equipment or data processing should be discussed.

Interested students could take this further and e.g. develop a device or app showing heart rate in real time. The project could be further extended to also detect respiration rate if time permits.

Primary basic software skills required: MATLAB and/or Python.

References:
[1] Archery debuts heart-rate graphics on broadcast of the Olympic Games (https://www.worldarchery.sport/news/200395/archery-debuts-heart-rate-graphics-broadcast-olympic-games), visited 16 sept. 2024
[2] Kolosov D, Kelefouras V, Kourtessis P, Mporas I. Contactless Camera-Based Heart Rate and Respiratory Rate Monitoring Using AI on Hardware. Sensors. 2023; 23(9):4550. https://doi.org/10.3390/s23094550
[3] Wu, H. Y., Rubinstein, M., Shih, E., Guttag, J., Durand, F., & Freeman, W. (2012). Eulerian video magnification for revealing subtle changes in the world. ACM transactions on graphics (TOG), 31(4), 1-8.

Project O3: Tools for Health-Care Data Processing

Contact: Ragnar Thobaben (ragnart@kth.se), Division of Information Science and Engineering (ISE)

In the last decade, a large amount of health care data has been collected in hospitals world-wide, which is now partially made available for research purposes in public data bases to foster the development of new data-driven approaches to health care and to take advantage of the recent progress in the field of machine learning. Common goals are to learn patterns from the data, to identify patient- and treatment-specific risk factors, to predict outcome and morality, or to derive algorithms for treatment automation and decision support.

A fundamental challenge in using data-driven approaches in health-care data is that data is inherently noisy as a side effect of the care environment, interventions, treatment, and patient-specific factors; for example, time stamps may be inaccurate for lab measurements, manually documented data can be false or incomplete (e.g., shifted decimal separator, data ends up in the wrong field), time-series measurements can be interrupted (e.g., due to treatment and interventions), the condition of a patient makes certain measurements difficult, and measurement noise in general. Another issue is the privacy of the patients and their data; patients may agree to their data being processed but may wish that only the important aspects (e.g., blood-pressure levels) of the data are considered and the remaining aspects of the data (e.g., age, gender, identity, other conditions) are kept private.

Pre-processing of clinical data (e.g., outlier detection, denoising of data, filtering, privacy mechanisms) is therefore an important step that if done manually, consumes a lot of time and resources and may lead to privacy breaches. These resources could thus be better used to offload the burden on care staff, and hence, contribute to improved patient safety.
The goal of this project is therefore to explore and validate how preprocessing (see examples above) affects the performance of learning algorithms that are trained for a specific task (e.g., outcome prediction, decision support) and to identify interesting tradeoffs.

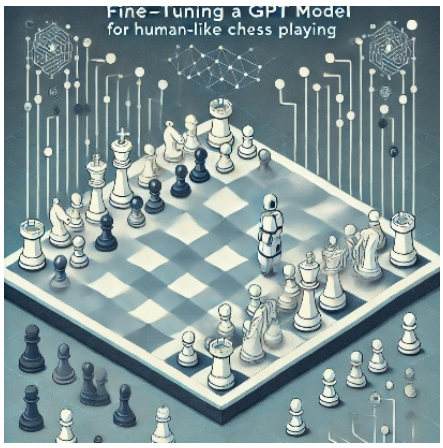
The steps in the project are as follows:

- In self-studies, the students areexpected to acquire the required machine learning background and skills to execute the work in this project. Following publicly available online lectures has been a successful approach to this in previous years.
- Together with the supervisor, you will identify a few suitable problems and data sets (e.g., outlier detection, data imputation, privacy mechanisms), for which you will train at least two different machine learning models using different methods.
- Next, you will adopt strategies from the literature and possibly develop new strategies to further analyse the models to identify interesting tradeoffs.
- You will summarize your findings and present the results of a comparison of the different approaches investigated in this project in the final report and the final presentation. The final report will also include a brief survey of recent approaches to outlier detection and data imputation in clinical data.

The project is fairly open and leaves students with a lot of space to develop and pursue own ideas. Since this freedom also can be a burden, this project is only recommended for creative students with strong mathematical and programming background. Students working in this project will be supported by Ragnar Thobaben.

Project O4: Fine-Tuning a GPT Model for Human-Like Chess Playing

Contact: Amaury Gouverneur (amauryg@kth.se), Information Science and Engineering Division



Problem Statement:
Traditional chess bots, such as those found on platforms like chess.com, often play moves that feel unnatural for human players. These bots frequently rely on making near-perfect opening moves, only to blunder strategically later on to match their claimed Elo rating (measures a player's level). This results in non-humanlike play, making it challenging for users to practice and improve their chess skills against more realistic opponents. The goal of this project is to develop a chess-playing AI based on the GPT architecture, which simulates human-like gameplay at different Elo ratings (800, 1000, and 1500). This project will offer practical experience in fine-tuning language models for specific tasks, as well as insights into AI-based game-playing systems.

Motivation:
This project is inspired by the work of Adam Karvonen, particularly his blog post and paper titled *"Emergent World Models and Latent Variable Estimation in Chess-Playing Language Models"*, which demonstrated that small language models, when trained on chess games, can learn to play chess without explicitly being given the rules. This thesis aims to extend Karvonen's approach by developing a GPT-based chess bot that plays at different skill levels.

Project Description:
The project will involve fine-tuning a pre-existing model, such as Andrej Karpathy's nanoGPT, on public PGN-format chess games available from Lichess.org. The model will be trained to play legal chess moves and to simulate Elo levels (800, 1000, and 1500). The bot should be capable of producing plausible moves, mistakes, and strategies at the corresponding Elo ratings.

Methodology:
- **Dataset Collection:** The model will be trained on public databases of PGN (Portable Game Notation) games from Lichess.org, which contain millions of human chess games.
- **Model Fine-tuning:** Using the nanoGPT model as the base, fine-tuning will focus on training the model to predict the next move in a PGN string, learning to play chess through supervised learning on game sequences. By segmenting the training data by Elo, we will develop distinct models or condition the model to play at specific skill levels.
- **Model Evaluation:** The trained model will be evaluated on several key metrics:
    - **Legal Move Rate:** Ensuring that the model always plays legal moves.
    - **ELO Evaluation:** The model's playing strength will be evaluated by playing against known ELO-rated engines like Stockfish.

Expected Outcomes:
The result will be a chess bot that plays at Elo levels of 800, 1000, and 1500 in a natural, human-like style. This bot can serve as a valuable tool for training players, especially for those looking to improve their chess skills against opponents whose mistakes and strategies more closely resemble human ones. The final code and scripts for fine-tuning and evaluating the model will be made available on Github.

Skills Required:
- Proficiency in Python programming.
- Basic understanding of machine learning principles and language models.
- Familiarity with chess would be advantageous.

Resources:
- Adam Karvonen's "Chess-GPT's Internal World Model" blog post: : https://adamkarvonen.github.io/machine_learning/2024/01/03/chess-world-models.html
- nano-GPT repository by Andrej Karpathy: https://github.com/karpathy/nanoGPT
- Lichess database (for chess games): https://database.lichess.org
- Nicholas Carlini's "Playing chess with large language models" blog post: https://nicholas.carlini.com/writing/2023/chess-llm.html
- Mathieu Archer's "Debunking the Chessboard" blog post: https://blog.mathieuacher.com/GPTsChessEloRatingLegalMoves/

Project O5: Learning to listen to radio

Contact: Mats Bengtsson matben@kth.se, Division of Information Science and Engineering (ISE)

Problem Statement:
Do you listen to radio? Have you ever wondered how a radio receiver works? In this project, you will design your own FM radio receiver, but not by reading up on the mathematics behind frequency modulation, but rather by training a neural network to do the work of demodulating a sampled signal from the antenna into something that you can listen to. This requires training data, i.e. examples of sound signals and the corresponding modulated radio signal. Luckily, there are software packages available, for example in Matlab or in GnuRadio, that makes it easy to generate such training data. As you might guess, these software packages also contain implementations of FM demodulation that can be used to implement the radio receiver directly, so why use machine learning?

First of all, it's interesting to see how well it works and what sound quality can be achieved using machine learning, compared to traditional engineered solutions, especially in situations with difficult radio propagation and disturbances. Secondly, a machine learning based approach could easily be re-trained to handle more difficult scenarios, such as

- If you know that there's an FM channel, but do not know at what frequency
- If you want to demodulate not only one, but multiple FM signals. For example, if you sample the full frequency band from 90MHz-110MHz and want to output several audio streams, with P1, P2, P3, P4, Rix FM, Lugna favoriter, …
- If you don't know if it's an FM signal or an AM signal that you want to listen to.

For you, it gives a chance to get some hands-on experience with standard machine learning toolboxes either in Matlab or in Python and to learn a bit about regression learning and

processing of streaming data. As mentioned above, there are many possible extensions to the basic problem formulation of demodulating a single FM-modulated sound signal with known carrier frequency. We also have access to hardware for software defined radio, so another possible extension is to try to trained machine learning solution on real-world data.

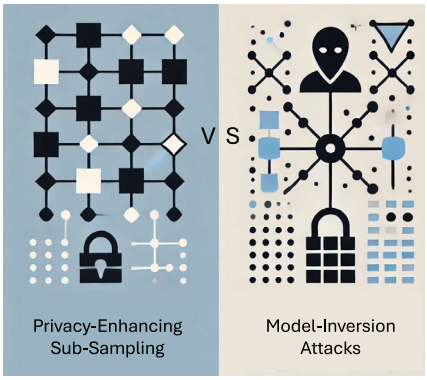
Previous knowledge of machine learning is not required.

References

[1] S. Zheng, Z. Pei, T. Chen, J. Chen, W. Lu and X. Yang, "Deep Learning-Based FM Demodulation in Complex Electromagnetic Environment," in *IEEE Open Journal of the Communications Society*, vol. 5, pp. 1579-1593, 2024
[2] GNU Radio, https://www.gnuradio.org/
[3] Mathworks, ”Analog passband modulation”, https://www.mathworks.com/help/comm/ug/analog-passband-modulation.html

Project O6: Privacy-Enhancing Sub-Sampling vs. Model Inversion Attacks

Contact: Leonhard Grosse, lgross@kth.se, Tobias Oechtering, oech@kth.se, ISE Division



Problem Statement:
Machine learning models trained on sensitive data pose significant privacy risks, as they can be vulnerable to attacks that reconstruct private information from model outputs. This project aims to explore the effectiveness of privacy-enhancing sub-sampling methods, particularly those that incorporate formal privacy guarantees, in mitigating these attacks. More specifically, the students will explore the effectiveness of sub-sampling methods used during model training on decreasing the vulnerability of the models to inversion attacks.

Technical Background:
In recent years, *differential privacy* has become a standard for providing provable privacy guarantees for data processing systems. When training a neural network with stochastic gradient descent, there are two main steps that can be used to enhance privacy: Noise addition during optimization, and batch-subsampling. As the latter is also used to increase efficiency, it could be possible to achieve a synergy of privacy and training efficiency through privacy-enhancing methods that utilize sub-sampling during training.

Pre-requisites: This project requires that the students:

- have a solid background in Probability and Statistics,
- are comfortable with coding in Python, and have some familiarity or interest in libraries like PyTorch and Tensorflow,
- have some basic knowledge of machine learning algorithms, and
- are motivated to learn new, sometimes complicated theoretical concepts

Tasks: The steps of the project are as follows:

1. *Theory phase:* We start out by reviewing relevant literature, with a focus on understanding the concepts necessary for the implementation, and to grasp the overall picture of the project.
2. *Implementation Phase*: Based on the reviewed literature, we will chose a suitable case-study for model inversion attacks, and implement an existing attack. Then, we will add the implementation of sub-sampling algorithms to the model training.
3. *Testing phase:* Once the implementation is up-and-running, we will investigate how different methods and parameters of the sub-sampling algorithms perform in terms of mitigating the success of model inversion attacks.

References

[1] Dionysiou,Antreas,VassilisVassiliades,andEliasAthanasopoulos. "Exploring model inversion attacks in the black-box setting." *Proceedings on Privacy Enhancing Technologies* (2023). Link to paper.

[2] Joy,Josh,andMarioGerla."Differentialprivacybysampling."*arXivpreprint arXiv:1708.01884* (2017). Link to paper.

Context P: AI, games, and strategy

Top: The very first AI-program was a computer program that played Checkers (www.chessprogramming.org/Christopher_Strachey). Bottom: The strategy game SIGNAL is used to study nuclear escalation dynamics (pong.berkeley.edu/e-game/).

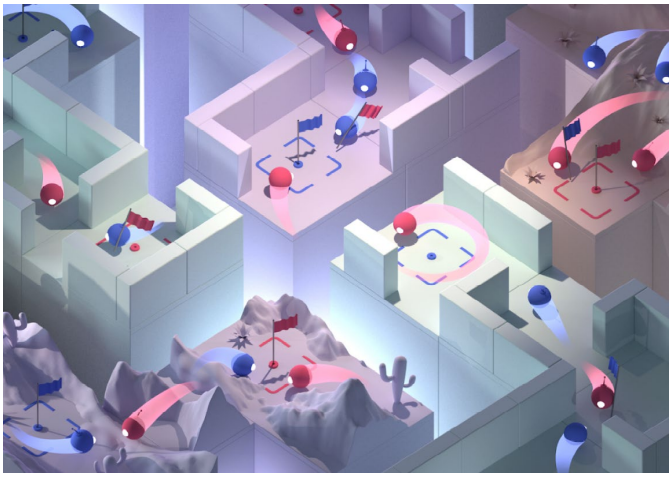
AI and strategy games have been intimately connected since the very inception of AI. Classic strategy games such as Checkers, Chess, Go, and Poker have served as shared research goals within the AI-community and as benchmarks for evaluating AI-algorithms.

The interest in strategy games within AI has also been motivated by the prospect of supporting real world decision making and strategy. In the social sciences and elsewhere, there is a long tradition of analyzing human interactions of various kinds as strategy games – from relatively peaceful interactions such as business negotiations or stock trading to directly hostile interactions such as dogfights in air combat.

Given a model of a conflict as a strategy game, the strategy space can be explored systematically. However, exploring the strategy space manually, e.g., by repeatedly playing the game, requires considerably time and effort. The recent advances in AI for strategy games have opened up for the possibility of automating decision making and strategy development. Application areas range from security and defence to finance

Project P1: Knowledge in Multi-Agent Games

Supervisor: Dilian Gurov (dilian@kth.se), Division of Theoretical Computer Science



Key Words: Multi-Agent Systems, Game Theory, Knowledge-Based Strategies

In a multi-player game, a coalition of **players** (also called agents) is attempting to achieve an **objective** within a (potentially hostile) environment, considered to be the opponent. Solving such a game means to find a **strategy** that achieves the objective regardless of the moves of the environment. Rescue missions involving robots and humans or pursuit-evasion games are examples of such games, often called multi-agent systems.

An interesting, but complicating circumstance is when the players have limited information about the current state of affairs, say due to limited observation capabilities. Such games are called games of **imperfect information**. A related aspect is posed by the communication capabilities between players. The problem of strategy synthesis under imperfect information and limited communication is known to be hard, and is an active research area. The present project investigates the modelling of such games, as well as algorithmic and machine learning-based techniques for strategy synthesis. In particular, the project focuses on strategies based on the notion of **knowledge**. In the context of this project, knowledge refers to information, structured suitably, stored and updated during the course of a play, for deciding on a course of action. Especially interesting is **higher-order knowledge**, where players maintain and use during play knowledge about the other players' knowledge.

Inspirational Reading:

[1] Gurov, D., Goranko, V., Lundberg, E.: *Knowledge-Based Strategies for Multi-Agent Teams Playing Against Nature*. Artificial Intelligence, vol.309, 2022, DOI: 10.1016/j.artint.2022.103728

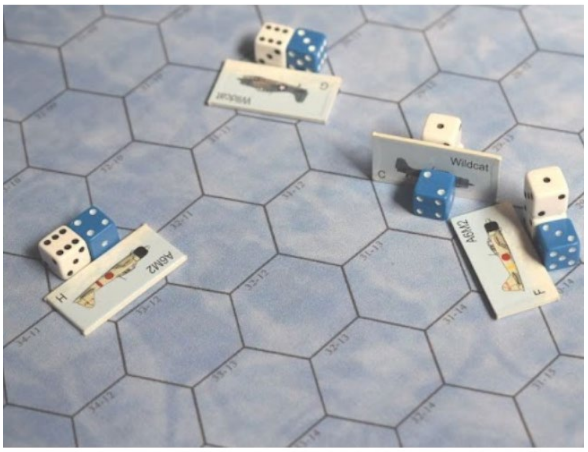
[2] Doyen, L., Raskin, J.F.: *Games with imperfect information: Theory and algorithms*. Lectures in Game Theory for Computer Scientists pp. 185–212 (2011)

[3] Berwanger, D., Kaiser, L., Puchala, B.: A *perfect-information construction for coordination in games*. In: Foundations of Software Technology and Theoretical Computer Science (FSTTCS'11). LIPIcs, vol. 13, pp. 387–398 (2011)

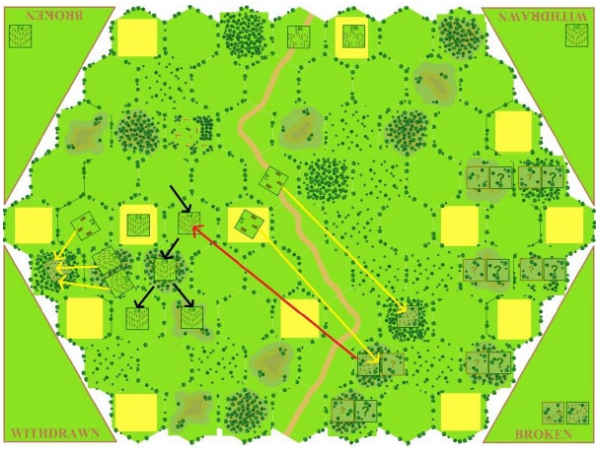
[4] Huang, X., van der Meyden, R.: *Synthesizing strategies for epistemic goals by epistemic model checking: An application to pursuit evasion games*. In: Proceedings of AAAI 2012 (2012)

Project P2: Optimal taktik med Monte-Carlo Trädsökning

Handledare: Mika Cohen (mikac@kth.se), Division of Theoretical Computer Science, Christopher Limér (christoffer.limer@foi.se), Daniel Oskarsson (daniel.oskarsson@foi.se)



Fighter Duel.



Combined Arms.

Sammanfattning: I det här projektet beräknar du (approximativt) optimal stridsteknik i ett spel som används för taktikstudier i krigsvetenskaplig forskning.

Bakgrund

I början av 1941 förstörde tyska ubåtar allierad sjöfart i en förödande takt. Winston Churchill beordrade att den brittiska flottan skulle "Ta reda på vad som händer och sänka U-båtarna!". En ny taktikutvecklingsenhet skapades, Western Approaches Tactical Unit (WATU), där man simulerade ubåtsattacker och utvecklade motåtgärder med hjälp av krigsspel. Krigsspelens spelregler speglade kända fysikaliska egenskaper hos handelsfartyg, eskorter och ubåtar vad gäller hastighet, vändcirkel, synlighet, beväpning och så vidare, men spelreglerna lämnade taktiska beslut kring formation, m.m. öppna för spelarna att välja fritt. Spelarna tilläts därvid att experimentera med taktiken och pröva sig fram och på så vis – genom trial-and-error – nå fram till den bästa taktiken för att skydda konvojerna. Denna taktikutveckling anses ha varit avgörande för utvecklingen i kriget i stort.

Idag är det rimligt att tänka sig att ”Liknande utmaningar i framtiden skulle kunna hanteras ännu snabbare och mer effektivt med hjälp av AI-program som AlphaZero” (Edward Stringer, generaldirektör för försvarshögskolan i Storbritannien).’

*AlphaZero***.** För fem år sedan förlorade Lee Sedol, legendarisk 18-faldig världsmästare i Go, mot AlphaGo, en AI från DeepMind. Händelsen väckte stor uppmärksamhet – att bemästra Go sågs av många som det yttersta inom mänsklig intelligens och kreativitet. DeepMind förenklade och generaliserade sedermera AlphaGo till en generell algoritm, AlphaZero, som kan lära sig godtyckliga strategispel (av ett visst slag) till övermänsklig skicklighet. AlphaZero lär sig ett spel genom att spela mot sig själv med s.k. *Monte-Carlo trädsökning* i en process av försök-och-misstag inte helt olik mänsklig inlärning i t.ex. WATU.

AlphaZero har i grunden förändrat förståelsen av klassiska strategispel som Go och Schack med nydanande, bitvis revolutionerande taktik som århundraden av omfattande, heroisk mänsklig ansträngning inte lyckats upptäcka.

Mikrokrigsspel med AlphaZero. Ubåtsspelen i WATU tillhör en typ av mycket småskaliga krigsspel, ibland kallade mikrokrigsspel, som i mångt och mycket påminner om klassiska strategispel som Go och Schack. Den avgörande skillnaden är att spelreglerna syftar till att

korrekt spegla dynamiken i en viss verklig militär konfliktsituation, om än på en hög abstraktionsnivå.

Eftersom AlphaZero har visat sig kunna bemästra klassiska strategispel och ge ett fönster mot optimalt spelande i dessa kan AphaZero förväntas att på liknande sätt kunna ge ett fönster mot optimalt spelande även i mikrokrigsspel.

Syfte
Projektet syftar till att generera (approximativt) optimal taktik för *Fighter Duel Lite* eller *Combined Arms*, två mikrokrigsspel som används inom krigsvetenskapen för att analysera taktiska problem från andra världskriget.

- Länk till *Fighter Duel Lite*: https://www.wargamevault.com/product/446605/Fighter-Duel-Lite.
- Länk till *Combined Arms*: https://sites.google.com/view/sabinwargames/home

Metod
Det valda mikrokrigsspelet analyseras med Monte-Carlo trädsökning, en nyckelkomponent i AlphaZero som också kan användas fristående utan djupinlärning. Lite grovt kan arbetet delas in i tre steg:

1. Spelreglerna implementeras. GUI är ett bonus, men inte ett krav.
2. Monte-Carlo trädsöknings-baserade agenter implementeras och anpassas till det specifika spelet.
3. Spelbalans (eng: game balance) och taktik undersöks med de Monte-Carlo trädsökningsbaserade agenterna.

Nytta
Projektet bedrivs i anslutning till forskningsprojekt om taktisk AI på FOI.

Vidare läsning

- *Krigsspel med AlphaZero*, FOI 2021, https://www.foi.se/rapportsammanfattning?reportNo=FOI-R--5057--SE

Tidigare kursomgångar
Projektet är det tredje i en serie av projekt kring taktisk AI med Monte-Carlo trädsökning inom denna kurskontext.

- *Exploring Game Balance in the Scandinavian Fox Game with Monte-Carlo Tree Search*, Anton Janshagen och Olof Mattsson, Workshop on Tabletop Games, 2022
- *Monte-Carlo Tree Search for Risk*, Erik Kalmer och Christoffer Limer, 14th NATO Operations Research and Analysis (OR&A) Conference, 2020

Project P3: Explainable Fuzzy Challenge 2025

Handledare: Mika Cohen (mikac@kth.se), Division of Theoretical Computer Science, Marianela Garcia Lozano (marianela.garcia.lozano@foi.se), Christopher Limér (christoffer.limer@foi.se)

Det klassiska arkadspelet *Asteroids*.

Sammanfattning: I det här projektet spelar du det klassiska arkadspelet Asteroids med förklarbar AI (XAI). Utmana andra studenter i Explainable Fuzzy Challange 2025!

Bakgrund

I det klassiska arkadspelet Asteroids manövrerar tvådimensionella rymdskepp för att undvika kollisioner med asteroider som dyker upp. Asteroiderna har olika former, storlekar och hastigheter. Rymdfarkosten är utrustad med en laser för att hantera de irriterande rymdstenarna. Om de avfyrade projektilerna når något av målen bryts de i mindre bitar. Ett kontrollsystem måste ta hänsyn till alla olika funktioner i systemet och bestämma rymdfarkostens rörelse- och skjutbeslut (https://xfuzzycomp.github.io/XFC/about.html).

Kan du skapa en AI (ett kontrollsystem) för Asteroids som inte bara manövrerar skickligt utan även kan förklara sina beslut om eld och rörelse på ett lättbegripligt sätt? Detta är utmaningen i *Explainable Fuzzy Challenge* (XFC), en årlig studenttävling inom förklarbar AI (XAI).

Syfte

Projektet syftar till att bygga en AI för spelet *Asteroids* som kan förklarar sitt agerande. Projektgruppen väljer själv om den vill delta med sin AI i Explainable Fuzzy Challenge 2025.

Metod

Se xfuzzycomp.github.io/XFC/FAQ.html. Projektgruppen har stor frihet att välja vad för slags AI som ska användas (genetiska algoritmer, förstärkningsinlärning, m.m.).

Nytta

Projektet bedrivs i anslutning till forskningsprojekt om taktisk AI på FOI.

Introduktion till XFC

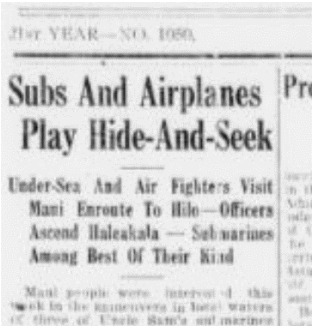
Se github.io/XFC/, specifikt följande videos:

- *Introduction to Asteroid Smashers, https://youtu.be/n9nf_EpCzck*
- *Introduction to Fuzzy Logic*, https://youtu.be/I3kN0NRIyyA
- *Gradient Free Optimiza*tion, *https://youtu.be/6qfPmJHaBNE*

Project P4: Nära optimal oförutsägbarhet i Kurragömma med hjälp av förstärkningsinlärning

Handledare: Mika Cohen (mikac@kth.se), Division of Theoretical Computer Science, Christopher Limér (christoffer.limer@foi.se)

Sammanfattning: I det här projektet försöker du hitta en nära optimalt oförutsägbar taktik till ett välkänt kurragömmaspel med tillämpning inom bl.a. ubåtsjakt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Subs And Airplanes Play Hide-And-Seek

Under-Sea And Air Fighters Visit Maui Enroute To Hilo—Officers Ascend Haleakala — Submarines Among Best Of Their Kind

The Maui news, 30 April 1920..

Bakgrund

The monster searches for the princess, the time required being the payoff. They are both in a totally dark room (of any shape), but they are each cognizant of its boundary. Capture means that the distance between the princess and the monster is within the capture radius, which is assumed to be small in comparison with the dimension of the room. The monster, supposed highly intelligent, moves at a known speed. We permit the princess full freedom of locomotion. (Differential Games, Rufus Isaacs, 1965)

Så introducerades spelet *Prinsessan och Monstret* för snart ett halvt sekel sedan, idag ett klassiskt spel inom spelteorin med tillämpning inom bl.a. ubåtsjakt och annan kurragömmaliknande jakt där gömmaren aktivt försöker undvika att bli hittad. I den diskreta versionen av spelet rör sig monstret och prinsessan över en graf. Monstret rör sig från en nod till en angränsande nod i ett tidssteg medan prinsessan kan röra sig fritt från en nod till en annan. Den diskreta versionen är alltjämt olöst snart ett halvsekel sedan spelet introducerades – bortsett från lösningar för några extremt enkla grafer.

Syfte

Projektet syftar till att beräkna en effektiv – men inte nödvändigt helt optimal – taktik för monstret med en beräkningslätt metod som utvecklats på FOI för kurragömmaliknande spel inom ubåtsjakt. Metoden innebär att monstret lär sig maximera prinsessans osäkerhet (entropi) med hjälp av förstärkningsinlärning.

Metod

Lite grovt kan arbetet delas in i följande steg:

1. Implementera kurragömmaspelet *Prinsessan och Monstret* över en godtycklig graf (lätt gjort!). GUI är ett bonus, men inte ett krav.
2. Implementera FOI:s metod för att ta fram en kalibrerat oförutsägbar taktik för monstret genom att maximera prinsessans osäkerhet med hjälp av förstärkningsinlärning.
3. Utvärdera metoden.
    a. Utvärdera hur väl metoden skalar till mer komplexa grafer.
    b. Utvärdera hur nära optimalt oförutsägbar taktik som metoden ger i enkla grafer med känd optimal lösning.
4. Bonus: Vidareutveckla algoritmen efter egna idéer.

Nytta

Projektet bedrivs i anslutning till forskningsprojekt om taktisk AI på FOI.

Vidare läsning

- Prinsessan och Monstret: https://en.wikipedia.org/wiki/Princess_and_monster_game
- Populär introduktion till förstärkningsinlärning: https://spinningup.openai.com/en/latest/spinningup/rl_intro.html

Project P5: Design och jämförelse av strategier för oförutsägbar utplacering av honungsfällor

Handledare: Joel Brynielsson (joel@kth.se), Edward Tjörnhammar (edward.tjornhammar@foi.se).

Sammanfattning: I det här projektet studeras cybervilseledning genom oförutsägbar utplacering av honungsfällor.

Bakgrund

All krigföring baserar sig på bluffspel. -- Sun Zi

Av alla mänskliga aktiviteter påminner krig mest om ett kortspel. -- Carl von Clausewitz

Runt om i världen använder numera säkerhetsoperatörer AI-algoritmer för att planera ett optimalt oförutsägbart försvar inom olika arenor – tillämpningarna handlar om övervakning av allt från flygplatser och hamnar till kust och hav. För att göra försvarsinsatser oförutsägbara i en konfliktsituation (exempelvis bekämpningen av tjuvjakt i ett naturreservat) tillförs ett element av slumpmässighet i hur försvarsresurserna (såsom fotpatruller) agerar. Men försvarsresurserna agerar inte helt godtyckligt utan algoritmerna slumpar agerandet på ett sätt som maximerar den avskräckande effekten i konfliktsituationen. Cyberförsvar utgör ett exempel på en sådan konfliktsituation som är asymmetrisk såtillvida att angriparen har möjlighet att skanna av och testa olika attacker över tid, samtidigt som försvararen utför motåtgärder i form av att placera ut olika typer av skyddsåtgärder såsom honungsfällor – falska servrar som placeras ut i en organisation i syfte att locka till sig angripare och kartlägga dem.

Nyligen genomförda experimentella studier har undersökt hur väl adaptiva strategier för utplacering av honungsfällor klarar att försvara sig mot mänskliga angripare. Men eftersom försökspersonerna hämtades från en okänd population av försökspersoner via Amazon Mechanical Turk,[1] är relevansen för försvar mot verkliga hackers oklar. I en studie som genomfördes 2023 i samband med förra årets kandidatexjobbskurs replikerades därför experimenten med mer relevanta försökspersoner. De erhållna resultaten tyder på att strategierna är mindre effektiva mot angripare i den studerade populationen, och att algoritmernas förmåga att förutsäga nästa attack stadigt minskar över tid: de mänskliga försökspersonerna lärde sig att attackera allt mindre förutsägbart.

Syfte

Projektet syftar till att designa och jämföra algoritmer för oförutsägbar utplacering av honungsfällor i en organisations datornätverk.

Metod

Projektet kan beroende på exjobbsgruppens intressen och bakgrund ges en i olika utsträckning utforskande, jämförande eller implementerande karaktär. Ett grovt utkast till metodologiskt upplägg skulle kunna vara följande:

[1] https://www.mturk.com/.

- Studera vad som hittills är gjort med fokus på inläsning på tidigare strategier för slumpvis utplacering, och välj sedan en delmängd av följande approacher för att designa strategier:
    - klura ut en helt ny strategi som skulle kunna spöa de som redan finns
    - skapa en ensemble-strategi som kombinerar bra egenskaper hos tidigare strategier
    - ta del av FOI:s idéer kring nya alternativa strategier och konkretisera dessa.
- Överväg att antingen använda det befintliga abstrakta spelet för honungsfällautplacering, eller att hitta på ett nytt spelproblem som bättre fångar/efterliknar en organisations datornätverkstopologi.
- Implementera de nya strategierna och stoppa in dem i det redan utvecklade FOI-systemet för experimentella studier.
- Genomför försök med en relevant population (gör som förra årets studenter som genomförde sina försök med en årskurs F-studenter som fick FOI-sponsrad choklad som pris då de spelade, eller genomför tillsammans med FOI försök med en relevant cybersäkerhetspopulation).

Nytta

Projektet bedrivs i anslutning till flera olika forskningsprojekt på FOI med bäring på AI för optimalt oförutsägbar allokering i cyberrymden.

Vidare läsning

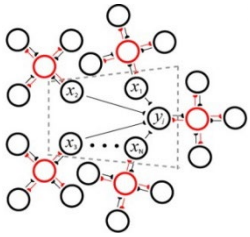
- J. Brynielsson, M. Cohen, P. Hansen, S. Lavebrink, M. Lindström, E. Tjörnhammar, ”Comparison of Strategies for Honeypot Deployment”, i Proceedings of the 2023 IEEE/ACM International Conference on Advances in Social Networks Analysis and Mining (ASONAM 2023). ACM, New York, NY, 2023.
- J. Brynielsson, M. Cohen, F. Kamrani, D. Oskarsson. Patrullering med poker-AI: Systematiskt oförutsägbar patrullering i sjö, mark och cyberrymd. Teknisk rapport FOI-R--5291--SE. Totalförsvarets forskningsinstitut, Stockholm, 2022.

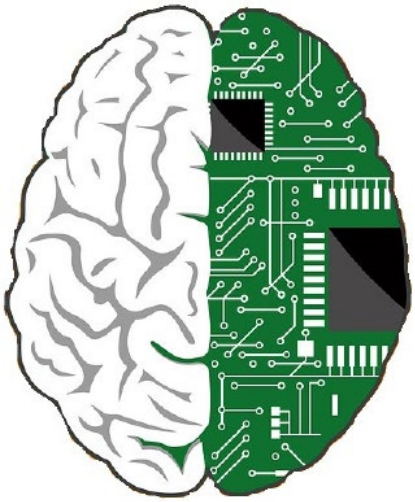
Context Q: Computational brain modelling and brain-like computing

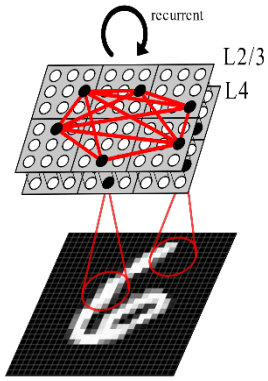
The general focus is here on developing, studying and/or applying connectionist (neural network based) models of the brain. The proposed topics range from simulating detailed spiking neural networks to investigating and validating more abstract brain-like computing architectures. Projects can be formulated to either address theoretical questions, develop neuromorphic methods or test the networks' functionality in applications.

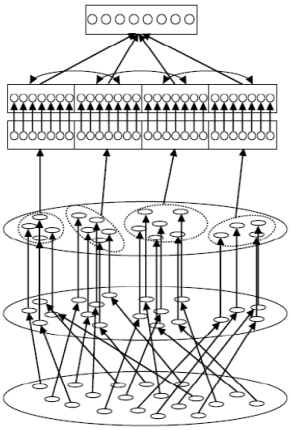
Please bear in mind that project details and specific research questions within the proposed themes are discussed individually with students depending on their interests. There is also a lot of flexibility in defining the scope and size of these projects. Some project ideas at the cross-sections of the following themes can be proposed/found. Students will have an opportunity to learn to use dedicated simulation software (with a possibility to rely on Python interface) or exploit their programming competence to build their own computational tools for theoretical or applied research. The focus however is on the scientific essence of the project, not on the methodology used.

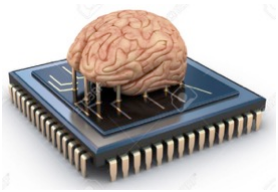
The suggested projects are organized in two main themes, each of which describes a set of proposed topics. The lists of topics and some project ideas are not meant to be limiting in any sense and can therefore be easily expanded by students' own ideas.

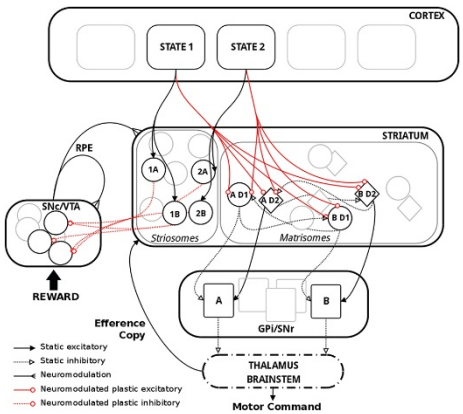












Project Q1: Simulations of attractor neural networks as models for human memory

Supervisor: Pawel Herman (paherman@kth.se)
Division of Computational Science and Technology (CST)

General theme

There have been a range of theoretical concepts of brain computations proposed in computational neuroscience. Among the connectionist (network-based) approaches to modelling brain function, an attractor theory of neural computations has recently received particular attention. The functionality of attractor networks has been found helpful in explaining various perceptual and memory phenomena. Consequently, these models can be considered as fundamental components of systems level approach to modelling brain function within the framework of network-of-networks architecture. An implementation of attractor memory models can range from a more biologically plausible networks of spiking neurons to more abstract networks of units with continuous rate-based input/output.

More biologically detailed models with spiking neurons and synapses provide an opportunity to study rich neural dynamics in close relation to biological data, and specifically, recordings from the brain tissue. This way both dynamical and functional aspects of fascinating cortical phenomena can be studied. Such spiking neural network models are usually developed using dedicated simulation software, e.g. Nest, Neuron, Genesis etc.

More abstract networks relying on rate-based units (i.e. with non-spiking real-valued input/output like in more classical artificial neural networks) on the other hand allow for constructing larger systems with the aim of exploring functional aspects of the simulated attractor memory system. In this context, both generic theoretical investigations into computational capabilities of memory (learning, memory capacity etc.) as well as specific applications in pattern recognition, whether in a biological or non-biological data mining context, can be pursued.

Within this theme other computational theories of the brain, e.g. liquid (echo) state machines or other recurrent architectures, can also be studied. In this regard, computational or dynamical aspects as well as application-oriented questions may be explored. Students can make use of existing software simulators or developed their own implementations of network models.

Project ideas

1. Studying the effect of different connectivity patterns, levels of modularity, network architectures, and their dimensionality on the dynamics and function of the attractor or other network models of selected brain function (memory, perception etc.).
2. Investigating the effect of different local learning rules on functional and operational capabilities of network models of the brain's memory function.
3. Exploring capabilities of attractor-like network memory models to operate on sequential memories (sequence learning capabilities, sequential mental planning etc.).
4. Investigating the storage capacity of brain's memory models for long-term memories acquired over the lifespan – simulation of long-term memory maintenance in our brains throughout our lives (subject to varying age-dependent processes).
5. Investigating the sensitivity of the model to the level of biological detail being accounted for (discussion on the required level of complexity and the relevance of biological constraints).

Project Q2*:* Brain-like neural networks and associated neuromorphic computing algorithms – theoretical developments and applications

Supervisor: Pawel Herman (paherman@kth.se)
Division of Computational Science and Technology (CST)

General theme

Development of brain models to study neural phenomena, as broadly discussed in the first theme above, often leads to better understanding of the nature and purpose of neural computations. From a broader perspective, these computations can be seen as an inspiration for novel approaches to generic information processing. Good reputation of neural network architectures in this regard is largely due to the impressive capabilities of information processing in the brain, which robustly handles large volumes of noisy multi-modal data received in continuous streams. Consequently, brain-like computing has long been considered as a particularly appealing concept in a broad field of information and, nowadays, data science. With the increasing availability of powerful computing platforms and intensive development of neural network based brain models as well as a growing body of knowledge about computational mechanisms underlying brain function, there is a surge of interest in adapting these functional aspects to devise algorithms in the form of brain-like neural networks for more generic applications in the field of data mining, pattern recognition etc. These efforts are urgently needed and particularly relevant to real-world problems involving so-called big data, for example in exploratory analysis of large volumes of high-dimensional neuroimaging data for research or clinical purposes.

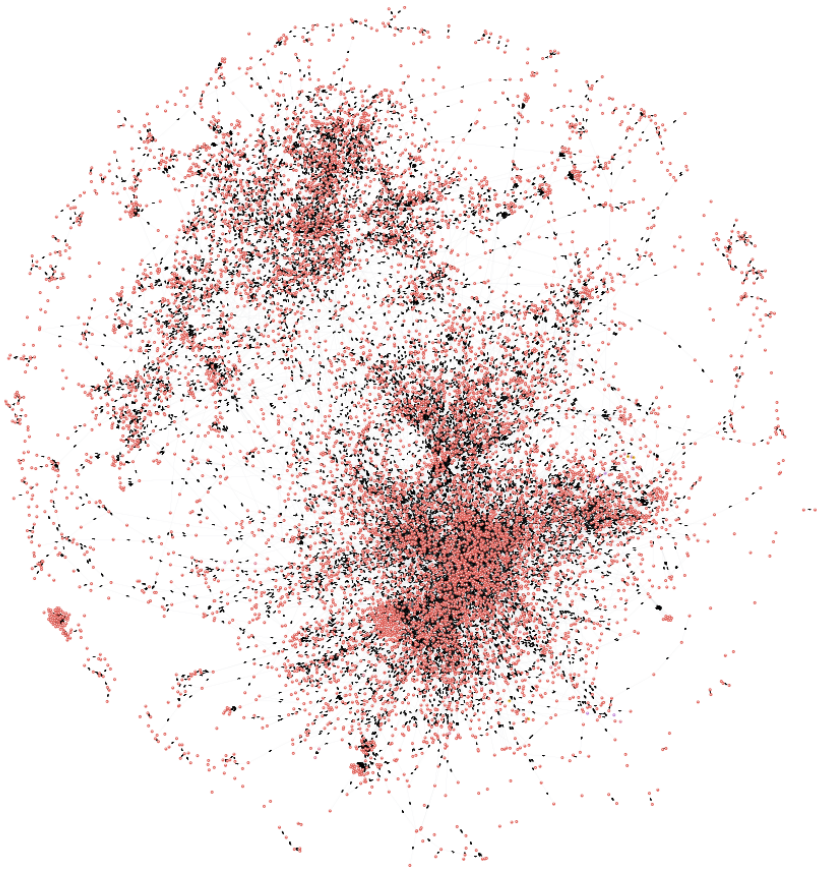
Brain-like neural networks differ from today's deep neural networks in the connectivity patterns, architectural design and learning methods among others. In consequence, they can help addressing different class of problems, e.g., in unsupervised or semi-supervised scenarios with lower demand for data and stronger demands for robustness. They can be deployed as spiking neural networks (event based asynchronous systems) in neuromorphic applications or as more abstract rate based neural network models (synchronous with continuous output similar to traditional neural networks) depending on the problem, specific application needs or given other constraints.

Project ideas

1. Adapting selected brain-like computing paradigms for large-scale data mining, e.g. to perform exploratory search for patterns in data.
2. Devising new brain network inspired approaches to generically process temporal or sequential data and/or comparing to the existing state-of-the art attempts.
3. General evaluation, benchmarking and validation of brain-like computing algorithms on different pattern recognition problems.
4. Testing robustness (sensitivity analysis, noise handling capabilities, computational speed) and benchmarking brain-like computing methods against more conventional machine (/statistical) learning techniques on a selected set of benchmark problems.
5. Exploring capabilities of recurrent brain-like neural networks for more challenging pattern recognition tasks corresponding to human perception, e.g. pattern completion, gestalt perception, clustering, denoising, figure-ground segmentation etc.

Context R: Automatic bug fixing and Securing Software Supply Chains

Context Responsible: Martin Monperrus, monperrus@kth.se



In this research context, we invent systems to automatically fix software bugs and secure supply chain vulnerabilities. Our systems repair Java code, are strongly validated on real bugs and large scale programs. Our software prototypes are all made open-source for sake of reproducible research and open-science.

Project R1: Automatic Categorization on AI Patches with AST Analysis

Supervisor: Martin Monperrus, (monperrus@kth.se)

Project description: KTH has invented a new system called Sequencer for producing patches with machine learning [1]. Sequencer learns from past diffs using sequence-to-sequence learning. The student will perform a large scale analysis of the Sequencer patches. The experiment will involve the Gumtree AST diff library and will be done on a scientific computing grid.

1. SequenceR: Sequence-to-Sequence Learning for End-to-End Program Repair
2. Benchmark of single-line bugs

Project R2: Automatic Program Repair of Bears with Repair Templates

Supervisor: Martin Monperrus, (monperrus@kth.se)

Project description*:* In automatic program repair, template-based repair is an effective way to reduce programs with little overfitting [1]. The student will implement template-based repair in Astor [3], based on the consolidated list by Liu et al [1]. The student will design design and perform a large scale experiment of template-based repair on the BEARS benchmark [2], with quantitative and qualitative analysis.

1. TBar: Revisiting Template-based Automated Program Repair
2. Bears: An Extensible Java Bug Benchmark for Automatic Program Repair Studies

   https://github.com/SpoonLabs/astor

Project R3: Neural Repair of Static Analysis Warnings

Supervisor: Martin Monperrus, (monperrus@kth.se)

Project description: Static analysis tools are much used in industry to statically detect bugs and code smells. You will research in the area of machine learning for repairing static analysis warnings. You will devise, implement and evaluate an approach based on sequence-to-sequence learning. The considered static analysis tools are SonarQube-java and Facebook infer.

1. Automatically Generating Fix Suggestions in Response to Static Code Analysis Warnings (2019)
2. Adversarial Robustness for Code (2021)

Project R4: Diverse Double Compilation for Java

Supervisor: Aman Sharma, (amansha@kth.se)

Project description: In this project we invent and implement systems to secure software supply chains. A software supply chain refers to the ecosystem of tools, dependencies, and processes involved in the development, delivery, and maintenance of software. It includes third-party libraries, build systems, version control, and deployment mechanisms. Software supply chains can be vulnerable to attacks, where malicious actors exploit dependencies or inject vulnerabilities during the software development lifecycle.

Java is a key programming language for enterprise applications. As such, the Java compiler is an ideal target for a trusting trust attack where malicious self-replicating code is inserted into the compiler binary. This can modify other programs at compile-time, for example adding a backdoor into a login-manager, without any chance of being discovered by traditional source code analysis. This thesis aims to investigate the feasibility of diverse-double compilation (DDC) – As described by David A. Wheeler in ‘Countering trusting trust through diverse double-compiling’ – to mitigate this problem. In this project you will design, implement and evaluate DDC for Java.

Project description

1. Read and explore existing research in this area
2. Design and implement DDC for Java
3. Evaluate your implementation

Further reading

1. Reflections on Trusting Trust
2. Countering trusting trust through diverse double-compiling
3. Diverse Double-Compiling to Harden Cryptocurrency Software (Master's thesis KTH 2023)

Project R5: Support for unordered nodes in tree diffing algorithm

Supervisor: Martin Monperrus, (monperrus@kth.se)

Gumtree [1] is a popular tree differencing tool which can show difference between ASTs of multiple languages like Java, C++, Rust, etc. Its major novelty over traditional diff tools is that it can show the diff between two code snippets using addition, deletion, update, and move operation. This helps developers understand the differences in the code better. However, there are some changes in the source code which do no affect meaning of the code and may not be important for it to be included in the diff. For example, in Java, the order of method declaration is irrelevant. As of now, Gumtree would show a move operation if the order of the method declaration is changed. In this thesis, we would want to add support for "Unordered Nodes" that would allow storing syntactic features (like method declarations, import statements) whose order is irrelevant. Thus, if the contents of this move somewhere else in the AST, Gumtree would no longer show the move operation.

Project description

1. API support for unordered nodes in Gumtree [1].
2. Implementation in Java based Gumtree diff tool [2].
3. Manual evaluation over pairs of Java source code submitted as test of this feature.

Further Reading

1. Fine-grained and Accurate Source Code Differencing
2. Add support for including unordered nodes