

## Excellence Center at Linköping – Lund in Information Technology

**Quality Review Report** 

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# Introduction

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ELLIIT has undergone tremendous development over the years. We now have a strategic research area within the broader field of information technology (IT) and mobile communications that spans 65 Ph.D. students, 24 recruited faculty members, and a dynamic research environment with more than 400 researchers at four partner universities. As directors, we are honored to be part of this journey and thank all our researchers for their commitment and contributions to the environment. Without our researchers, there is no ELLIIT.

Erik G. Larsson, Linköping University, Director Fredrik Tufvesson, Lund University, Co-Director

### 2. About ELLIIT

IT and mobile communications are transforming our lives and constitute a backbone of Swedish industry. ELLIIT is one of two strategic research environments in Sweden in the area of IT and mobile communications. It has been funded by the Swedish government since 2010, and was expanded significantly in 2020 to meet the needs of technology development and a skilled workforce for the digital transformation of society.

The overarching goals of ELLIIT are to perform fundamental research within IT and mobile communications, to supply the Swedish industry with competence, to educate the next generation of engineers, and to generate research results that can be exploited by industry and in society.

ELLIIT partners are Linköping University (LiU), Lund University (LU), Blekinge Institute of Technology (BTH) and Halmstad University (HH). Linköping University is the coordinating partner. At LiU, large parts of the three departments of Computer Science, Electrical Engineering, and Science of Technology are involved; a few projects have (co-)PIs at other departments. At LU, activities are mainly focused within the four departments of Automatic Control, Computer Science, Electrical and Information Technology, and Center for Mathematical Sciences. At BTH, the activities are focused within the three departments of Computer Science, Health, and Software Engineering. At HH, activities are based within the School of Information Technology and divided between its two constituent departments: Computing and Electronics for Real-Time, and Embedded Systems; and Intelligent Systems and Digital Design.

#### Organization

The ELLIIT management consists of a director (E. G. Larsson, LiU), a co-director (F. Tufvesson, LU), a Steering Group (SG) and a Program Group (PG); see the chart on top of the next page. These governing bodies are supported by the ELLIIT Operations Team that provides administrative, fiscal, and communication support.

The Steering Group (SG) monitors the overall operation of ELLIIT and makes decisions on the allocation of funding and on the ELLIIT recruited faculty positions. The Program Group (PG) consists of faculty members from within ELLIIT, and is responsible for the day-to-day management of the program, follow-up of the scientific activities, and planning of future activities. The PG is led by a PG chair. The director and co-director are members of the PG.

The SG and PG members are appointed by the respective partners. The director, co-director, and PG chair are formally not members of the SG, but they participate in the SG meetings.



#### Strategy Development Work

The ELLIIT directors, SG, PG and the ELLIIT recruited faculty are undertaking continuous strategy development work to address new social changes and opportunities. In 2019, we published the *ELLIIT 2030 Technology Foresight* that defined the prioritized research directions for the next decade. This document had co-authors both from within and from outside of ELLIIT, and was widely distributed to stakeholders and decision makers. In 2023, we authored the *ELLIIT Technology Foresight*, 2023 Companion, which describes ten additional emerging trends and challenges that we have identified. The *Technology Foresight* together with the *Foresight Companion* will drive ELLIIT's long-term development.

#### **Our Goals and Values**

ELLIIT's main mission is to foster fundamental research.

We have adopted the following goals and values:

- Scientific excellence: We publish in the best journals and conferences.
- Education: We give the best courses and drive the new education programs.
- Outreach: We disseminate knowledge in venues beyond traditional topical academic journals.
- We have impact
  - on *academia*, through publications, talks, academic service, and courses;
  - on *industry*, by educating the next generation of engineers, and commercializing research results;
  - on *society*, by generating and disseminating knowledge, and educating engineers who make use of their knowledge to design, develop and deploy new products and services.
- We cooperate between traditional disciplines.
- We are active partners in Horizon Europe projects.

#### **Funding Instruments**

ELLIIT started its operation in 2010 with 40 partially funded Ph.D. student projects and faculty recruitments in areas where we saw a need for strategic renewal and reinforcement. Initially, ELLIIT's operating budget was 31 MSEK/year. In 2020 the government increased the funding substantially, and the total budget for 2024 is



114 MSEK. We reorganized the operation, opened new Ph.D. student calls, identified critical infrastructure to leverage the research, and recruited additional faculty members in our prioritized areas.

The ELLIIT funding is provided by the Swedish government in its annual regulatory letter to LiU and constitutes a part of the university's base faculty funding. This funding is earmarked for basic research and graduate education in IT and mobile communications. By agreement between the partners, the funding is split as follows: 45% to each LiU and LU, and 5% to each of BTH and HH. The principle for funding use, as agreed by the partners, is that 30–50% should be used to support projects, 30–50% should be used to fund tenured and tenured positions in the research area of ELLIIT, and up to 20% should be used for special initiatives.

#### Ph.D. Student and Postdoc Projects

The ELLIIT projects support doctoral students and postdocs. The chart at the top of the page gives an overview of the current and past project structure (calls A, B, C, and D); details are given in Part II. Call A supported postdoc projects; calls B, C, and D support Ph.D. student projects. The projects in calls B and C are twinned, such that in each project there are two Ph.D. students, each one based at a different site. In call D, the Ph.D. students are not twinned, but the students have a co-supervisor from one of the other partner universities.

#### **Recruited Faculty**

A major priority for ELLIIT is the recruitment of highly skilled and internationally competitive researchers to full-time faculty positions. This is crucial both for the growth of the environment and to find successors when faculty members retire. We currently support 24 recruited faculty members within the environment; for details, see Part III.

#### Infrastructure

We support eight infrastructure initiatives; see Chapter 8.

#### **Special Initiatives**

Important special initiatives are the ELLIIT Focus Periods (Chapter 9), the ELLIIT Workshop (Chapter 10), and the ELLIIT Gender Program (Chapter 11). The workshop and the focus periods also serve to improve cohesion within ELLIIT and its four partner universities. In addition, we have a Distinguished Lecture series with many invited talks that are open to anyone in the environment.

We also support a 20% adjunct professorship at LU in the area of Automatic Control with Focus on Machine-Learning and Bioinformatics, to help foster interdisciplinary research.

#### **ELLIIT Core and Environment**

Within ELLIIT, we have defined the terms ELLIIT core and ELLIIT environment.

The ELLIIT core includes:

- senior researchers recruited with support from ELLIIT (especially ELLIIT recruited faculty), fully or partially funded.
- PIs and co-PIs of with doctoral student and postdoc projects, and other participants in projects funded by ELLIIT.
- Ph.D. students, fully or partially funded by ELLIIT (via projects or recruitment packages).
- The members of the ELLIIT PG.
- Other personnel with direct funding from ELLIIT.

The ELLIIT environment includes:

- The ELLIIT core.
- The ELLIIT SG.
- Researchers (including doctoral students) in research groups where ELLIIT funds constitute an important part of the funding of the research group's activities. Examples include smaller research groups or departments with at least two ELLIIT-funded doctoral or postdoctoral projects, larger research groups or departments with at least three ELLIIT-funded doctoral or postdoctoral projects, and research groups with support for senior researchers.
- Doctoral students with supervisors who have an ELLIIT doctoral student project, or direct funding from ELLIIT, within a field that is scientifically relevant to ELLIIT.
- Researchers who have previously received ELLIIT funding, or had ELLIIT projects in the past.

#### **Contributions to Education**

Making contributions to education at all levels is an important goal of ELLIIT. ELLIIT recruited faculty and project leaders are expected to teach at all levels, to drive course and curriculum development, and to lead the development of new education programs. These efforts are summarized under the respective headings in Parts II and III.

#### **Outreach and Broader Impact**

ELLIIT project leaders and recruited faculty are active in outreach activities, as detailed in Parts II and III.

In 2021 we published the *ELLIIT – Strategic Research for Society and Industry*. This book uses 17 case studies to illustrate how ELLIIT has generated new ideas within basic research, and how it has developed and exploited these ideas, making an impact on Swedish society and industry. A version in Swedish is also available.

Outreach activities organized centrally within ELLIIT include the ELLIIT Tech Talks (Chapter 12), and local events targeting the business sector around Linköping/Norrköping, Lund, Karlskrona and Halmstad. An example of the latter is the industry forum breakfast and infrastructure kickoff event to be held in Linköping on January 25, 2024.

#### **Exploitation and Industry Cooperation**

ELLIIT's focus is fundamental research, that in turn can support more applied projects and cooperation with industry. Exploitation activities therefore primarily take place within bilateral agreements between the respective research groups and companies. See Parts II and III for details on industry cooperation and exploitation activities undertaken specifically within the ELLIIT-funded projects, and by the ELLIIT recruited faculty.

#### Chapter 2. About ELLIIT

To support new forms of cooperation, ELLIIT encourages matchmaking between ELLIIT project leaders, ELLIIT recruited faculty, and relevant corporations. We also leverage our industrial advisory board and industry forum (see Chapter 13), and activities in fora where these groups participate.

#### **Evaluation Criteria**

The overarching objective of ELLIIT is to achieve scientific excellence in combination with industrial and societal relevance and impact. To benchmark our success, we have defined the following criteria:

- 1. Scientific excellence and impact, as measured by publications in highly ranked, high-impact peer-reviewed international venues, and by citations.
- 2. Quality of the ELLIIT Recruited Faculty as evidenced by publications, international experience and visibility.
- 3. New interdisciplinary cooperation initiated as a direct result of ELLIIT.
- 4. New inter-site (LiU-LU-BTH-HH) cooperation, initiated as a direct result of ELLIIT.
- 5. Industrial cooperation and impact as quantified via master thesis projects with industry, joint publications with industry, adjunct faculty positions, commissioned research and/or cooperation agreements with co-funding of research, patent applications and patents, and successful commercialization or use of technology developed in ELLIIT.
- 6. Distinctions including prestigious grants to ELLIIT researchers, international awards to its researchers, and service to the international academic community.
- 7. Outreach and broader impact for example: publicly available software, dissemination in popular scientific venues, and media impact.
- 8. Impact on education both undergraduate and graduate courses and programs.
- 9. External funding attracted as a direct result of new ELLIIT faculty recruitment.
- 10. The careers of ELLIIT alumni after leaving the environment how they bring skills and new knowledge to industry, the public sector and the civil society.

#### **Publications**

A complete list of scientific publications is available from the publications section of the ELLIIT webpage.

#### About this Quality Review Report

This report has been written for the internal evaluation to be performed by our International Advisory Board (IAB) in March 2024.

Additional information is available on the ELLIIT webpage.



# **Projects**

# 3 Call A 17 4 Call B 41 5 Call C 101 6 Call D 125



#### 3.1 Overview

In 2020, a project call ("Call A") was launched to kickstart the expansion of ELLIIT. 21 postdoc projects were awarded to allow promising young researchers to explore new directions within the scope of the ELLIIT Technology Foresight 2030. These projects were funded for two years and started during the second half of 2020.

#### 3.2 A1. Cooperative Autonomous Vehicles: Vehicular Communications for Maneuver Coordination in Urban Environment

PI: Alexey Vinel (HH) Co-PI: Maria Kihl (LU)

#### Objectives

Vehicle-to-everything (V2X) communications is a crucial component of future autonomous vehicles. The objective of this project was to design V2X protocols for maneuver coordination which would serve as a basis for Levels 3-4 autonomous driving and enable safe cooperative maneuvering in urban environment. This postdoctoral research proposal initiates new ELLIIT activity in focus themes 1 and 3 as a collaboration between Professor Alexey Vinel at Halmstad University (PI) and Professor Maria Kihl at Lund University (co-PI). The project was driven by the needs of Swedish automotive industry, specifically Volvo Cars.

#### **Main Scientific Achievements**

We focused on the interplay between unreliable V2X communication and the resulting impact on traffic safety during cooperative maneuvering. For the former we derived the age-of-information for the IEEE 802.11p V2X protocol together with Volvo Cars [Lyamin, 2021]. For the latter we introduced a so-called safety time functions and provided a computationally efficient algorithm for their computation even in dense traffic scenarios with many vehicles involved [Thunberg, 2021]. We provided an optimization-based procedure for efficient and safe passing of traffic lights (or other temporary road blockage) using V2X communication. We locally optimized

objectives that promote efficiency such as less deceleration and larger minimum velocity, while maintaining safety in terms of no collisions [Saeed, 2023]. Further collaboration has being continued in the framework of the project B5.



An approach for the safety analysis of cooperative maneuvering

#### Lasting Impact

The postdoctoral researcher hired at HH (together by Professor Alexey Vinel at HH and Professor Maria Kihl at LU) for this project was Taqwa Saeed. Now she is the postdoctoral fellow at LU.

Associate professor Johan Thunberg (HH, now LU), postdoctoral researcher Aleksei Fedorov (LU) and Ph.D.student Galina Sidorenko (HH) were also involved in this project and together with Professor Alexey Vinel (HH) obtained the main scientific result on formal safety modelling for the autonomous vehicles [Sidorenko, 2022]. We shown that a famous Mobileye Responsibility-Sensitive Safety (RSS) model fails to cover situations where the ego vehicle has a higher decelerating capacity than its preceding vehicle. We designed framework which allows calculating minimum safe inter-vehicular distances for arbitrary ego vehicle control policies and use it to extend the RSS model.

#### 3.3 A2. Scalable Data Processing in Networked Systems

#### PI: Anders Rantzer (LU)

Co-PIs: Richard Pates (LU), Claudio Altafini (LiU) and Anders Hansson (LiU)

#### **Objectives**

The aim of this project was to develop scalable algorithms to monitor, predict, and analyze data from large scale dynamic networks. The objectives were: 1) To exploit structural properties (such as graph properties, symmetries and conservation laws) in large dynamic networks to for scalable estimation and filtering with noisy and unreliable data and 2) To develop tools to support network operators monitoring the behaviour of networked systems, through scalable algorithms with provable performance guarantees.

#### Main Scientific Achievements

The efforts to develop scalable methods have mainly been based on the theory of positive systems. [Rantzer, 2021]. A methodology for designing structured optimal filters and control laws for transportation networks was also developed. In particular, it was shown that for optimal transport networks with delays, the information flow can be greatly simplified by exploiting tree structure [Heyden, 2021], [Heyden, 2022]. Applications in energy networks [Agner, 2023], [Agner, 2022], were coordinated by the postdoc Pauline Kergus. Here the



Scalable methods for coordination in district heating networks have been developed as an application study. The purpose is to reduce the risk for unfair distribution when in overload situations.

focus has been district heating operating in overload situations. Traditional network design suffers from the problem that buildings located far from the production units sometimes experience reduced flow rates resulting in lower temperatures. A coordinating control strategy has been derived, reducing the effect of such bottlenecks on the comfort of customers. The methods requires little information about models for individual units and minimal communication between control systems. Theoretical progress to support the strategy has also been made. In particular, robustness to uncertain network flow characteristics has been analysed using theory of positive systems.

#### Lasting Impact

Positive systems theory is gradually becoming one of the leading paradigms to modeling and control of large scale dynamic networks. The main contribution of this project has been the connection to energy networks. After her postdoc in Lund, Pauline Kergus became permanent CNRS researcher in Toulouse and the collaboration with ELLIIT has continued after her departure.

#### 3.4 A3. Autonomous Radiation Mapping and Isotope Composition Identification by Mobile Gamma Spectroscopy

PI: Anders Robertsson (LU) Co-PIs: Rolf Johansson (LU), Marcus Greiff (LU), Rikard Tyllström (LU) and Emil Rofors (LU)

#### Objectives

During commissioning, operation, and decommissioning of nuclear power plants, particle accelerators, and industries dealing with radioactive materials, there is a need to monitor radiation levels and isotope composition over large swathes of land surrounding the facilities. Ideally, this would be done regularly by an automated system, but during today's decommissioning of the Barsebäck plant and the building of European Spallation Source (ESS) in Lund, such measurements are taken manually using handheld devices by foot, or along roads around the facilities using car-mounted detector systems. Consequently, the goal of this project was to develop statistical methods for inference of radioactive isotope composition from gamma-radiation spectroscopy taken from an autonomous Unmanned Aerial Vehicle (UAV), permitting the automation of the process of radiation monitoring. This has been a joint project between (i) the Department of Automatic Control (Lund University) responsible for the development of novel algorithmic solutions, (ii) the Department of Nuclear Physics (Lund University) providing new radiation detectors capable of being carried by the UAV, and (iii) the Lund University School of Aviation (LUSA) providing the piloting and expertise during field experiments.

#### Main Scientific Achievements

Field tests were conducted to measure the radiation levels at various sites in the forests around Gävle, which is the region in Sweden that was most polluted after the Chernobyl accident in 1986. This resulted in a technical report and several data sets which will be used in future validation experiments.



Field tests on UAV-based radiation measurements (left) and the Matrice 600 pro UVA with added components labeled (right).

Similar measurements and algorithm development for estimation of background radiation have been performed around the European Spallation Source, Lund, and around the closed nuclear power plant at Barsebäck, where the UAV-carried sensor allows for measurement over both rougher terrain, buildings, and structures exposed to radiation.



UAV-based intensity measurements from site 'Kalhygget', Söderhamn (left) and Comparison of measurements at different sites and heights (right).

#### Lasting Impact

Existing radiation mapping methods were extended and published in a paper titled "Gamma-Ray Imaging with Spatially Continuous Intensity Statistics" [Greiff, 2021] at the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). This work proposed a novel method involving machine-learning techniques related to expectation maximization, and leverages classical numerical integration theory along with Bayesian model selection to estimate intensity of radiation intensity fields. Importantly, the proposed model class is large enough to encompass point sources—in which case both location and intensity are estimated. The method also includes nonlinear estimation models and incorporates known surface geometries. The method was evaluated on experimental data collected within the project using the UAV. This novel method holds promise to have lasting impact in the field.

To facilitate usage of the developed method, the open-source code [AerialVehicleControl.jl] was published to

#### Chapter 3. Call A

be used in future autonomous operations of UAVs for missions such as radiation mapping. While originally published in late 2020, it is affiliated with a publication that was published in 2021, titled "Attitude Control on SU(2): Stability, Robustness, and Similarities" [Greiff, 2021] that was presented at the American Control Conference (ACC).

Emil Rofors was awarded a postdoc position at UC Berkeley, in part due to his work and affiliation with the radiation mapping project. Marcus Greiff is now employed by Mitsubishi Electric Research Labs (MERL) in Boston, MA.

#### 3.5 A4. Secure Transparent Communications in the Industrial Internet

PI: Andrei Gurtov (LiU)

#### Objectives

Industry 4.0 calls for combining industrial machine sensor connectivity with cloud big data analytics. Sample application areas include smart factories, autonomous ships and vehicles, predictive maintenance and optimizations of flights.



Cyber-Security-and-Privacy-Threats-in-Industry-4.0.

The project focused on secure and scalable interworking of industrial equipment with assets protection and privacy control. The high-level objective of the project was to realize the following goals: 1- Cloaked IoT and industrial environment, 2- Usable and interoperable policy management, and 3- Scalable, high-performance, real-time multi-LAN architecture. Thus, Secure Data Sharing and Privacy with Standardization are main proposed thrust areas. It is of high relevance to industrial partners such as Combitech, Ericsson and ABB.

#### **Main Scientific Achievements**

We have examined the impact of Dual Connectivity (DC) on QUIC, a protocol that has not been previously studied in relation to DC. Through a series of experiments, we have demonstrated how QUIC is affected by DC parameters and network conditions. We have developed a privacy-assuring authentication protocol for Ambient Intelligence (AmI) Internet of Things (IoT) applications. This protocol uses blockchain and fog computing for unforgeability, non-repudiation, and efficient bandwidth utilization. The work on optimization of relay placement for scalable virtual private LAN services studied the effects of relay-based routing and proposes an algorithm that provides an approximate but efficient solution, leading to a reduction in memory required for routing tables. The study of Dew-Cloud-based hierarchical federated learning for intrusion detection addressed the issue of securing data in IoT devices. The proposed solution is a Dew-Cloud based model that uses hierarchical federated learning with a hierarchical long-term memory model deployed on distributed Dew servers and supported by

cloud computing. The model achieves high training accuracy with minimum loss and outperforms existing schemes in terms of performance metrics.

#### **Lasting Impact**

The results provide insights for network operators on how to deploy DC to achieve optimal performance and fairness for end-to-end service. The proposed protocol for IoT-AmI environments is computationally inexpensive and resource-efficient, providing a better solution than conventional centralized infrastructure-based authentication approaches. The proposed Dew-Cloud based model provides a higher level of data privacy and greater availability of critical IoT applications. The PI and his team contributed to the development of OpenHIP, an open-source protocol. Along with that, they have developed an open-source attack simulator to raise awareness among stakeholders about potential cyber threats. The research group also developed DRIP, an open-source protocol, for the reliable identity verification of drones.

One postdoc now works at Ericsson Research in Stockholm. Another postdoc was hired at Linköping University.

#### 3.6 A5. Dynamics and Control of Data-Driven Networks

PI: Claudio Altafini (LiU) Co-PI: Anders Rantzer (LU) and Erik G. Larsson (LiU)

#### Objectives

The overall goal of this project is to interface control systems and network science methodology, with the purpose of investigating two specific topics: 1- Developing network-level graph learning approaches from big data, 2- Investigating dynamical models of "opinion" forming and their emerging properties (e.g. consensus, polarization, clustering, etc.) on the resulting networks.

#### Main Scientific Achievements

**Graph-learning approaches from big data.** We have developed algorithms to investigate conditional independence in Gaussian graphical models, and applied them to multiomics data in Systems Biology (ATAC-seq, RNA-seq and mass-spec). In particular the algorithms rely on exploring the properties of the signed graph associated to a data covariance matrix, and to its inverse, the so-called precision (or concentration) matrix. The graph of this latter matrix carries the "true" information on the dependencies and independencies that are encoded in the random variables [Zenere, 2022a].

We have shown that its sign patterns are related to the behavior of a graphical model upon conditioning on certain variables, namely that the properties of structural balance/unbalance of the graph of the precision matrix can predict when conditioning leads to contraction/expansion upon conditioning.

**Models for opinion dynamics.** We have developed a model which we call concatenated Friedkin-Johnsen (FJ) model, dealing with a concatenation of opinion dynamics processes, i.e., a sequence of discussions in each of which an agent is behaving stubbornly, i.e., it is defending its own viewpoint when interacting with other agents. For this model, we have then investigated how an agent having a certain budget of stubbornness to spend in the concatenation of discussions should behave in order to maximize its social power. The problem is formulated as a strategic game, for which the solution can be explicitly computed. It turns out that the optimal solution (which is a Nash equilibrium for the strategic game, as well as a dominant strategy under certain assumptions) relies on a basic principle which we call "early mover advantage" expressing the fact that a early stubborn behavior in a sequence of discussions leads to a greater advantage in terms of social power when compared to a late stubbornness. The concept has been applied to experimental data describing the negotiation process going on at UN-sponsored climate conferences. The project is still on-going, and we are currently investigating extensions of the "social power game" formulation to other contexts and to opinion dynamics models other than the concatenated FJ model.



Achieving consensus in multilateral international negotiations: The case study of the 2015 Paris Agreement on climate change. For more information, see [Bernardo, 2021].

A parallel line of research has dealt with another class of opinion dynamics models, the so-called Hegselmann-Krause (or bounded confidence) model. The results were published in [Bernardo 2022] and [Bernardo 2024].

#### Lasting Impact

**Graph-learning approaches from big data.** Expressing contractivity/expansivity upon conditioning of covariance matrices in terms of the sign pattern of the associated precision matrix is a novel approach, not observed before. We believe that it might lead to a better classification of covariance matrices, and thereby to a better understanding of the properties of the associated multivariable Gaussian distributions and Bayesian networks. This property is useful for instance in discerning true and false positives in the statistical correlations of multivariate data, as our application to multiomics data in Systems Biology shows (see details in [Zenere, 2022b]).

**Models for opinion dynamics.** The "concatenated FJ" opinion dynamics model we developed was applied to experimental data collected by us on the UN-sponsored conferences on climate change. The results, published in a couple of papers in journals with high impact, see [Bernardo, 2021] and [Bernardo, 2023], essentially confirm the soundness of the model considered, in particular for what concerns the model-based calculation of the leadership profile of the countries in the negotiations. For this aspect, in fact, a validation could be carried out by comparing the results of our model with independent assessments of the leadership of the countries through survey questionnaires (the correlation between the two ways to rank leaders is up to 0.85). We believe our work is one of the first in the field of opinion dynamics in which an independent validation was carried out (excluding small-scale controlled experiments with volunteers).

Concerning bounded confidence models, the upcoming paper [Bernardo 2024] is a comprehensive survey of this widely popular class of models. We expect it to serve as a reference point for this rapidly expanding field.

The post-doc hired on the grant (Carmela Bernardo) is the first author of many of the major publications cited above (and a co-author in the other works related to the project, such as [Wang, 2023]). Currently (November 2023) she is still working in LiU on a follow-up topic.

#### 3.7 A6. Robust Motion Planning

PI: Daniel Axehill (LiU) Co-PI: Johan Löfberg (LiU)

#### Objectives

This project aimed to, in different ways, incorporate more precise and up-to-date information about disturbances and to decrease uncertainties in the plan that often traditionally are handled by introducing conservativeness. The proposed research presented four different directions to provide a better combination of performance and safety: disturbance-parameterized motion primitives to explicitly take into account disturbances, realtime improvement to essentially convert an open-loop plan to a closed-loop policy, learning to eliminate systematic errors over time, and High Performance Computing (HPC) in the cloud to be able to consider advanced approaches at reasonable computation times.

#### Main Scientific Achievements

The main scientific outcome of the project is a framework for disturbance-parameterized motion primitives, [Dhar, 2023]. The presented framework introduces the possibility to better take into account approximate knowledge of future disturbances and compute optimal plans making use of this knowledge. This means that, e.g., an autonomous ship gets the possibility to exploit approximate knowledge of wind strengths and directions to reduce the energy required to perform its maneuvers. And this is done under formal stability guarantees for safe execution of the planned motion. An important property of the framework is that the more detailed knowledge that is provided to the system, the less conservative it will be. The work includes theory, algorithms, and a challenging marine application. Apart from this main focus, work has been performed within realtime certification for Model Predictive Control (MPC) which is important for the execution of motion plans, now also making use of HPC to be able to take the step to larger applications. The results within realtime certification has been partially implemented in Julia and partially in library-free C-code and made available at github under the names ASCertain and daqp, respectively.

#### Lasting Impact

The lasting impact is that it is now possible to rather efficiently, with formal stability guarantees for the motion execution, incorporate knowledge about disturbances in optimal motion planning. It is clear from our results that this can have interesting and practically relevant applications, such as within energy optimal motion planning. Beyond the marine application, more applications within autonomous vehicles and aerial vehicles are currently being investigated. Furthermore, when it comes to motion execution, our results on realtime optimization and certification has received considerable interest and its impact will not only last, but be refined to be applicable to larger real-world problems. Furthermore, in an ongoing research collaboration with ETH Zürich, learning is investigated for robust motion planning, and a first manuscript is ready to be submitted for review.

Open-source software contributions:

- daqp (now integrated into YALMIP). The QP algorithm and software have been shown to be very competitive compared to other state-of-the-art software commonly used for MPC.
- ASCertain
- YALMIP

The postdoc hired for the A6 project, Abhishek Dhar, continues to work in another project on motion planning under uncertainty, at Linköping University with Scania as industry partner.

#### **3.8** A7. Effective Business Prototyping for Software Startups

PI: Elizabeth Bjarnason (LU)

#### Objectives

One important success factor of new business ventures is to test the business idea early on to validate its viability in the market. While prototyping is emphasized in recent methods such as Lean Startup and Design Thinking, there is little research on how to effectively use prototypes integrated in the dynamic business context of startups. For this reason, the project aimed to explore the use of different types of prototypes, their costs and benefits, through literature reviews, theory building and case studies. The aim was to support startups in making more effective use of prototyping for validating new ideas, and for communicating with stakeholders. Software startups can then more accurately pinpoint which business ideas are viable and shorten the leadtime to market these products, and thereby increase their chances of success.

#### **Main Scientific Achievements**

The main scientific results of the project consist of novel empirical insights into the prototyping practices of software startups including the selection of prototyping technology, and a theoretical model of prototyping aspects (PAM). The findings provide insights into common challenges and benefits with prototyping, and relationships between the costs and benefits of the practice depending on how the aspects are defined, e.g. the degree of refinement of a prototype or with whom and with what methods a prototype is evaluated.

The project explored how prototyping is used in startups through interviews with 12 local case companies. The initial results of these interviews were published [Bjarnason, 2021] and presented at an international workshop on requirements engineering for startups and emerging technologies (RESET 2021), thereby connecting to the international research community around software startups. The findings include a description of current practices among startups and found that prototyping is implicitly required by investors, and that software engineering competence plays an important role in enabling startups to effectively apply prototyping practices.

The project also defined a theoretical framework / model of prototyping aspects (PAM) based on a systematic literature review and empirical data from startups. The first version was published at a conference [Bjarnason, 2021], while the final version is published in the Empirical Software Engineering journal [Bjarnason, 2023] and was validated with the 12 case companies. The model can be used to reflect on why, what, and how to use prototyping to obtain different gains, e.g. validate requirements or elicit new ideas. Among other aspects, the PAM model points to the importance of considering the environment (digital and physical) in which a prototype is used, and the realism of the data included in the prototype.

Furthermore, the adoption of prototyping technology was explored in collaboration with Dr. V Gupta (Alcala, Spain). The results include a set of factors that affect the decision making within startups when selecting prototyping technologies and were published in IT Professional [Gupta, 2022].

#### Lasting Impact

The project has resulted in new empirical insights into how software startups use prototyping to explore and validate their business ideas, and how they can select suitable prototyping technology to support their needs. The results have been published and presented in scientific venues, and have lead to establishing a new collaboration with Henry Edison (BTH, Sweden) and Jorge Melegati (Free University of Bozen-Bolzano, Italy) on experimentation within software startups.

The insights gained from the research have been incorporated into a course on software business at LTH; ETSF25, around 140 engineering students (D and C programme) per year. The course provides the students with insights into the use of prototyping to explore, define, and validate new business models, and thus reduce the risks of wasting effort on unviable business ideas. The project has also led to new and strengthened connections between our education and local startups, including guest lectures from successful entrepreneurs (in ETSF25) and involving startups in student projects in our requirements engineering course (ETSN15).



Overview of the research method used to design and validate the Prototyping Aspects Model (PAM). From [Bjarnason, 2023].

Elizabeth Bjarnason is a senior lecturer of software engineering at Lund University, Sweden. The project has enabled her to broaden her research interests and her network within the software engineering community.

#### 3.9 A8. Gazing at Code Review(s)

#### PI: Emma Söderberg (LU)

Co-PIs: Luke Church (Univ. Cambridge/LU), Diederick Niehorster (LU), Markus Nyström (LU), Johanna Persson (LU), Christofer Rydenfält (LU), Christoph Reichenbach (LU) and Jürgen Börstler (BTH)

#### Objectives

Modern code review, where developers use tools to review code diffs to improve quality and build shared understanding, has gained wide-spread adoption in industry. Consequently, developers are spending a lot of time trying to understand and review other developers' code. Given the limited supply of (expensive) engineers there is much to be gained from simplifying this task. Progress in the area of eye-tracking (measuring what engineers look at and in what order) has opened up the possibility of providing developer tools that can adapt to the current needs of a developer in a specific context. Using eye-tracking, we aim to study modern code review and to investigate how intelligent assistance, driven by eye-tracking, may assist developers during this activity. This project proposal is aimed at the ELLIIT focus theme 'next-generation software technology' (theme C) and is a cross-disciplinary collaboration between Computer Science, Software Engineering, Design Sciences, and Psychology at LU and BTH.

#### Main Scientific Achievements

The empirical code review study carried out in the project was wrapped up and the results were reported in two publications, [Söderberg et al., 2022a] and [Söderberg et al., 2022b]. The final pieces of the GANDER framework developed in the project came together during 2022 to a point where it has been used to run gradually larger user studies. The first results exploring gaze-assistance in code review were accepted for publication in the beginning of 2023 [Saranpää et al., 2023], along with the contribution of the platform which is now released as open-source as part of the publication, the GANDER platform.

#### Lasting Impact

The platform developed in the project, shared as open-source (the GANDER platform), provides a platform for further study of gaze in code review and exploration of gaze-driven tool assistance. The empirical results from the project contributes to a deepened understanding of the developer experience during code review and provides directions for how to improve this experience along with developer productivity in code review.

## 3.10 A9. Safety and Resilience in Multi-Vehicle Behavioral Control for Autonomous Ground Vehicles

PI: Erik Frisk (LiU) Co-PIs: Lars Nielsen (LiU) and Björn Olofsson (LU/LiU)

#### Objectives

In this project we developed techniques for fault-tolerant decision-making and resilient behavioral control of autonomous ground vehicles in multi-vehicle traffic situations, strengthening an academically and industrially relevant research topic. The main topic area is "*1. Autonomous vehicles and robots*" and the application concerns techniques to introduce resilience to disturbances and faults and ensure safety for autonomous vehicles in traffic scenarios where there are multiple vehicles, being autonomous or not. A key is to include the dynamic behavior of the controlled vehicle for proper decision-making.

#### Main Scientific Achievements

The focus has been on safety and resilience in different multi-vehicle traffic situations. Main efforts have been directed at the development of methods for decision-making and prediction in uncertain multi-agent environments. To safely navigate in complex traffic situations, e.g., a busy roundabout or intersection, reliable prediction of surrounding vehicles over a control horizon and methods to act in a resilient way is one possibility to increase the safety and robustness of automated vehicles.

The two key scientific achievements can be highlighted, both published in IEEE Transactions on Intelligent Vehicles, a major international journal in the field. First, a method for acting in an uncertain world, [Fors, 2022], where estimation of adversarial agent behavior is combined with model predictive control (MPC), resulting in real-time performant control providing proactive autonomous behavior that is competitive with state-of-the-art reinforcement learning techniques without any need of training. A second main contribution is a method for probabilistic prediction behavior of surrounding road users in busy traffic situations, [Westny, 2023], where graph neural networks are combined with neural ordinary differential equations to predict the future trajectories of surrounding traffic. After the project, and in connection with the ELLIIT project B14, the techniques for probabilistic prediction of surrounding traffic have been extended.

#### Lasting Impact

The postdoc who has been involved in the project, Victor Fors, is now doing a postdoc at the Dynamic Design Lab at Stanford University. There, the theoretical research has been developed further and previous results have been implemented in a real vehicle.

Open source software contributions:

- MTP-GO: Graph-Based Probabilistic Multi-Agent Trajectory Prediction with Neural ODEs (https://github.com/westny/mtp-go)
- Vehicle Behavior Prediction and Generalization Using Imbalanced Learning Techniques (https://github.com/westny/imb-behavior-prediction)

#### 3.11 A10. Privacy-Preserving Machine Learning for Synthetic Spatio-Temporal Trajectory Data Generation

PI: Fredrik Heintz (LiU)

#### **Objectives**

A major open research challenge is developing privacy-preserving machine learning methods that both achieves high performance and privacy guarantees even though the original training data contains sensitive personal information. The applications are abundant, from making cities safer, via on-demand public transportation systems to improved medical diagnosis. The goal of the project was to develop new machine learning methods for creating synthetic spatiotemporal trajectory data sets preserving the privacy of the individuals in the original data. The project will 1) extend generative adversarial network (GAN) methods to learn generative spatiotemporal trajectory models and 2) develop new Bayesian Optimization methods for creating tailored privacy-preserving synthetic data sets using these generative models. The project has had access to unique trajectory data of people, busses and trains through collaborations with organizations such as Telia, Trafikverket and Östgötatrafiken. The project lies in topic A with strong connections to topics B and E in the ELLIIT 2030 Technology Foresight with important applications in themes 1 and 2. It complements and significantly extends ongoing research and will further strengthen the existing research collaborations with Lund University.

#### Main Scientific Achievements

- Bt-GAN: Generating Fair Synthetic Healthdata via Bias-transforming Generative Adversarial Network (paper accepted for publication in Journal of AI Research). We have developed a Bias-transforming Generative Adversarial Networks (Bt-GAN), a fair synthetic data generator, for the healthcare domain to tackle the correlation biases in the electronic healthcare datasets, MIMIC III (Medical Information Mart Intensive Care, version 3).
- 2. Fair Latent Deep Generative Models (FLDGM) for Syntax-agnostic and Fair Synthetic Data Generation [Ramachandranpillai, 2024]. There is a lack of study in learning fair Deep Generative Models to reach an optimal point between accessibility, fairness, quality, and flexibility (fine-tuning to various architectures, tasks, and fairness measures). To address this, we proposed Fair Latent Deep Generative Models (FLDGM) as enablers for more flexible and stable training of fair DGMs, by first learning a syntax-agnostic, model-agnostic fair latent vector representation of the data. This separates the fairness optimization and data generation processes thereby boosting stability and optimization performance. We conduct extensive experiments on image and tabular domains using Generative Adversarial Networks (GANs) and Diffusion Models (DM) and compare them to the state-of-the-art in terms of fairness and utility.

The project also has some work in progress:

- 1. A Systematic Review on Fair-XAI: the Interaction between Fairness and Explainability in Machine Learning Motivated by recent studies that showed incorporating explanations into decision-making increases the system's transparency and trust, we conduct a systematic review on Fair-XAI, the interaction between fairness and explainability framework. Considering the various aspects of Fair-XAI methods, we propose a Fair-XAI wheel that covers six core properties of Fair-XAI that must be verified and evaluated. Moreover, we identify some challenges and conflicts in the interactions that could open potential future avenues to enhance the trustworthiness of a system. Being the first review of this kind, we hope this survey may inspire scholars to take on these problems by examining current research in their respective domains. A paper is currently Under review.
- 2. Fair Generative models via hints-based knowledge distillation in latent space This work addresses fairness of synthetic data under the settings that the training data is not available, but we have access to a small fair dataset.

#### Lasting Impact

Concerning the Bt-GAN, the results demonstrate that we achieved state-of-the-art accuracy with significantly better fairness and minimal bias amplification. Furthermore, we performed an explainability analysis to substantiate our study.

Our proposed FLDGM achieves superior performance in generating high-quality, high-fidelity, and high-diversity fair synthetic data compared to the state-of-the-art fair generative models.

#### 3.12 A11. Novel Sounder Development, Parameter Estimation and Modeling for lower THz Radio Channels

PI: Fredrik Tufvesson (LU)

#### Objectives

The rapid evolution of wireless communication systems has significantly changed the daily life of people in recent decades. Fifth Generation (5G) and beyond 5G (B5G) wireless communication systems are expected to provide much higher network capacities, multigigabit per second (Gbps) data rates, low latency, and ultra-reliable communication while at a cost and energy dissipation similar to today. The millimeter wave (mmWave) and lower THz frequency bands (30-300 GHz) have been seen as a key enabler for B5G. Research to understand the mmWave and lower THz propagation channels is essential, since the propagation channels are distinct at different frequency bands, and devices and applications have to be designed with the constraints set by the propagation channel. Currently, extensive measurements and investigations have been conducted across the world at 28, 38, 60, and 73 GHz, but there are significantly fewer investigations above 100 GHz. Standard bodies and projects such as 3GPP, METIS and mmMAGIC have also proposed channel models for below-100 GHz frequency bands based on extensive field data. Compared to frequencies below 100 GHz, there are much wider spectrum slots available above 100 GHz, which have the potential for advanced applications such as wireless backhaul for fix links, indoor/WiFi access, velocity sensors, passive mmWave cameras, radar, navigation, and on-body communication. Among the spectrum slots, the D-band (110-170 GHz) is favorable due to the low atmospheric absorption loss and its very wide available spectrum. However, very little is known about the channel characteristics in this lower THz band. The reasons for the scarcity of investigations include the difficulties in developing double-directional channel sounders for dynamic channel characterization, efficiently and accurately extracting propagation channel parameters from the measurement data, and developing lowcomplexity channel models, yet with high fidelity to the real channels. To fill the gaps, the project aimed to explore the 'new frequency bands' and the possibilities they open up. The goal of the project was to create basic theory, technology and knowledge in channel characterization, parameter estimation, and modeling for the lower THz channel. We aim to gain the first understanding, make breakthroughs, and provide guidelines to open up realistic system design and performance analysis of communication, positioning, and sensing in the lower THz band.

#### **Main Scientific Achievements**

We have authored one paper in IEEE Communications Magazine about sub-THz propagation channels [Cai, 2024]. A low-complexity high-resolution channel parameter estimation algorithm has been developed for the mmWave channel sounder measurement data in both static and dynamic scenarios. The main difficulty of high computational complexity caused by the large number of antenna pairs was successfully overcome.

We continued working on the switched-array-based mmWave channel sounder and the mirror-based sub-THz channel sounder. We successfully made the mmWave channel sounder work in a good condition [Cai, 2023a]. The corresponding high-resolution algorithm was also developed [Cai, 2023b], [Al Ameri, 2023]. Both the sounder and the algorithm have been tested and verified in measurements and simulations. The summarizing papers are in the second round of revision.

Meanwhile, the progress of upgrading the sounder to the 140 GHz band is ongoing. We successfully monitored the output pulses from the mirror sensors, and the new sounding principle has been verified at lower frequencies.

#### Lasting Impact

We have successfully made the switched array-based mmWave channel sounder work perfectly by debugging and modifying the LabVIEW code, calibrating the antenna arrays, etc., and adopted it for sub-THz sounding. This channel sounder serves as the basic hardware for the development of the mirror-based THz channel sounder. The new sounder setup will enable us to characterize dynamic sub-Thz channels, which is currently lacking in the literature as of today. Hence, we foresee that this opens up for answering many of the unsolved questions



Millimeter wave channel sounder that has been converted to sub-THz frequencies.

when it comes to dynamic sub-THz channel characteristics.

At an academic level, we have received a VR starting grant for the postdoc, Xuesong Cai, and an EU grant as Marie Skodowska-Curie Actions (MSCA) Postdoctoral Fellow. Xuesong Cai has been recruited as an assistant professor at Lund University and an ELLIIT faculty member.

#### 3.13 A12. Usable Digital Twins in Healthcare

PI: Gunnar Cedersund (LiU)

#### Objectives

We have developed the only digital twin for humans that combines such diverse aspects as brain activity, blood flow, metabolism, and inflammation into a single model. However, to make this mathematical model usable in actual healthcare, there are remaining challenges that must be overcome. In this project, we addressed such critical challenges in three steps. Step 1: by examining the benefits of a patient-owned information platform, where patient-specific data and information from all relevant sources can be stored. Step 2: by creating new hybrid AI methodologies, which combines the strengths of mechanistic modelling and machine learning, and which allows e.g. for usage of a large variety of small- and large-scale data, to create personalized digital twins. Step 3: by designing new Intelligent Assistants, which combines the digital twins with the new patient-specific data storages, and which is helpful for both medical doctors, patients and ordinary citizen. These improvements should enhance and find synergies with parallel implementations of a corresponding eHealth app in the spin-off company "SUND sound medical decisions", and join forces and find synergies with other parallel projects: e.g. two projects funded by the Swedish Research Council (VR-NT and VR-M), and two funded by VINNOVA.

#### Main Scientific Achievements

We have developed a new hybrid approach that combines mechanistic multi-level models with machine learning models [Herrgårdh, 2021]. This new approach has also been implemented into a hybrid model for stroke [Herrgårdh, 2023]; [Herrgårdh, 2022]. This hybrid model can simulate, e.g., how different lifestyle changes and medications can result in both physiological and statistical changes. The physiological changes includes e.g. a prediction of how weight, glucose, insulin, and blood pressure changes in response to the lifestyle changes. These physiological variables are then entered into a new machine learning model that assesses the corresponding risk of a stroke. We have also shown how this model can be personalized using patient-specific data [Silvergren, 2022]. We have also verified that our hypothesis that a patient-specific vault is legally sound, and that it overcomes many of the legal and ethical limitations that are involved in traditional storage of patient-specific data in hospital or state-driven system. Finally, the new models have been entered into an Intelligent Assistant, i.e. into an eHealth app, which now is ready to be tested in real healthcare applications.

#### Lasting Impact

Due to changing demographics, current healthcare systems are facing enormous challenges: by 2030 the Swedish annual cost will have increased by >250 BSEK, and there will be a need for tens of thousands of additional nurses and doctors, which Sweden will not have. In this project, we have laid the methodological, legal, and ethical foundation for a new approach to this problem: an Intelligent Assistant in the form of a digital twin of yourself. This assistant can, if implemented, make healthcare more distributed, patient-driven, preventive, and patient-centric. This option is one of the few available alternatives that could tackle the scale of the upcoming challenges. The initial funding during this project has enabled a prototype, which now will to be tested in 200 patients, in 6 countries, during preventive Health Conversations. This will be done within the large scale EU-project STRATIF-AI, coordinated by Cedersund. If successful, this approach could become a part of all Health Conversations, and then a majority of all Swedes >40 years of age would have access to an intelligent assistant – a digital twin of themselves. This could happen within 10 years.

#### 3.14 A14. Embodied Visual Active Learning

PI: Kalle Åström (LU) Co-PI: Cristian Sminchisescu (LU)

#### Objectives

We focused on the task of embodied visual active learning, where an agent is set to explore a 3d environment with the goal of acquiring visual scene understanding by actively selecting views for which to request annotation. Today's deep visual recognition pipelines, while accurate on some datasets or benchmarks, tend to not generalize well to certain real-world scenarios. In robotic perception there is often a need to refine the recognition capabilities for the conditions under which the robot operates (e.g. cluttered indoor environments, poor illumination). This motivated our project, which can be interpreted as a form of life-long learning, where an agent's visual perception ability continually improves during its lifetime. To study embodied visual active learning in a concrete setup, we plan to develop a set of methods - both learned and pre-specified, and with different levels of knowledge of the environment - which seek to explore and acquire informative annotated views on which to train an underlying segmentation network. The learned methods would use reinforcement learning with a reward function balancing the competing objectives of task accuracy (which requires exploring the environment) and controlling the amount of annotated data requested. We planned to extensively evaluate our proposed models on the photorealistic Matterport3D simulators well as in real scenes. To the best of our knowledge this would be the first work to explores visual active learning for embodied agents navigating in realistic 3d environments.

#### Main Scientific Achievements

The project has made progress in several areas of learning with little or no annotation. Within embodied visual active learning, where an agent is set to explore a 3d environment with the goal of acquiring visual scene understanding by actively selecting views for which to request annotation, we have made progress, see for results published in 2022 and collected in E. Gärtner's Ph.D. thesis "Active and Physics-Based Human Pose Reconstruction". We have also started studying how limited labeling such as labelling ground truth sparsely in time can be used for learning detectors that exploit motion and propose the task Future Object Detection, in which the goal is to predict the bounding boxes for all visible objects in a future video frame, see [Tonderski, 2022]. Note that dynamics are learnt without having labels for consecutive frames which would normally be needed to learn sensor and object dynamics. We have continued our work on self-supervised learning on skeleton sequence data and propose a new data augmentation strategy including two asymmetric transformation pipelines. We have several results in this area both in terms of scientific papers and master's theses. In the project we have also explored how reinforcement learning can be used for learning with little annotation, e.g., within [Pirinen, 2022].

#### Lasting Impact

One of the major difficulties of machine learning is the need for ground truth labelling. This is costly and cumbersome and limits the potential use-cases. In this project we explore solutions to this problem, by developing methods that use little or no annotation. This includes new self-supervised learning such as (BYOL, SimCLR), embodied visual learning and new formulations such as future object prediction.

#### 3.15 A15. Relation Extraction with Deep Neural Language Models

PI: Marco Kuhlmann (LiU)

#### Objectives

The field of natural language processing (NLP) has seen major progress during the last few years with the development of deep neural language models, which learn tasks such as question answering, machine translation, and text summarization without any explicit supervision. This project aimed to apply these models to the task of extracting semantic relations between named entities from raw text. Our main goal was to design, implement, and evaluate an end-to-end system for relation extraction based on deep neural language models. Because training these models from scratch is extremely resource-intensive, we were specifically interested in developing methods for maximizing the performance that can be obtained by fine-tuning pre-trained models, and in particular models for smaller languages such as Swedish. Main topic area Focus Theme 5, 'Intelligent assistants and tools'.

#### Main Scientific Achievements

The main achievement of the project is a study on how to reduce the computational cost of fine-tuning large language models. A language model is initially pre-trained on a large volume of data and then adapted to a target downstream task. Fine-tuning is among the widely used adaptation techniques for knowledge transfer from the pre-training to the target domain. However, despite its simplicity and tremendous success in knowledge transfer, fine-tuning comes at an extensive computational cost, limiting applications. Furthermore, it reduces the deployment of language models in a cloud environment due to in-place parameter updates, which specialise language models and decrease their re-usability. Our project initially addressed the weaknesses of fine-tuning large language models for relation extraction. We then generalized the approach to a larger task domain of structure prediction, modelling the interactions between words within a sentence.

#### Lasting Impact

Our experimental results show that our proposed solution can retain more than 99% of the fine-tuning performance at a fraction of the training cost, while being as efficient as a fine-tuned model at inference time. Furthermore, compared with other techniques, our adaptation method performs significantly better on standard benchmarks while addressing the computational cost and the shareability issues of fine-tuning.

The postdoc hired for the project, Ali Basirat, is now assistant professor at the University of Copenhagen.

#### 3.16 A16. Control-as-a-Service: Resilient feedback control systems for Industry 4.0 based on Commercial-Off-The-Shelf components and cloud platforms

#### PI: Maria Kihl (LU)

Co-PIs: Anton Cervin (LU), Karl-Erik Årzén (LU), Anders Robertsson (LU), Emma Fitzgerald (LU), William Tärneberg (LU) and Niklas Carlsson (LiU)

#### Objectives

The project addressed the challenge of realizing highly time-sensitive and mission-critical feedback control systems for Industry 4.0 in the clouds. However, to take advantage of the clouds, rather than adapting the clouds to the control systems, we approach the problem by adapting the control systems to the clouds. The project proposes to address system performance, architecture, and management challenges associated with realizing a so-called Control-as-a-Service. The project is highly cross-disciplinary and the first of its kind in ELLIIT and it will be a starting point for a larger project.

#### Main Scientific Achievements

The research has mainly been focused on cloud-based industrial control systems, so called Cloud Control Systems (CCS). Within the research environment, we have the recent years published several papers investigating different topics within this subject. The main scientific advancements have been on intrusion detection mechanisms for cloud control systems [Akbarian, 2020] [Akbarian, 2023] [Akbarian, 2021]. The postdoc hired in this project focused on replay attack detection mechanisms for cloud control systems, where the results were published recently [Biswas, 2023]. Our proposed solutions have been implemented in the Kubernetes cluster provided by the ELLIIT infrastructure at EIT, LU. We have shown that cloud control systems can be deployed for time-critical applications, and that the cloud-based control systems have several advantages compared with traditional industrial control systems. However, we have also shown that the design of cloud control systems must take into account the uncertainties that comes with the clouds. The research activities are continuing after the project, mainly in two Ph.D. student projects at EIT.

#### Lasting Impact

The main work has been to validate the real-time performances of a published and well-known intrusion detection solution for industrial control systems. The specific solution has previously only been analyzed using theoretical models and numerical investigations. In our work, the solution was deployed in our Kubernetes edge cloud provided by the ELLIIT infrastructure, and its real-time performance was analyzed. The results show several real-time challenges when taking a theoretical solution to a real system. The postdoc that was employed in the project is now a postdoc at NTNU, Norway.

#### 3.17 A17. Multistatic high-resolution sensing at THz

PI: Mats Pettersson (BTH)

Co-PIs: Hans Hellsten (HH) and Fredrik Gustafsson (LiU)

#### Objectives

Multistatic high-resolution sensing at THz frequencies is the goal of this project, with applications in many areas, such as industry, logistics, health care, and surveillance. Autofocus for THz SAR imaging is the first step in future multistatic THz SAR system development. Project members Mats Pettersson at Blekinge Institute of Technology and other partners, including both Hans Hellsten in Halmstad university and Fredrik Gustafsson at Linköping university, have had strong and long collaborations for more than 20 years. We have good knowledge on UWB SAR system development, UWB SAR imaging, bistatic system development, bistatic SAR imaging, and even THz SAR measurements and imaging.

#### **Main Scientific Achievements**

The scientific results of this project include (1) the improved interpolation methods with the phase-control procedure that provides the opportunity to avoid upsampling THz signals [Ivanenko, 2022], (2) 3D THz SAR imaging algorithm, named Range Migration [Vu, 2022], (3) the limitations of the validity of the start-stop approximation in processing FMCW radar signals (including the signals at sub-THz and THz frequencies) [Vu, 2023], and (4) the autofocusing procedure based on compressed sensing that is incorporated into the backprojection algorithm [Ivanenko, 2023]. In summary, the research results of the project have been published in three (03) journals and eleven (11) conference papers, mainly in IEEE.

After the project, we received funding for one year from the Crafoord Foundation to work on the project entitled "Fundamentals and applications of bistatic SAR systems at THz frequencies," which will be a spin-off of the completed ELLIIT project. Several conference contributions on the topic of localization of mobile equipment in an indoor environment for future 6G cellular networks have been published in 2023.

In parallel to this research project, there has been bistatic SAR imaging research, such as bistatic SAR area resolution, sidelobe control and the tilt phenomenon, which is the first step for multistatic research. All of the results have been published in IEEE journals.

#### Lasting Impact

Avoiding the upsampling procedure minimizes the amount of hardware resources needed to store data for accurate THz SAR imaging. The study on the limitations of the start-stop approximation will be used as a basis in the further development of image formation algorithms for THz FMCW SARs, because the majority of the existing radar signal processing algorithms have been developed for pulse radar SARs, and future systems operating at THz frequencies will be designed based on FMCW radars. These results constitute the most impactful result of the project, which will be used in the continuation projects.

Concerning the postdoctoral researcher, Yevhen Ivanenko, he is currently working as a lecturer (universitetsadjunkt) at the Department of Mathematics and Natural Sciences, Blekinge Institute of Technology, Karlskrona. Very recently, the postdoctoral researcher and his colleagues received an approval of the pre-study project "Ny THz-avbildning för förbättrad avsigning i industriella productionprocesser" funded by Vinnova. The project will be conducted in collaboration with NKT High-Voltage Cables AB and SafeRadar AB.

#### 3.18 A18. Rational Oversampling in Coherent Optical

PI: Oscar Gustafsson (LiU) Co-PI: Håkan Johansson (LiU)

#### Objectives

Optical networks provide a backbone of the contemporary and future communication infrastructure, enabling high-speed interconnection among the myriad of devices connected through fixed or wireless interfaces. To obtain very high date rates, typically, very high sample rates are used, limited by achievable rates of ADCs and process technology. To maximize the utilization of the ADC sample rates, only limited oversampling can be used. However, signal processing blocks such as transmit and receive filters, synchronization, and most equalizer structures are expecting an integer number of samples per symbol. While possible to upsample to an integer oversampling factor in the receiver, this comes at a cost, both for the interpolation filters and for performing the signal processing at an even higher sample rate. The purpose of this project was to develop efficient algorithms and architectures performing the required signal processing at a fractional oversampling rate.

#### Main Scientific Achievements

A design method for chromatic dispersion compensation (CDC) filters in the frequency domain implemented using overlap-save techniques has been proposed [Gustafsson, 2023]. By not zero-extending the impulse response, but rather including those values in the design procedure, better compensation can be obtained at the same implementation complexity. This builds on another work, analyzing the effects of overlap-save implementation in practice [Johansson, 2023].

Different aspects of implementing CDC filters have been considered, with a focus on frequency-domain implementation. Word length optimization for shows that there are benefits in selecting heterogeneous word lengths for data, FFT twiddle factors and filter coefficient multiplications, respectively [Bae, 2021]. Additional work includes architectural trade-offs when realizing CDC filters in the frequency domain, illustrating that the minimal arithmetic complexity does not always give the least energy consuming solution. As part of that, we have developed systematic ways to shuffle data needed for streaming filters realized in the frequency domain using overlap-save and overlap-add processing. This becomes non-trivial for the general case when considering the high sample rates involved and, somewhat surprisingly, was not covered in the literature earlier.

Finally, the problem of convergence for high sample rate adaptation has been studied and bounds on the step-size has been derived when considering pipelining and block processing simultaneously [Khan, 2023].

#### Lasting Impact

The first post-doc, Krishna Chaitanya Patchava, only stayed for about half a year before departing to industry. The second post-doc, Mohd. Tasleem Khan, is still at the group as a post-doc, but is considering alternatives from universities abroad for a permanent position. The grant also provided partial support and inspiration for a Ph.D. student, Cheolyong Bae, with expected graduation in 2024.

The novel design method for frequency-domain FIR filters is likely to have the most impact long-term as it simply improves the results without any negative effects. Indirectly, the work explaining how this can be obtained naturally has a place there. The work on frequency-design implementation of FIR filters are relevant reference material illustrating the possible trade-offs. Finally, the new convergence results form an important background parameter when determining the pipelining vs block processing trade-off to reach a certain sample rate.



Bit-error rate (BER) in a 220 km optical fiber with chromatic dispersion using optimal time-domain filter design and proposed frequency-domain filter design [Gustafsson, 2023] with different FFT lengths, N.

#### 3.19 A19. Software Regression Testing with Near Failure Assertions

PI: Per Runeson (LU)

#### Objectives

Automated testing (AT) is one of the cornerstones of agile software engineering, with its short development cycles. In continuous integration/deployment (CI/CD) pipelines, AT is a safeguard against software regression due to side effects, unintentional changes, or changes in the environment. While AT provides huge benefits for agile software engineering, there is a risk that the test cases are too specific – only testing one sample pair of input–output – thus making them inefficient. Similar problems are identified for automated program repair, where generated patches may over-fit the test suite. We propose "near failure assertion" to analyse variation around the output of a test case. In contrast to the standard assertion, where test cases are asserted a specific output value or condition, the proposed approach asserts a wider range of factors, to identify if the software feature works as expected or is at risk of failing. The assertion is hence not only a binary pass/fail, but a pass/fail risk distribution. The new approach – inspired by near crash analysis in traffic monitoring – is expected to provide more information from each of the automated test cases, and thereby make regression testing more efficient.

#### Main Scientific Achievements

We started the project by surveying the literature with a focus on assertions and found 119 papers addressing various aspects of assertions. Our analysis of the literature on assertions, summarizing the state of research on the topic, indicates that there is little work directly focused on assertions but rather use of assertions for various purposes. We synthesize the literature in relation to 1) assertions problems, 2) solutions to assertion problems, and 3) evaluation practices of the proposed solutions. The results were recently published in the Springer LNCS proceedings of the ECBS conference in Västerås, Sweden [Taromirad, 2023]

During the project, the technical focus was set towards asserting multiple characteristics of the test case execution, including behavioral data. This helped operationalize the "near failure" concept. We then built a prototype tool to demonstrate and evaluate the concept. The approach taken is to monitor behavioural dynamic data, such as memory consumption and execution time, during general testing. Then an ML prediction model is trained on the data to indicate risk for erroneous functional behavior, based on the dynamic data. We refer to this approach as *Potential Failure Analysis (PoFA)*. Evaluations based on two open source projects – the Math project from Defects4J and PdfBox from Apache – provided indications of a precision and recall in the range of of 76–80% and 64–71%, respectively. Initial results were published in the Springer LNCS proceedings of the PROFES conference in Jyväskylä, Finland [Taromirad, 2022] and the full exploration is currently under review (since April 2023) for a Springer journal.


Overview of the supervised failure prediction approach. From [Taromirad, 2022].

## Lasting Impact

We proposed a novel, supervised failure prediction framework (PoFA) that classifies the program behaviour into two classes, namely *faulty* and *healthy*, based on dynamic behavioural data gathered throughout its execution. Using dynamic data (e.g., execution time) collected from various executions of different faulty and healthy versions of a program under test (PUT), a machine learning-based model is designed and trained to predict whether or not an arbitrary (and possibly new) version of the PUT includes a defect. The project operationalized the concept, evaluated an initial solution, and found it promising. We hope the solution can be further advanced and packaged for further exploration and use.

Masoumeh Taromirad is now Assistant Professor at Jönköping University.

# 3.20 A20. Efficient and Reliable Training of Generative Adversarial Networks

PI: Pontus Giselsson (LU)

## Objectives

Generative adversarial networks (GANs) are generative networks designed to learn probability distributions of training data. They consist of two deep neural networks with opposite objectives. One network, the generator, generates new fake data instances, while the other, the discriminator, evaluates them for authenticity. This adversarial structure gives rise to training problems with saddle-point structure. These are inherently different from standard deep neural network training (minimization) problems and are considered very difficult to train. A reason is that stochastic gradient descent (SGD), that works well for standard deep learning training, is often blindly applied to also train GANs. SGD, and its deterministic counterpart gradient descent, may fail to converge even on very simple convex-concave saddle-point problems. This research project will provide a strong mathematical foundation for training of GANs. The project introduced the novel mathematical concept of nonlinear resolvents, and a nonlinear forward-backward method. Two, among many, special cases of the proposed method are forward-backward-forward splitting (FBF) and the extra-gradient method (EG) that both can solve saddle-point problems. Our framework opens up a completely new research direction in large-scale optimization and it sheds new light on how FBF and EG work. This project will take the first steps into this research direction with one long term objective being to devise algorithms that efficiently and reliably can train GANs.

#### **Main Scientific Achievements**

We numerically examined the effectiveness of different training algorithms for generative adversarial networks (GANs). We found that while Stochastic Gradient Descent (SGD) and Adam algorithms are widely used for the minimax training problem, alternatives like stochastic optimistic gradient descent and the stochastic extra-gradient method offer superior robustness and stability without compromising performance. We also initiated theoretical research on algorithms applicable to minimax problems in 2021 and has continued with this in 2022. We focused on the convex-concave and nonsmooth setting that is not yet fully understood or explored. This is a first step towards understanding and developing methods in the nonconvex-nonconcave and nonsmooth setting. The main scientific achievement during 2022 is the development of a flexible algorithm framework that can, e.g., solve minimax problems. The theoretical analysis allows for many degrees of freedom in the algorithms with improved performance compared to existing alternatives.

Based on ideas developed in this project, we continued the theoretical line of research and devised a very general and versatile algorithm that is applicable to several fields in machine learning. It reuses previous iterates in a clever way to enhance convergence. We believe that this can be used to not only improve performance in minimax optimization, such as GAN training, but also for value iteration in reinforcement learning.

## Lasting Impact

The postdoc stayed in the group for some time after this project ended and is currently at Bremen University. The main work is very theoretical and has therefore had limited impact so far. We believe it has great potential, and we will work towards reaching a broader audience with our ideas by applying the resulting algorithms to solve relevant problems in different application domains.

## 3.21 A21. Protecting Software against Side-Channel Leakage

PI: Thomas Johansson (LU)

#### Objectives

The project investigated attacks using side-channel leakage in software implementations, in particular, towards existing and future libraries implementing standard security protocols and cryptographic primitives such as OpenSSL. The focus was on cache-timing attacks of different forms and included both developing attacks as well as investigating different protection methods, such as guaranteeing a constant-time implementation. The work continued a recently established research direction for the group in the area of side-channel attacks.

#### Main Scientific Achievements

Due to the future possibility of quantum computers, standardization bodies are currently evaluating new cryptographic algorithms that will come to replace the current standard algorithms. Hamming Quasi-Cyclic (HQC) is a candidate algorithm for standardization by the National Institute of Standards and Technology (NIST), currently in round 4 in the standardization process. In this project, we developed the first chosen-ciphertext (CC) cache-timing attacks on the reference implementation of HQC. We built a cache-timing-based distinguisher for implementing a plaintext-checking (PC) oracle. The PC oracle uses side-channel information to check if a given ciphertext decrypts to a given message. This is done by identifying a vulnerability during the generating process of two vectors in the reference implementation of HQC. We also developed a new method of using PC oracles for chosen-ciphertext side-channel attacks against HQC, which may have independent interest. The work took place in collaboration with a research group in Australia.

Based on the work in this project, we continued to work on the theoretical treatment of the problem of recovery of secret values in the side-channel setting using Ph.D. students from other projects. A new framework based on iterative decoding, that increases efficiency (requiring a smaller number of traces) for different recovery

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approaches has been developed. Further work on micro-architectural attacks on cryptographic algorithms is currently ongoing.

### Lasting Impact

We developed a general proof-of-concept attack as described above, where we used the Flush+Reload technique and also derived, in more detail, a practical attack on an HQC execution on Intel SGX, where the Prime+Probe technique is used. We showed the exact path to do key recovery by explaining the detailed steps, using the PC oracle. The new attack proved to be efficient and will be something future implementers will need to take into account in certain threat scenarios. The postdoc Senyang Huang worked in the group for two years and then moved to industry in Norway.

## 3.22 A22. Human Interaction with Autonomous Minibuses (HIAM)

PI: Tom Ziemke (LiU) Co-PIs: Jan Andersson (VTI), Anna Anund (VTI)

### Objectives

The project addressed pedestrians' and bicyclists' interactions with the autonomous minibus platform ELIN on LiU's Campus Valla. The minibus platform offers unique research opportunities for empirical and systematic studies of human interaction with autonomous vehicles in the real world over extended periods of time. Methodologies for such research are, however, still underdeveloped, due to the novelty, complexity and interdisciplinary nature of crucial research issues, such as the mechanisms of human (social) trust in such autonomous vehicles. The project has carried out empirical studies of how people interact with the minibuses (through behavioral observations, questionnaires, in-depth interviews, etc.), focusing in particular on the development of quantitative and qualitative methods, experimental protocols, and measurements for the study of human interaction with autonomous vehicles. This was also intended to generate new research directions for larger future projects in collaboration between LiU and VTI (the *Swedish National Road and Transport Research Institute*).

#### Main Scientific Achievements

In a study of people's capacity to interpret and anticipate the minibuses' behavior, participants were asked to take the perspective of videotaped pedestrians and cyclists crossing paths with an automated shuttle bus, and to (1) judge whether the bus would stop safely in front of them and (2) report whether the bus's actual stopping behavior accorded with their expectations. The results show that participants expected the bus to brake safely in approximately two thirds of the human–vehicle interactions, more so for pedestrians than cyclists, and that they tended to underestimate rather than overestimate the bus's capability to yield in ways that they considered as safe. These findings have implications for the design and implementation of automated shuttle bus services.

#### Lasting Impact

The project started in the beginning of 2022 and is currently being wrapped up at the end of 2023. The postdoc (Sam Thellman) was hired as an assistant professor at IDA/LiU (Sw. *biträdande universitetslektor*) as of 1 October 2023 and continues to work in the same research team. Two new postdocs (Franziska Babel & Philipp Hock) were recruited from the University of Ulm (Germany) to continue and extend the work of human-vehicle and human-robot interaction 2023-2025. The work in this project contributed to the PI (TZ) receiving a new grant from the *Swedish Research Council (Vetenskapsrådet)* on *"Social cognition in human-robot interaction"* (2023-2026), which studies human understanding of a range of robotic systems, from automated vehicles over animal-like robots to humanoid robots. The postdocs and PI also organized a workshop on *"Cars as Social Agents"* to be held in Gothenburg in December 2023 (incl. a keynote speaker from Scania) and are considering editing a journal special issue on the same topic. That means the work in this project has also contributed to



Study participants were presented with six short video clips featuring three different human–vehicle interaction scenarios that were shot from pedestrian and cyclist perspectives: shared pedestrian and bicycle path intersection (Scenario 1), zebra crossing (Scenario 2), bus on pedestrian and bicycle path (Scenario 3). From [Thellman, 2023].

community building. Last, but not least, the during the course of this project the collaboration with VTI has been intensified, with a new joint Ph.D. student and joint project proposals.



## 4.1 Overview

In December 2020, a number of ELLIIT research projects had been running for five years and reached their intended closing date. The ELLIIT board decided to initiate 15 new projects with 31 Ph.D. students in mostly existing constellations of PIs/co-PIs. These projects are funded with 1 MSEK/year per Ph.D. student, for five years (2021–2025).

## 4.2 B1. Ultra-Reliable Wireless for 6G Applications

PI: Fredrik Tufvesson (LU) Co-PI: Erik G. Larsson (LiU)

## Objectives

In this project, we focus on the foundations for 6G and ultra-reliable low latency communication from a theoretical and practical perspective. We specifically target multi-node connectivity known under names such as Large Intelligent Surfaces, D-MIMO, Radiostripes, RadioWeaves, and cell-free massive MIMO. We perform radio channel measurements to characterize and model spatial diversity aspects of the radio channel for this purpose, both at mid-band (at 3-6 GHz) and at high-band (at 26-30 GHz), and develop algorithms for scalable signal processing, coding, and ultra-low-latency grant-free random access solutions.

## Main Scientific Achievements

In the past 5 years, we have seen a transition from 5G research toward 6G research, and we have contributed to this transition both in terms of key 6G survey papers and in papers targeting key technologies for reliable and energy-efficient 6G networks. The 6G overview paper [Tataria, 2021] has already received 668 citations, and recently a 6G survey paper [Wang, 2023] was published in the *IEEE Surveys and Tutorials*. We have continued to work on cell-free massive MIMO as an enabler for 6G [Ngo, 2018] and worked extensively on grant-free multiple access [Liu 2018]. We have also investigated channel hardening in massive MIMO as an enabler for ultra-reliable low-latency communication [Willhammar, 2020] and performed one of the few truly distributed

MIMO channel investigations. A conference paper on the latter topic received a best student paper award at EuCAP 2023. In 2022 Sara Willhammar (fully funded by the project) and Xuhong Li (partially funded by the project but also active in project B11) defended their Ph.D.

## Long-Term Impact

ELLIIT researchers, together with cooperation partners, have been instrumental in bringing the massive MIMO concept from a theoretical academic concept to actual algorithm and hardware development, and field demonstrations. At an early stage ELLIIT researchers wrote two seminal papers with partners from Linköping University and Bell Labs: "Scaling up MIMO: Opportunities and challenges with very large arrays" in the *IEEE Signal Processing Magazine* and "Massive MIMO for next-generation wireless systems" in the *IEEE Communications Magazine*. Those publications are by far the most influential papers on Massive MIMO technology with over 6,200 and 7,200 citations, respectively. The latter was awarded the best tutorial paper award by the IEEE Communications Society in 2018 and was one of the 10 most cited papers in the entire area of computer science during 2015–2020. Later, we also demonstrated for the first time the possibility of efficient time-division duplexing-based communication with a very large antenna array at the base station and low-complexity terminals. The prototype demonstrations by Lund University performed extensive spatial multiplexing and showed that this is possible even in high-mobility scenarios (cars driving at >50 km/h).

The main path to impact was the close multidisciplinary cooperation between ELLIIT researchers, academic and industrial partners in various constellations and projects. Dissemination efforts included many tutorials, papers, and talks, both for the specialized audience and for generalists and industry strategists. There were, in the early days, many misconceptions, and because of the clean break with conventional thinking that a Massive MIMO implementation requires, it was not entirely uncontroversial. Our researchers were able to educate and influence key decision makers in European industry to recognize the potential of Massive MIMO, and timely invest in research and development. European telecommunications equipment vendors could get a head start in the race to 5G, and are today playing a leading role in the global rollout of networks. We could provide early and in-depth insights to understand the impact of Massive MIMO on semiconductor technology and devices. Studies predict that 5G will account for nearly half of mobile subscriptions by 2027. The new networks support a variety of services, ranging from better entertainment to personal support. In emergency situations, it has become very clear that wireless networks are a vital resource. For example, people in Ukraine indicate that mobile apps that provide up-to-date and location-specific information are essential for their safety. Previous generations of networks lack capacity in crowded places (e.g., as evidenced by 4G when attacks occurred in Brussels).

Over the years, concerns about global warming caused by CO2 emissions have continued to increase. The need to deploy energy-sustainable solutions in wireless networks is crucial. Increasing the number of transmitted bits by 1000 times without increasing the energy consumption requires solutions that are 1000 times more energy efficient. In a recent trial, Ericsson and Vodafone have shown that significant improvements in energy efficiency can be realised in 5G deploying massive MIMO technology. Wireless access is at the heart of future living, business communication, robotized factories, emerging applications such as self-driving cars, and many sectors that currently undergo a major digital transformation. Massive MIMO technology can support increased requirements in terms of reliability, wireless capacity, and number of connected devices. Massive MIMO will likely remain a core technology in future networks.

#### Plans for 2024-2025

In early 2024, we will perform radio channel characterization using tiles or panels, with multiple coherent multiantenna nodes for both communication and sensing, see Figure 4.1, paving the way for a real-time implementation of the concept in the LIS testbed.

We will continue to develop algorithms for grant-free random access, especially methods for activity detection that do not rely on block fading and pilot allocation algorithms. We will also investigate the use of smart repeaters and advanced duplexing techniques (dynamic TDD and network full duplex) to improve the performance of distributed MIMO networks. We will furthermore develop scalable solutions for over-the-air phase synchronization of distributed MIMO panels, especially solutions that can work without cable-based solutions



Multinode measurement system for distributed MIMO measurements.

for locking of the phase loops.

## Awards and Recognitions

- IEEE Signal Processing Society Donald G. Fink Overview Paper Award, 2023: Scaling up MIMO: Opportunities and Challenges with Very Large Arrays
- IEEE Communication Society Best Tutorial Paper Award, 2021: 5G: A Tutorial Overview of Standards, Trials, Challenges, Deployment, and Practice
- IEEE ComSoc Fred W. Ellersick Prize, 2019: Massive MIMO: Ten Myths and one Critical Question
- IEEE Communication Society Best Tutorial Paper Award, 2018: *Massive MIMO for Next Generation Wireless Systems*
- IEEE ComSoc Leonard G. Abraham Prize, 2017: *Multipair Full-Duplex Relaying With Massive Arrays* and Linear Processing
- IEEE ComSoc Stephen O. Rice Prize in the Field of Communications Theory, 2015: *Energy and Spectral Efficiency of Very Large Multiuser MIMO Systems*
- IEEE Neal Shepherd Memorial Award 2015 Best propagation paper in IEEE Transactions on Vehicular Technology: *Path Loss Modeling for Vehicle-to-Vehicle Communications*
- E. G. Larsson won the *Gyllene Moroten* ("golden carrot") best teacher award 2021 by LinTek, the Engineering College student union at LiU.
- E. G. Larsson elected member of the Royal Swedish Academy of Sciences (KVA), 2021.
- E. G. Larsson highly cited according to ISI Web of Science, 2018, 2019, 2020, 2021, 2022, 2023.
- F. Tufvesson IEEE Fellow 2017
- E. G. Larsson IEEE Fellow 2016
- 7 conference papers that were granted best paper/student paper awards.

## **External Funding Attracted**

Project Name	Funding agency	Total Amount	Duration
		(kSEK)	
H2020 REINDEER	EU	6000(LiU)	2021-2024
		8580(LU)	
H2020-SNS-6GTandem	EU	6000(LiU)	2023-2026
		7854(LU)	
SURPRISE (cyber security call)	SSF	4000	2018-2022
Wallenberg Scholar	KAW	18000	2019–2024
Adversarial attacks on the wireless	VR	4100	2020-2023
Phase alignment in large-scale	VR	4100	2024–2028
Commissioned research (LiU)	Ericsson	2700	2023-2024
Turning the air into an AI computer	KAW		2023-2028
MiFuture	EU	6750	2024-2027
Simulation and verification of wireless connec-	Vinnova/FFI	4010	2022-2025
tivity 2			
HEU MINTS - European Training Network on	EU	6474	2019-2023
MIllimeter-wave NeTworking and Sensing for			
Beyond 5G			
H2020 5G for smart manufacturing	EU	2863	2019-2022
Optimizing Radio Access Networks for effi-	SSF	2500	2019-2023
cient massive MIMO operation			
Massive MIMO technology and applications	Ericsson		2018-2024
Next Generation Communication and Com-	Vinnova	36 000 (in total)	2024–2028
putational Infrastructures and Technologies			
(NextG2Com)			

## Inter-University Cooperation within ELLIIT

The cooperation between LiU and LU, together with Bell Labs researchers, pioneered the massive MIMO concept [Rusek, 2013]. Their work resulted in the combined theoretical analysis and testbed development that eventually demonstrated the feasibility of Massive MIMO with reciprocity-based coherent multiuser beamforming and time-division duplex (TDD) operation in high-mobility scenarios. Much of this work was carried out in H2020-MAMMOET, H2020-REINDEER, the SSF-funded DISTRANT project, and a VR framework grant. The cooperation also resulted in methods and experimental results on channel characterization [Flordelis, 2018], [Gao, 2015] and sensing using wireless massive MIMO [Manoj, 2021].

## Inter-Disciplinary Cooperation

F. Tufvesson is a founding member and active in the LU profile area Natural and Artificial Cognition, where we are approaching learning, sensing and interaction from an engineering, societal and biological perspective. Within ELLIIT, he is also contributing to the projects in local positioning and vehicular communication.

## International Collaboration

We have a strong network with other universities and research institutes, with well-established collaboration in terms of joint projects, publications, or applications; examples include: University of Southern California, US (A. Molisch), Austrian Institute of Technology, Austria (T. Zemen), Aalto University, Finland (K. Haneda), KU Leuven, Belgium (L. Van der Perre), Aalborg University, Denmark (G.F. Pedersen). Within the European projects MAMMOET, REINDEER, and 5G-WIRELESS, MINTS (all H2020), we have cooperated with a range of partners, with co-authored publications for example with KU Leuven, TU Graz, and University of Padova.

## Patent Applications, Open Source Software, and Contributions to Standards

Recently published patent applications connected to the project: WO2023211321A1, WO2023104324A1, WO2023101579A1, WO2023099019A1, WO2023099006A1, WO2022214169A1, US11337090B2, EP3508009A1

## Exploitation and Cooperation with Industry and Institutes

At LiU, the exploitation of research results has taken place substantially within the above-mentioned European projects and within commissioned research. At LU, in addition to the European projects mentioned above, we have a deep collaboration with joint research with large companies such as Ericsson, Sony Europe, Volvo Cars, and smaller companies such as Terranet and Acconeer in the area. We are supervising industrial Ph.D. students from Ericsson, Volvo cars, and Terranet, which provides a natural way of exploitation of results. Furthermore, there are typically 3-5 master's theses supervised at various local companies each year.

## Contributions to Undergraduate/Graduate Education

At LiU, E. G. Larsson has developed the new master program Data Science and Information Engineering, and the new specialization on Data Science and Machine Intelligence for the Engineering Physical and Electrical Engineering (Y) 5-year degree program. New courses include TSKS15 Detection and Estimation of Signals, TSKS33 Complex Networks and Big Data, and TSKS34 Complex Networks (to be taught for the first time in 2024, on the 5-year Engineering Math 5-year program). At LU, the content of the courses EITN85, Wireless channels, and EITN21, Project in wireless communication, are continuously updated based on the results of the project. F. Tufvesson is also responsible for the specialization in communication systems for students in electrical engineering.

## **Outreach Activities**

F. Tufvesson has been responsible for the video series about Digitalization "ELLIIT tech talks", including planning and realization of 12 episodes of 1.5 hours each. In total there are 24 presenters and 12 discussions. The series is available on YouTube since October 2022. F. Tufvesson is also a regular speaker at the NMT days in Lund for high school students and at the Redeye technology days on communication technologies for investors. E. G. Larsson is co-host of the Wireless Future podcast (available on YouTube, Spotify, Google, Apple) with 24,000 subscribers, launched in 2020.

## Keynotes, Plenaries and Academic Service

- E. G. Larsson was co-general chair of the Joint IEEE SPS and EURASIP Summer School on Defining 6G, co-general chair, in Linköping, August 2022.
- *Next-Generation MIMO and the New Applications it Enables*, keynote by E. G. Larsson at the International ITG WSA and SCC Conference, Braunschweig, Germany, March 2, 2023.
- *Physical layer for next generation wireless: Lessons learned from 5G and directions for 6G*, keynote by E. G. Larsson at the 16th International Symposium on Wireless Communications Systems (ISWCS), Oulu, Finland, August 28, 2019.
- *Massive MIMO: Lessons Learned and the Road Ahead*, keynote by E. G. Larsson at the 2019 Annual Taiwan Telecommunications Meeting, Taichung, Taiwan, January 25, 2019.
- Special issue guest-editorships: *IEEE Wireless Communications Mag.*, massive machine-type communications for IoT, 2021; *IEEE Journal on Selected Areas in Comm.*, massive access for 5G and beyond, 2020; *IEEE Journal on Selected Topics in Signal Proc.*, array signal processing for MaMIMO, 2019.
- E. G. Larsson served as tutorial co-chair for EUSIPCO 2023; awards co-chair of IEEE WCNC 2022; tutorial co-chair of IEEE SPAWC 2021; tutorial co-chair of IEEE Globecom 2020; and technical co-chair of the IEEE Communication Theory Workshop, 2019
- E. G. Larsson served on the steering committee of the *IEEE Transactions on Wireless Communications* (2019-2022), and on the editorial board of the *IEEE Signal Processing Magazine* (2018-2022).
- E. G. Larsson served as panel chair at the Swedish Research Council (VR) in 2023, for the cybersecurity

call

- F. Tufvesson, Invited talk, 6G key technologies and research opportunities, Royal Swedish Academy of Engineering Sciences, june 2023
- F. Tufvesson, keynote, Channel modelling and characterization for communication and sensing in a 6G era, AES 2023, 9th International Conference on Antennas and Electromagnetic Systems, Torremolinos, Spain, June 2023
- F. Tufvesson, keynote, IEEE Globecom, Workshop on Propagation channel models and evaluation methodologies for 6G, "Channel modelling, channel characteristics and the implication on 6G" December 2022.
- F. Tufvesson, keynote, 15th European Conference on Antennas and Propagation, EuCAP 2021, "Propagation and Channel modelling for automotive environments" Dusseldof, Germany/online, March 2021
- F. Tufvesson, member of the organizing committee for the ELLIIT focus period on 6G, 2023
- F. Tufvesson is leading the LTH profile area AI and Digitalization and is currently also chairing the collegium of the 12 strategic research areas at LU.

## 4.3 B2. Baseband Processing for Beyond 5G Wireless

PI: Liang Liu (LU) Co-PI: Håkan Johansson (LiU)

## Objectives

Project B2 focuses on efficient digital baseband processing algorithms and the corresponding hardware implementations for beyond 5G and 6G wireless systems. More specifically, the project leverages expertise from different research groups to explore system-algorithm-hardware-software co-design, enabling the efficient implementation of distributed massive MIMO (multiple-input multiple-output) technology, such as Large Intelligent Surfaces (LIS) and Cell-free massive MIMO. Design trade-offs will be investigated between system performance and implementation cost, with energy efficiency being one of the primary objectives. The project also explores the potential of beyond 5G and 6G systems for services such as accurate positioning, processing off-loading, and sensor fusion.

To achieve this objective, researchers from Lund University (LU), Linköping University (LiU), and Halmstad University (HH) collaborate to conduct three Ph.D. projects on 1) distributed processing algorithms and hardware architectures, 2) low-complexity digital processing algorithms for correction and compensation of errors in analog processing, and 3) high-level design methodologies and tool chain for accelerating baseband processing in many-core processor architecture. The team will also explore synergy effects with other ELLIIT projects, including system and application level research in B1, analog electronics design in B3, and positioning research in B11 to achieve overall implementation efficiency.

## **Main Scientific Achievements**

Partners in project B2 investigated different aspects of digital baseband processing for the distributed massive MIMO systems. LU looked at the overall system hardware architecture, processing distribution, and prototyping methods. LiU investigated digital processing methods for analogy error mitigation and beamforming functionalities, which are one of the most power consumption parts in the system. HH studied how to accelerated MIMO signal processing algorithms by leveraging parallel computing architectures like GPU and many-core architectures. Together the project B2 team forms a full picture of digital baseband processing for future 6G systems and co-optimizations can be performed to further improve the energy efficiency.

Over the last five years, the main scientific contributions of the LiU team include the development of energyefficient algorithms for: (i) digital error mitigation, including predistortion in massive MIMO systems [Prasad, 2023], neural-network based linearization, calibration of time-interleaved analog-to-digital converters, beamforming under conditions of IQ-impaired channels and analog phase shifter impairments; (ii) beamforming and channel estimation for passive intelligent surface (PIS) assisted MISO energy transfer [Mishra, 2023].

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LU has been looking into the distributed processing architectures, including distributed MIMO processing algorithms as well as the topologies to connect different processing elements together. In [Sánchez, 2022], algorithm-architecture co-design has been conducted to develop distributed interference cancellation algorithms for tree-based topology, which reduces the data movement among processing elements significantly. [Sánchez, 2021] has developed machine learning based distributed algorithms for high-precision radiobased positioning, when a large number of antenna panels are deployed in an indoor environment. Besides on the theoretical analysis of the distributed architecture, Lund University is also building a 6G testbed using AMD/Xilinx RFSoC technology (supported by SSF-LIS and ELLIIT LISA projects). Each RFSoC has 16 transceivers with direct RF sampling capability to form one 16-antenna panel. Distributed panels are connected via 100G Ethernet links for data exchange to perform coherence processing.

The HH research team aims to answer determine the suitable processing/architectural infrastructure for beyond 5G applications. In [Nada, 2023], we investigated different ML architectures to enhance the accuracy of fingerprint-based positioning system in massive MIMOs. Convolutional Neural Networks (CNNs) have been proposed to infer the position of a user from the Channel State Information (CSI) of a massive MIMO system. The results show that we are able to infer the position of a user with a mean error of 10.09 mm. Also, we investigate hardware and software acceleration of massive MIMOs detection algorithms to come up with new architectures that satisfy the requirements of the next generation of wireless communications.

### Long-Term Impact

From a technical point of view, project B2 investigates distributed massive MIMO, a relative new concept and technology for next generation wireless systems. The research combines theory study with practical implementation considerations to answer important questions whether the new system can be implemented, and if it can, how should it be implemented for maximum efficiency and flexibility. The project will develop enabling implementation strategies to bring the promising concept of distributed massive MIMO into practice, with the hope of facilitating the future commercial deployment of the technology. The problem formulation in the project is also general enough to allow for results that can be applied to distributed processing well beyond the targeted distributed massive MIMO concept, e.g., distributed machine learning, distributed cloud-edge processing, sensor networks.

The project has generated knowledge within the design and implementation of energy-efficient high-capacity signal processing and communication systems. The general methodology and framework of algorithm-hardware co-design are of interest for academia as well as companies that produce equipment for communication systems. The foremost long lasting impact is that Ph.D. students and undergraduate students acquire the knowledge generated in the project which contributes to the competence supply in the field. Within the topic of 5G/6G baseband processing, the project B2 team has established and further enhanced collaborations with world-leading companies, which has a long-term impact on both the technology development in industry and research/education at universities.

#### Plans for 2024-2025

As discussed, one of the key features of 6G systems is supporting multiple wireless services including communication, sensing, accurate positioning. The team will leverage the outcomes from the project to further investigate suitable processing architectures and computing infrastructures that can support multiple of these services to improve the implementation efficiency. For digital error mitigation, we plan to develop energy-efficient algorithms and implementation strategy for linearization and predistortion based on binary neural networks, in particular for distributed massive MIMO systems. This includes exploring massive MIMO system-level features to relax the processing complexity for both the digital and analog parts of the system. To further find out the suitable computing infrastructures and architectures for massive MIMO signal processing, we plan to look into both hardware and software acceleration of massive MIMOs detection/precoding algorithms to satisfy the high throughput and low latency requirements of 6G, while keeping in mind the requirements in energy efficiency and flexibility/programmability, e.g., to support different algorithms and functionalities.

To further enhance and solidate the collaborations, the B2 project team is building common working platforms

that everyone can contribute and collaborate. This includes a software simulator for distributed massive MIMO systems allowing the design trade-offs from different parts of the system as well as for different system performance metrics. The plan is also to collaborate on the real-time 6G testbed LISA. This includes verifying the digital error mitigation algorithms and implementations in real systems, or integrate the GPU acceleration into the LISA testbed.

## Awards and Recognitions

Researchers within the projects have received the following awards and recognitions:

- Ph.D. student Steffen Malkowsky (together with Paul Harris, University of Bristol) won first prize in five of ten prize categories at the 2016 National Instruments Engineering Impact Awards for breaking the world record on spectrum efficiency. for the paper [Malkowsky, 2017]
- Liang Liu received Göran Linds Prize in Electronics, Royal Physiographic Society of Lund, 2017, for building the world's first 5G massive MIMO testbed.
- Outstanding 28nm FD-SOI Chips taped out through CMP (Multi-Project Wafer) for the first 5G massive MIMO digital baseband processing chip, 2018, for the news [Irish, 2018], for the paper [Prabhu, 2017]

Project Name	Funding agency	Total Amount	Duration
A market and find for the American American	X7'	(KSEK)	2010 2021
Array Antennas for SatCom Applications on	vinnova	1200 (L1U)	2019-2021
Mobile Platforms			
Calibration of Time-Interleaved Analog-to-	Huawei	2472 (LiU)	2020-2022
Digital Converters			
Receiver Linearization Techniques	Huawei	1600 (LiU)	2022-2023
Chalmers-Lund Center for Advanced Semi-	SSF	60000 (2 LU	2023 - 2028
conductor System Design, ClassIC		Ph.D. students	
		for baseband	
		processing)	
Large Intelligent Surfaces – Architecture and	SSF	26300 (LU)	2021 - 2025
Hardware			
REINDEER: REsilient INteractive applica-	EU H2020	7800 (LU)	2021 - 2024
tions through hyper Diversity in Energy Ef-			
ficient RadioWeaves technology			
Scalable and Distributed Computing for Large	VR	3600 (LU)	2020 - 2024
Intelligent Surfaces			
Beyond5: Building the fully European supplY	EU H2020-ECSEL	6800 (LU)	2021 - 2024
chain on RFSOI, enabling New RF Domains			
for Sensing, Communication, 5G and beyond			
Massive MIMO Technology and Applications	Ericsson	2 Ph.D. students	2018 - 2023
		and 1 postdoc	
		for baseband	
		processing (LU)	
Next Generation Communication and Com-	Vinnova	36 000 kSEK in	2024-2028
putational Infrastructures and Technologies		total, (LU)	
(NextG2Com)			

## **External Funding Attracted**

## Inter-University Cooperation within ELLIIT

Within the B2 project, inter-university cooperations are listed as follows:

• 6G baseband processing workshops: project B2 arranges two technical workshops every year to discuss

and exchange research status and ideas. The workshops are mainly in-person and partners in project B2 take turns to host the workshop.

- HH Ph.D. student Ali Nada did exchange to LU, for taking Ph.D. courses as well as research discussions with LU Ph.D. students.
- Liang Liu serves in the supervision team of HH Ph.D. student Ali Nada, attending weekly supervision meetings. A recently published paper [Nada, 2023]
- A common simulation framework is being built for the distributed massive MIMO systems, so that project B2 partners can work together.

LU and LiU are also collaborating in many EU projects in the area of 6G, including MAMMOET (Massive MIMO for Efficient Transmission), REINDEER (REsilient INteractive applications through hyper Diversity in Energy Efficient RadioWeaves technology), and 6GTandem (A dual-frequency distributed MIMO approach for future 6G applications).

## Inter-Disciplinary Cooperation

To explore the potential of 6G for services beyond communication, the department of Electrical and Information Technology (EIT), LU are working together with the Computer Science, Automatic Control, Centre for Mathematical Sciences, and the Humanities Lab in LU to create an open source data-set, LuViRA, for multisensory positioning in indoor environment. This is a link between projects B2 and B11 where PIs of these two projects are involved in the work [YamanDataset, 2023], [YamanResult, 2023]. The cooperation with Prof. Henrik Sjöland in project B3 allows us to look at both digital and analog processing for improved system performance and energy efficiency, e.g., [Munner, 2020].

### International Collaboration

The LU team collaborates with TEC (Austria), NXP (Austria), Infineon (Austria), TU Graz (Austria), IMEC (Belgium), KU Leuven (Belgium), UNIVERSIDAD CARLOS III DE MADRID (Spain), and TID (Spain) via EU projects MAMMOET, REINDEER, and MiFuture. In the EU H2020 project BEYOND5, close collaborations are with TUD (Germany), Fraunhofer (Germany), and Leti (France). In the field of 5G/6G systems, the LU team works together with Prof. Mark Beach at University of Bristol (UK) on testbed activities, with Prof. Zhengya Zhang University of Michigan (USA), Prof. Dejan Markovic UCLA (USA), and Prof. Norbert Wehn at Technical University of Kaiserslautern on 5G/6G signal processing and digital hardware implementation. LiU has cooperated with universities in Australia (School of Electrical Engineering and Telecommunications in Sydney), India (National Institute of Technology, Silchar), and China (College of Electronic Science and Technology in Changsha).

## Patent Applications, Open Source Software, and Contributions to Standards

- The LuViRA (Lund University Vision, Radio, and Audio) dataset is publicly available, [LUViRA, 2023]. This project is supported by VR and ELLIIT.
- The system parameters used in project B2, e.g., the frame structure, for the system simulator and testbed are based on 3GPP standard.
- The patent application (System and method for convolution of an image) is not directly from project B2, but the ideas and the methods of performing memory access and convolution operations can be used in digital baseband processing.

## Exploitation and Cooperation with Industry and Institutes

LU has cooperated with Ericsson, Axis Communication, and Sony mobile on both research and education, including invited industry lectures in the master's courses, master thesis projects (around 10-20 projects every year), and research (e.g., the Massive MIMO project from Ericsson and many EU projects mentioned). LU also cooperates with National Instruments and AMD/Xilinx on building the 5G/6G testbed. In the area of digital integrated circuits (IC) design using advanced CMOS technologies, LU collaborates with Intel,

STMicroelectronics, and GlobalFoundries. With Candence and Synopsys, LU has access to the advanced CAD (Computer Aided Design) tools for implementations of baseband processing circuits. LiU has cooperated with RequTech and Forsway (Vinnova project Array Antennas for SatCom Applications on Mobile Platforms) and with Huawei in two projects (see the Table with external funding).

## Contributions to Undergraduate/Graduate Education

- At LiU, two new courses have been developed that incorporate research results: the undergraduate course Signal Processing for Communication (given every year since 2019) and the Ph.D. course Multirate Digital Signal Processing (given 2023).
- The co-PI at LiU has been the director of research studies (2015-2021) and deputy member of the board of Ph.D. studies (2021-2023).
- At LU, baseband processing and implementation for massive MIMO is an important case study for courses (EITF35) Introduction to Structured VLSI Design and (EITF20) Computer Architecture, where the PI Liang Liu is the course coordinator.
- Invited lecture "Digital Signal Processing for Wireless Communication Systems" in the course ETIN45 DSP-Design at LU.
- The PI serves as the programme director of the international master programme Embedded Electroncis Engineering at LU.
- At HH, we designed a set of master thesis topics where the students of Embedded and Intelligent Systems (EIS) can do their master thesis and get engaged with ELLIIT. Two master students from the EIS master program in HH have conducted a master thesis titled "Acceleration of Massive MIMO algorithms for Beyond 5G Baseband Processing" [Nihl and de Bruijckere, 2023].

## **Outreach Activities**

- Hazem Ali from HH has given an introduction lecture on the B2 ELLIIT project and the research questions addressed. The Lecture was held in the Instituto de Informática at Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil [Ali, 2023].
- ELLIIT Tech Talks, "Mobile Processing Architectures and Devices", 2022, [YousraLiang, 2023].
- IEEE European Solid-State Circuits Conference, workshop presentation "What is expecting from 6G circuits and transceivers?", 2023, [ESSCIRC, 2023].
- Liang Liu gave a presentation "Digital baseband implementation challenges in 6G distributed networks", 6GSymposium, 2022.
- Liang Liu, Ove Edfors, and Henrik Sjöland gave a tutorial on 5G Circuits and Systems, IEEE Nordic Circuits and Systems Conference, 2017.
- Liang Liu and Fredrik Tufvesson, IEEE Live Webinar, Massive Signal Processing for Massive MIMO: Challenges and Lessons Learned, 2016.

## Keynotes, Plenaries and Academic Service

- The co-PI at LiU has served as a member of the IEEE International Symposium on Circuits Systems (ISCAS) DSP track committee (2000-2023).
- The PI at LU serves in IEEE Technical Committees, Circuits Systems for Communication and VLSI Systems and Applications.
- The PI at LU organized special sessions for international conferences IEEE ISCAS 2020, Asilomar Conference 2020, and IEEE SiPS 2021.
- The PI at LU served as guest Editor, IEEE Open J. Circuits and Systems, Special Section on Circuits, Systems, and Algorithms for Beyond 5G and towards 6G, 2020.
- The PI at LU serves as Review Committee member for IEEE ISCAS 2014-2024.

# 4.4 B3. Energy-Efficient ICs for 6G and Radars Transceivers

PI: Atila Alvandpour (LiU) Co-PI: Henrik Sjöland (LU)

### Objectives

With 6G the journey towards ever-higher carrier frequencies and bandwidths continues. For the first time in cellular systems, the carrier frequency will exceed 100 GHz and the bandwidth 10GHz. To achieve useful communication distance and radar range, devices and especially base stations will use beamforming with very large antenna arrays. The goal of this project is research and development of a small sized wideband energy-efficient IC, including RF analog front-end and analog-to-digital converter (ADC) to be used as a building block in 6G equipment for up to Tbit/s communication also capable of high-resolution radar measurements.

### Main Scientific Achievements

During the last 5 years (previous and the current project), we have developed several innovative solutions for energy-efficient integrated circuits and systems for next generation (5G/6G) wireless communications, all based on measurements of our fabricated chips, benchmarked against state-of-the-art, and published in strong and prestigious international journals and conferences in the field. Furthermore, the graduated Ph.D.s (Oscar Morales, Mohamad Resa Sadeghifar and Jonas Lindstrand) from the project are now employed as expert IC designers at major companies such as Ericsson. Examples of results and solutions from previous projects are: Energy efficient mm-wave frequency generation circuits, radio power amplifiers, and wideband low-power data converters (ADCs and DACs) [Abdulaziz 2019], [Lindstrand 2019], [Sundström 2020], [Morales 2022].

During the current project (last 3 years) we have developed:

- An innovative modular system-level test-bench [Gannedahl 2023] programmed in Matlab, for simulating
  and exploring next generations massive antenna arrays and beamforming transceivers architectures with
  near circuit-level fidelity (has been welcomed and well-received by the international society). What
  makes this testbench stand out from other system-level works is the very detailed modelling level of the
  analog/RF and mixed-signal hardware, enabling simulations and verifications of the impact of hardware
  imperfections on the overall system performance and power consumption. It can also be used to obtain
  design specifications for each hardware block.
- A chip with baseband filters suitable for 6G bandwidths has been designed and fabricated, featuring both passive and active filters. Measurement results indicate that the filters achieve state-of-the-art performance at multi-GHz baseband frequencies, accepted and to be presented at Asia-Pacific Microwave Conference 2023.
- An integrated tunable active all-pass filter-based true time delay (TTD) element covering a 3–5-GHz ultra-wideband (UWB) frequency [Saberkari 2022].
- A chip with a wideband pipeline ADC, [Bagheri 2023], suitable as a Sub-ADC for interleaved ADCs, has been designed and fabricated. The chip is operating successfully, currently under detailed measurement to be reported and published soon.
- We have also developed and demonstrated techniques to extend the wireless power transfer range in miniaturized remotely powered micro-devices to overcome the challenges of limited harvested RF energy due to the very small effective area and low gain of the mm-sized antenna utilized in these devices [Saberkari 2023].

## Long-Term Impact

Our project has been addressing some of the key important hardware design challenges, with special focus on energy-efficient wireless transceiver frontends and data converters for future mobile broadband communications as well as for ultra-low-power smart sensors for future IoT, AI, and biomedical implant devices. Example of lasting impacts are: Improved strong national/European competence in semiconductor IC and chip design, educating and generating future talents and leaders in the field, supporting the industry partners to (i) make

better strategic decisions about their future product development, (ii) to have access to our research results and innovative technologies of high relevance, and (iii) to recruit many of our well-trained researchers and engineers who will be the future leaders.

## Plans for 2024-2025

The plan is:

- Further development of our above-described system-level testbench for simulating and exploring next generations massive antenna arrays and beamforming transceivers architectures with near circuit-level fidelity. The aim is to better understand the complex interplay between different parts of the system and their performance/imperfection parameters in different scenarios, and to then be able to extract appropriate requirements for each sub-block.
- Further development, design, and manufacturing of the key radio frontend RF/analog circuits and the ADC.
- Design and demonstration of a modular building block consisting of a 4-element beamforming array antenna receiver frontend, utilizing our own system-level test-bench/tool, RF circuits, and the ADC.

## Awards and Recognitions

N/A

### **External Funding Attracted**

Project Name	Funding agency	Total Amount	Duration
		(kSEK)	
Micrometer-scale wireless cell fluorescence	SSF	33 MSEK	2020-2025
detection device		(about 15	
		MSEK (LiU))	
Next generation distributed processing plat-	VINNOVA	1 MSEK (LiU)	2018-2022
form for sensor signal and avionics data pro-			
cessing			
Nuclear Magnetic Resonance (NMR) Minia-	VR	3.6 MSEK	2023-2026
turization for Spectroscopy: A Platform for		(LiU)	
Portable and Sensitive Probing			
Digital Receivers that are Extremely Wide-	VINNOVA	2.5 MSEK (LU	2019-2021
band (DREW)		with Saab)	
Digital pre-distortion PA for NB-IoT	VINNOVA	2 MSEK (LU	2019-2021
		with Xenergic)	
Neuromorphic computing in memristor-	SSF	2.5MSEK (LU	2023-2027
enhanced analog circuits		with Ericsson)	

## Inter-University Cooperation within ELLIIT

The project and results so far are based on close collaboration and joint research work between the project partners from Lund and LiU. The two Ph.D. students Rikard Gannedahl (Lund) and Javad Bagheri (LiU) have been working together on modeling and development of an innovative modular system-level testbench (a unique tool) for simulating and exploring next generations massive antenna arrays and beamforming transceivers architectures with near circuit-level fidelity. The project partners have regular meetings and exchange ideas and technical support in design of the RF circuits and ADC design as well.

#### Inter-Disciplinary Cooperation

Research in Electronic circuits and systems is today very application driven and our ongoing research projects are all highly interdisciplinary projects, requiring close collaboration across a broad spectrum of knowledge, scientific areas, and engineering disciplines. As examples: The VINNOVA project between Saab and LiU with the title "Next generation distributed processing platform for sensor signal and avionics data processing". The project is a close collaboration between Saab (Linköping, Göteborg, Järfälla), LiU (Integrated circuits and systems group at ISY, and software security group at IDA), KTH (electronics and embedded systems), jointly addressing new computing architectures, signal processing algorithms and systems, radio communication/radar systems, advanced IC design, hardware/software co-design, software security and algorithms. An industrial Ph.D. student (Ufuk Özdemir) has just started at Ericsson in Lund with funding from SSF on the topic of Neuromorphic Computing using CMOS analog integrated circuits together with memristors. The project is a cooperation between the Electromagnetics and Nanoelectronics group (EIT, LTH), the Integrated Electronic Systems group (EIT, LTH), and Ericsson Research in Lund. The project is truly interdisciplinary involving neural networks, analog circuit design, and memristor devices. The SSF frame project between Linköping University, Karolinska Institutet, and KTH, developing an implantable fluorescence micro-detector imaging device utilizing wireless power and data transfer for in vivo monitoring of pancreatic cells and development of new effective medicine for diabetes.

#### International Collaboration

We have developed and published several innovative works and results on high-speed DACs for 6G in close collaboration (joint Ph.D. program) between Linköping University and Nanyang Technological University (NTU) Singapore.

#### Patent Applications, Open Source Software, and Contributions to Standards

N/A

#### Exploitation and Cooperation with Industry and Institutes

Henrik Sjöland is the main supervisor of two industrial Ph.D. students from Ericsson Research in Lund, in the field of integrated mm-wave transmitters and power amplifiers. The topic is very well aligned with this ELLIIT project, addressing mm-waves, wide bandwidths, and power efficiency. The two industrial Ph.D. students are Imad ud Din and Christian Elgaard. An industrial Ph.D. student has just started at Ericsson in Lund with funding from SSF on the topic of Neuromorphic Computing using CMOS analog integrated circuits together with memristors. The project is a cooperation between the Electromagnetics and Nanoelectronics group (EIT, LTH), the Integrated Electronic Systems group (EIT, LTH), and Ericsson Research in Lund. In a close collaboration between LiU, Saab and Brazil, Atila Alvandpour has been contributing with many tutorials, lectures, courses, supervisions of Brazilian students and senior researcher at ITA Brazil on design of integrated circuits and advanced chip design techniques.

#### Contributions to Undergraduate/Graduate Education

1) Course VLSI Chip Design (Alvandpour LiU), undergraduate. 2) Course Analog CMOS integrated circuits (Alireza Saberkari LiU), undergraduate. 3) Course Integrated radio frequency circuits (Alireza Saberkari LiU), undergraduate. 4) Course Radio electronics (Alireza Saberkari LiU), undergraduate. 5) Course Sigma-Delta data converters (Alvandpour, LiU), graduate.

Atila Alvandpour is the director of the international master program in Electronics Engineering at LiU.

Alireza Saberkari is the leader of Electronics profile for LiU undergraduate education programs.

## **Outreach Activities**

Atila Alvandpour has been the main contact person for the national competence hub (kompetensnav) for Integrated Circuits and Systems in the VINNOVA/Energimyndigheten/Formas national SIO program, 'Smartare elektroniksystems'. The competence hub aims to establish strong national network, joint collaboration, and research projects between and within electronics industry and Universities in Sweden.

## Keynotes, Plenaries and Academic Service

Henrik Sjöland has been an associate editor of IEEE Transactions on Circuits and Systems – I, from 2016 to 2023. Henrik Sjöland is a new member of the ITPC RF sub-committee at the International Solid-State Circuits Conference (ISSCC). Atila Alvandpour has been a member of the steering board of IEEE Nordic Circuits and Systems Conference (NORCAS) as well as technical program committee member in other international conferences such as IEEE European Solid-State Circuits (ESSCIRC). Alireza Saberkari has been the guest editor for a Special Issue entitled "Advanced High-Performance Integrated Circuits for Sensing Technologies and IoT Applications" in "Electronics" Journal, MDPI, (ISSN 2079-9292).

# 4.5 B4. 5G/6G Security

PI: Thomas Johansson (LU) Co-PI: Simin Nadjm-Tehrani (LiU)

## Objectives

The scope of the 5G and beyond security project is wide-ranging, aiming to address the evolving threat landscape specific to new generations of wireless communication. This project includes conducting an in-depth analysis of potential threats and vulnerabilities, collaborating with industry stakeholders to establish robust security standards, and designing resilient network architectures capable of withstanding advanced cyber attacks. Privacy protection mechanisms, including encryption and access controls, are fundamental in the 5G and 6G environments. The project explores the integration of security primitives, ensuring the development and implementation of holistic end-to-end security. Creating a secure foundation for the widespread adoption of new 5G/6G security technologies and fostering trust and confidence in their use is a key objective.

## Main Scientific Achievements

The main scientific achievements over the last five years include (i) new results on the security analysis of the ZUC algorithm in 4G, and 5G standards [Yang, 2020a], (ii) new results on the security analysis of the SNOW 3G algorithm in 4G, and 5G standards [Yang, 2020b], (iii) new design of a cipher called SNOW-V, which in a modified version that will go into the 5G standard [Ekdahl, 2019], (iv) an AEAD (authenticated encryption with associated data) version of the stream cipher Grain (Grain-128AEAD) suitable for constrained devices with minimum latency compared with similar ciphers, (v) Security analysis of 5G handover, (vi) dynamic load management at the edge with elastic and proximity-aware orchestration, (vii) ongoing work on formal protocol verification of the Julia key agreement protocol for IoT devices.

## Long-Term Impact

The impact of 5G security research is pivotal in ensuring the robustness and resilience of the next generation of wireless communication. As 5G technology becomes more integral to global connectivity and plays a vital role in mission-critical applications identifying and addressing potential vulnerabilities becomes crucial. These may be hard to fix in future generations after mass deployment. The outcomes of our research contribute to the development of advanced security protocols, encryption algorithms, and other security mechanisms with proven (formal) correctness properties, that safeguard data integrity and user privacy. In addition, understanding resource allocation trade-offs in dynamic environments with load spikes appearing in both time and space

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dimensions helps to characterise the border between benign and hostile load changes. The research in this project has already provided profoundly lasting impacts, as our results have found their way to the 5G standardization body. Implementations of security algorithms developed in this project will be found in future mobile phones and base stations. In addition, our work on the security analysis of the 5G and beyond landscape provides the basis for choices made in future standardization.

### Plans for 2024-2025

We have two Ph.D. students in the ELLIIT project (D. Wang, N. Sivaraman), supported by senior staff. After a long initial delay waiting for the visa, we are running the project with full manpower. In the two Ph.D. student projects, we will continue with research on security mechanisms in 5G/6G including special emphasis on low latency use cases, but also other cases. Examples of future areas of study include research on (i) user authentication through USIM (Universal Subscriber Identity Module) and eSIM (embedded-SIM), (ii) security solutions for 5G-powered IoT devices, (iii) new cryptographic solutions for new security demands in 6G, (iv) formal protocol verification of protocols used in or suggested for use in 5G and 6G communication networks and (v) analysis of resource trade-offs in mechanisms to mitigate effects of adversarial flows.

### Awards and Recognitions

Best paper awards at the IACR (The International Association for Cryptologic Research) flagship conference Asiacrypt 2014 for the paper "Solving LPN using covering codes", Q Guo, T Johansson, C Löndahl, (255 submissions).

Simin Nadjm-Tehrani was awarded the Women in homeland security award by the IEEE Systems, Man, and Cybernetics (SMC) Technical Committee on Homeland Security, July 2022. She has served as an elector for members of the board and scientific council of the Swedish Research Council (VR) for two mandate periods. She is a member of the Swedish Royal Academy of Engineering Sciences (IVA) since 2022.

Project Name	Funding agency	Total Amount	Duration
		(kSEK)	
Lightweight Cryptography for Autonomous	WASP-NTU collab-	3000	2020-2023
Vehicles	oration project		(3 years)
Analysis of emerging cryptographic algo-	VR	3900	2020-2023
rithms in a post-quantum setting			
Side-Channel Vulnerability and Threat Analy-	MSB	4600	2021-2025
sis with Machine Learning Awareness [PI: E.			
Dubrova]			
SURPRISE: Secure and private connectivity	SSF	5400	2018-2024
in smart environments [PI: P. Papadimitratos]			
SSF mobility (T. Johansson)	SSF	1132	2023-2025
RICS: Resilient Information and Control Sys-	MSB	2750	2015-2024
tems (S. Nadjm-Tehrani)			
AIR <sup>2</sup> : AI for Attack Identification, Response	WASP(NEST)	2000	2024-2028
and Recovery (S. Nadjm-Tehrani)			

## **External Funding Attracted**

## Inter-University Cooperation within ELLIIT

The PI setting involved in the project is new and we have only recently started to collaborate. Our inter-university interactions involve regular meetings and currently, we are focused on the joint work around protocol analysis and in particular the the Julia key agreement protocol.

We also have regular interaction with other ELLIIT groups in the security domain, mostly security researchers

around Prof. C. Gehrmann at LU. We have also collaborated on a grant application with H. Grahn, BTH.

## International Collaboration

The project has extensive international cooperation, e.g. with Bergen University, KU Leuven, University of Melbourne, University of Applied Sciences and Arts Northwestern Switzerland, Fraunhofer Institute Darmstadt, Technische Universität Wien, INRIA and University of Renne. The Co-PI is a regular invitee or organiser of Dagstuhl seminars within the area of network intrusion detection and security for softwarised networks where active researchers meet regularly (Seminars 12061, 14292, 16361, 22171, 23431).

## Patent Applications, Open Source Software, and Contributions to Standards

Algorithms developed in this project are the basis for standard algorithms developed by standardization bodies ETSI SAGE and 3GPP SA WP3.

## Exploitation and Cooperation with Industry and Institutes

Within the scope of the project, there have been numerous master's thesis projects examined both in academia and in cooperation with local industry, such as Axis, Advenica, Bosch, Saab, Sectra and Ericsson. In the research groups, we have also hosted several industrial Ph.D. student projects, e.g. in collaboration with Saab, Combitech, Sectra and Advenica. An example of a spin-off company from the research group is DEBRICKED.

## Contributions to Undergraduate/Graduate Education

The courses Advanced Web Security and Cryptography at LU have been updated, incorporating recent research results. Lecture notes have been updated. A Ph.D. course on advanced cryptology is held at LU.

## **Outreach Activities**

- Qian Guo: Participation in the NMT-days in Lund 2022, 2023.
- Simin Nadjm-Tehrani: Acting as a judge in the Cyberchallenge competition at Swedish Defence University (2020-2023), and at the Cyberchallenge Geneva (2022-2023).
- Simin Nadjm-Tehrani: Fly High Seminar at Digital Futures (KTH), 2021.
- Simin Nadjm-Tehrani: Contributions to the Cyber Campus formational workshops (2022-2023).
- Simin Nadjm-Tehrani: SVT interview 2021 Nätattacker kan hyras på Darknet
- Simin Nadjm-Tehrani: Seminar at LiU for high school teachers (October 2022).
- Simin Nadjm-Tehrani: contribution to the radio program Gräns Så kan fiender attackera vårt elnät (December 2022).
- Simin Nadjm-Tehrani: Presentation at the Cybernode Collaboration conference (January 2023).
- Simin Nadjm-Tehrani: Coordinator of the Cybernode working group AI and Security since 2021. Participation in several other working groups.
- Simin Nadjm-Tehrani: Presentation at the SCADA Security conference for practitioners (September 2023).
- Simin Nadjm-Tehrani: Contribution to the pod "Innovationslandet" WASP Djupdykning i AI och cybersäkerhet, on the theme of AI and Cybersecurity (October 2023).
- Simin Nadjm-Tehrani: Contribution to the IVA project on cybersecurity and presentation of the report Cybersäkerhet för ökad konkurrenskraft on several occasions including to members of the Swedish parliament.

## Keynotes, Plenaries and Academic Service

- Thomas Johansson and Simin Nadjm-Tehrani were invited speakers on WASP4ALL 2023.
- Thomas Johansson was invited speaker on the Nyberg Fest at Aalto University 2023.
- Thomas Johansson was co-chair of PQCrypto 2022.

- Thomas Johansson was co-chair of PQCrypto 2023 in Washington.
- Thomas Johansson is an Associate Editor in IEEE Trans. on Information Theory 2021-.
- Simin Nadjm-Tehrani is the associate editor of IEEE Transactions on Dependable and Secure Computing (TDSC), and regular PC member of the flagship conference on dependability (A-ranked), as well as several other conferences on dependability and security.
- Simin Nadjm-Tehrani serves as an opponent or member of the examination committee for Ph.D. theses (several per year) at various universities (including Aalto, Twente, Darmstadt, KTH, Uppsala, Karlstad, Luleå, Linneus, Chalmers in the past 5 years).

## 4.6 B5. 6G Wireless, Sub-Project: Vehicular Communications

PI: Alexey Vinel (HH) Co-PI: Maria Kihl (LU)

## Objectives

The project will work with futuristic heterogeneous cooperative automated driving scenarios in smart cities, which will include both traditional and remotely human-driven vehicles, as well as computer-driven vehicles in complex city environments with different levels of autonomy. We will address the challenges of scalability, robustness, and accommodate uncertainty in cooperative driving by introducing quality elasticity through a hierarchy of decision-making algorithms placed on different levels in the ecosystem of autonomous vehicles. The hierarchical solution could be based on local decision algorithms in vehicles, edge cloud coordination of small areas, such as an intersection, and global orchestration of larger areas in order to fulfill more global traffic requirements in, for example, a city. We will enhance the vehicular networking concepts of cooperative awareness (when vehicles exchange information about themselves), collective perception (when vehicles exchange information about objects they have observed by their local sensors) and cooperative maneuvering (when vehicles exchange their trajectories and intentions) to achieve the degrees of flexibility required for the designed decision making algorithms.

#### Main Scientific Achievements

The PI of the project Professor Alexey Vinel pushed forward four main lines of scientific advances, which are summarized in respective Ph.D.-thesis under his main supervision: Marco Marinho "Array Processing Techniques for Direction of Arrival Estimation, Communications, and Localization in Vehicular and Wireless Sensor Networks" (2018, in cooperation with Professor Fredrik Tufvesson, LU), Nikita Lyamin "Performance evaluation of safety critical ITS-G5 V2V communications for cooperative driving applications" (2019), Quentin Delooz "Sensor Data Sharing in V2X Communications: Protocol Design and Performance Optimization of Collective Perception" (2023), Galina Sidorenko "Cooperative Automated Driving for Enhanced Safety and Ethical Decision-Making" (tbd 2024). The latter includes pioneering work on "Ethical V2X", where we argue that an information exchange between vehicles via vehicular communications is the foundation for ethical driving. In other words – autonomous vehicles must be cooperative to be able to resolve ethical dilemmas in a multi-vehicle scenario.

The co-PI of the project, Professor Maria Kihl, investigates networked control systems for collaborating connected vehicles. The main scientific achievement of this part of the project is that we have shown that control systems for collaborating vehicles must take connectivity uncertainties into account, which means that control systems cannot assume perfect communication models. This research provides valuable insights into the challenges of designing robust autonomous systems that can withstand various connectivity uncertainties and demonstrates the potential of AVs in enhancing ITS. The work will be published in a Ph.D. thesis during 2024. We have proposed a new autonomous intersection management (AIM) system, called hierarchical model predictive control (HMPC). [Chamideh, 2022]. In HMPC, the intersection coordination unit (ICU) in a global centralized layer is responsible for assigning a safe speed to each vehicle while minimizing the system's cost. In the Local decentralized layer, each vehicle is responsible for tracking the reference speed assigned by the ICU,

while avoiding collisions. In our method, each vehicle can use its own sensors to monitor its close surroundings and take its own decisions on its movements, independent of the control decisions sent from the ICU. We investigate the safety, scalability, and robustness of HMPC compared with two well-known AIM methods based on centralized and decentralized control strategies. Our simulation results show that HMPC can safely handle high traffic flow rates. In addition, HMPC is robust to the uncertainties caused by wireless communication. This proposed solution solves the challenges of scalability and communication uncertainties resulting in packet loss. Further, we have focused on uncertainties in positioning. This work investigates the level of positioning errors that HMPC can tolerate. The investigation reveals that HMPC can safely handle vehicle movements in the presence of positioning errors of up to four meters at high traffic flow. Furthermore, the impact of sensor accuracy and wireless communication uncertainties on control strategies is considered. Furthermore, we have investigated AIM systems for mixed traffic scenarios [Chamideh, 2023]. This wprk presents an innovative AIM system designed to optimize traffic flow and improve intersection safety in mixed traffic scenarios. The results demonstrate that the proposed system effectively enhances intersection throughput and ensures safe and efficient operations, particularly in situations involving a high proportion of autonomous vehicles. Furthermore, the robustness of the system is demonstrated by evaluating its performance under various traffic flow rates and considering imperfect wireless communication conditions.

## Long-Term Impact

The project allowed to establish internationally visible groups in V2X communications at both HH and LU, which currently includes Professor Alexey Vinel (HH, part-time), Professor Maria Kihl (LU), Assistant Professor Oscar Molina (HH), Assistant Professor William Tärneberg (LU), Ph.D. students Eduardo Duarte (HH), Felipe Valle (HH), Galina Sidorenko (HH) and Zahra Chamideh (LU). Also, another long-term impact of the project is the VINNOVA Competence Center NEXTG2COM (project manager: Maria Kihl at LU), where Volvo Cars is a core partner.

## Plans for 2024-2025

The main plan for 2024-2025 is to use NEXTG2COM as a platform for new collaborations and research topics. We will continue the work on control systems for connected vehicles within the center. In addition, new topics related to the integration of distributed federated learning approaches into the V2X will be included in the project. The PI and co-PI might work closer together in the upcoming years.

#### Awards and Recognitions

N/A

#### **External Funding Attracted**

Project Name	Funding agency	Total Amount	Duration
		(kSEK)	
Next Generation Communication and Com-	Vinnova	36 000 (in total)	2024-2028
putational Infrastructures and Technologies			
(NextG2Com)			
Safety of Connected Intelligent Vehicles in	KKS	23 000 (in total)	2019-2024
Smart Cities (SAFESMART)			
Intelligent Management of next genera-	Celtic-Next via	1.8 MSEK (LU	2021-2023
tion Mobile Networks aNd services (IMMI-	VINNOVA	part)	
NENCE)			
Cyber Security for Next Generation Factory	SSF	30 MSEK (in to-	2018-2024
(SEC4FACTORY)		tal)	

## Inter-University Cooperation within ELLIIT

Apart from joint publications HH-LU we see close integration of faculty members between two institutions e.g. Johan Thunberg: now LU, previously HH.

## Inter-Disciplinary Cooperation

At LU, there are many inter-disciplinary cooperation activities, resulting in the competence center NEXTG2COM. For example, there has been a long-term inter-disciplinary cooperation between Maria Kihl and different researchers at the Dept. of Automatic Control, resulting in joint papers, projects and jointly supervised Ph.D. students. Also at HH, the main inter-disciplinary cooperation is in bringing together wireless networking (Alexey Vinel) and automatic control (Johan Thunberg).

## International Collaboration

The main line of international collaboration in this project is via the PI Professor Alexey Vinel, who is a professor at Karlsruhe Institute of Technology (KIT) since October 2022, and (part-time) Professor at HH. Other examples of long-term international collaboration include TH Ingolstadt (Professor Andreas Festag) [Delooz, 2022] and University "La Sapienza" (Professor Andrea Baiocchi) [Turcanu, 2022].

## Patent Applications, Open Source Software, and Contributions to Standards

Quentin Delooz (HH, Ph.D.-defence 2023) was a part of the ETSI Special Task Force STF585 working on multiple channel operation for V2X communications.

## Exploitation and Cooperation with Industry and Institutes

The main cooperation at HH is with Volvo Autonomous Solutions [Sidorenko, 2021]. Other industrial partners include EVAM [Duarte, 2021], Zenseact [Alvarez, 2021] and Bosch Corporate Research [Thunberg, 2021]. At LU, there is a highly active industrial cooperation with several companies, as shown in NEXTG2COM which includes 17 external partners. The main industrial cooperation partner is Ericsson AB, where a joint 5G network research infrastructure has been developed as an ELLIIT Infrastructure. This long-term cooperation has resulted in numerous joint papers, for example, [Peng, 2022] and [Skarin, 2020].

## Contributions to Undergraduate/Graduate Education

At LU, the undergraduate course ETSN11 Wireless Networks and Applications: System design and Performance includes the main use-cases and communication technologies from this project.

## **Outreach Activities**

- Presentation at Automotive Functional Safety Week (Munich) in 2023: "Cooperative Autonomous Systems, Discuss the role of SOTIF in connected vehicles", Alexey Vinel
- Presentation at BRAIN BITES (Karlsruhe) in 2023: "Why do vehicles talk?", Alexey Vinel
- Presentation at the LU NMT days in 2023: "Världen är full av moln, och det lär bli fler", Maria Kihl.
- Science and Innovation talk at Tetra Pak in 2022: "Industry 4.0 and connectivity Enabling technologies for sustainability", Maria Kihl

## Keynotes, Plenaries and Academic Service

- Keynote at The 5th Joint Workshop on CPS & IoT Security and Privacy (CPSIoTSec) 2023: "Security and privacy challenges for next generation communication and computational infrastructures and applications", Maria Kihl
- Keynote at the 8th International Conference on Vehicle Technology and Intelligent Transport Systems (VEHITS) 2022, Alexey Vinel

 Keynote at International Symposium on Connected and Autonomous Vehicles (SoCAV) 2022, Alexey Vinel

## 4.7 B6. Robust and Secure Control over the Cloud

PI: Zebo Peng (LiU) Co-PI: Karl-Erik Årzén (LU)

## Objectives

This project explores how the cloud, with its virtually infinite compute capacity, can improve the security and performance of feedback control systems. We will (1) study verifiable computation protocols (VPC) for secure outsourcing of cloud-based control computations; (2) develop a cloud-based cyber-physical system platform, with a focus on ultra-reliable low-latency communication over the cloud; (3) investigate collaboration and negotiation between cloud-aware control applications and the cloud/edge resource management; (4) investigate how control techniques can be used for cloud resource management in order to increase the temporal determinism of the cloud and improve the possibilities for offloading time-critical control applications; and (5) investigate the interplay between local and cloud-based control computations and derive guarantees on robustness and performance. In general, there is an interesting trade-off between security, round-trip delay, and control performance that will be studied. The developed techniques will be verified in experiments, where physical processes are controlled remotely over the cloud.

## Main Scientific Achievements

At LiU, we have studied several issues related to outsourcing control applications to the cloud and the security challenges implied by such an approach. In particular, we have focused on the need for a mechanism for verifying the control signal received from the outsourced controller (cloud). We have employed a recent cryptographic technique, called verifiable computation, which allows a client to check the correctness of remote execution. We have demonstrated the practicality of verifiable computation schemes with advanced control methods like Model Predictive Control (MPC), where the computationally heavy part of the controller is outsourced to a cloud platform [Mahfouzi, 2021]. A Ph.D. thesis on this technique and the general issues of security-aware design of cyber-physical systems for control applications has been completed (Rouhollah Mahfouzi 2021). Additionally, we have developed a 5G configured grant (CG) scheduling technique to implement a periodicity-based schedule to reduce control signaling time and guarantee service quality. This technique will enable real-time applications, such as industrial automation and control. We have also studied the trade-off between scheduling flexibility and control overhead when performing CG scheduling. The problem was first formulated using Satisfiability Modulo Theories (SMT) so that an SMT solver can be used to generate optimal solutions. To enhance scalability, we have proposed several heuristic algorithms, which have been demonstrated to generate efficient solutions quickly [Pan, 2023].

At LU, we have studied offloading-based control over the cloud [Skarin, 2021], and modeling, control and learning of edge and cloud infrastructures. This has resulted in five Ph.D. theses during 2019-2023 (Victor Millnert (2019), Per Skarin (2021), Alexandre Martins (2022), Tommi Berner (2022), Johan Ruuskanen (2022), and Albin Heimerson (2023)). In addition to this Nils Vreman has finished a Ph.D. thesis on cyber-security of embedded control systems in 2022. Our current Ph.D. student Nyberg Carlsson has studied how one can use known or measured latency and sampling instant sequences deriving from, e.g., cloud offloading, to design optimal LQG-type controllers [Nyberg Carlsson, 2023]. He is currently investigating the use of nonlinear and adaptive control techniques for designing queue length controllers for cloud servers based on a server model developed by Berner and Ruuskanen.

### Long-Term Impact

The development of robust and secure control techniques over the cloud has a significant impact on academia, industry, and society. It will lead to the implementation of control systems that are more robust and resilient to various types of failures, such as hardware faults, software bugs, and cyber-attacks. This enhanced resilience is critical for the operation of critical infrastructure, manufacturing, transportation, and many other sectors. As cloud-based control systems are susceptible to cyber threats, our research will contribute to the development of advanced security mechanisms and practices, which is vital for protecting sensitive data and critical infrastructure, and ensuring the privacy and integrity of systems and information. By developing more robust and secure control systems for cloud environments, organizations can reduce the financial impact of cyber incidents and system downtime. This leads to cost savings and improved operational efficiency. In the long run, our research can drive innovation in cloud computing, control systems, and cyber-security. Companies that implement the findings of our research can gain a competitive edge by providing more secure and reliable solutions to their customers. The security and robustness of cloud-based control systems are also closely tied to public safety. Ensuring the integrity of these systems has a direct impact on the well-being and safety of individuals and communities.

In summary, our research on robust and secure control over the cloud is significant because it addresses fundamental challenges in technology and cybersecurity that impact various aspects of society, including safety, privacy, economics, and technological advancement. It plays a critical role in shaping the future of cloud-based control systems and their role in our increasingly interconnected world.

#### Plans for 2024-2025

Two Ph.D. students are directly financed by this ELLIIT project (Y. Pan at LiU and M. Nyberg Carlsson at LU). At LiU, we will continue the development and refinement of the proposed 5G configured grant (CG) scheduling technique to make it more powerful for resource optimization and fault tolerance. We will also integrate the proposed CG scheduling technique with JitterTime and JitterBug, developed by the LU partner, so that control performance optimization can be achieved. At LU, we will continue the work on adaptive control of cloud server queues with the goal of increasing the level of determinism, thus increasing the performance of control applications closed over the cloud. We will also study controller offloading from a software architecture point of view, focusing on how controller code can dynamically migrate between different nodes.

#### Awards and Recognitions

Researchers within the current project and our previous project on "Co-Design of Robust and Secure Networked Embedded Control Systems" have received the following awards and recognitions:

- Nils Vreman, Anton Cervin and Martina Maggio received the Best Paper Award for their paper "Stability and Performance Analysis of Control Systems Subject to Bursts of Deadline Misses" at the 33rd Euromicro Conference on Real-Time Systems (ECRTS 2021).
- Per Skarin, William Tärneberg, Karl-Erik Årzén and Maria Kihl received the Best Paper Award for their paper "Towards Mission-Critical Control at the Edge and Over 5G" at IEEE Edge in July 2018.
- Amir Aminifar, Petru Eles and Zebo Peng received the Best student paper award for their paper "Jfair: A Scheduling Algorithm to Stabilize Control Applications" at the 21st IEEE Real-Time and Embedded Technology and Applications Symposium, Seattle, USA, (RTAS 2015) [Aminifar, 2015].
- Zebo Peng received the IEEE Computer Society Distinguished Contributor Award in 2022.
- Zebo Peng received the Meritorious Service Award from IEEE Computer Society in 2015.
- Zebo Peng received the Outstanding Contribution Award in 2010 from IEEE Computer Society, for "significant services as Chair of TTTC European Committee for 4 years."
- Petru Eles received the IEEE Council on EDA Outstanding Service Recognition award for outstanding service to the community as ESWeek General Chair in 2019.

## **External Funding Attracted**

Project Name	Funding agency	Total Amount	Duration
		(kSEK)	
Adaptive Software for the Heterogeneous	Swedish Founda-	6,000 kSEK	2022-2027
Edge-Cloud Continuum	tion for Strategic		
	Research (SSF)		
Temperature-Aware Design and Optimization	Swedish Research	3,980 kSEK	2018-2021
of Cyber-Physical Systems	Council (VR)		
AORTA – Advanced Offloading of Real-Time	VINNOVA	3,600 kSEK	2023-2025
Applications			
HI2OT – Nordic Hub on Industrial IoT	Nordforsk	900 kSEK	2018-2024
Control-based resource management in the dis-	WASP Ph.D. stu-	4,000 kSEK	2016-2021
tributed cloud	dent project		
Mission-Critical Control over the Cloud	WASP Industrial	2,400 kSEK	2017-2021
	Ph.D. student		
	project		
Resource Management in Distributed Camera	WASP Industrial	2,400 kSEK	2017–2021
Systems	Ph.D. Student		
	Project		
Event-Based Information Fusion for the Self-	WASP Ph.D. Stu-	4,000 kSEK	2018-2022
Adaptive Cloud	dent Project		
Autonomous datacenter for long term deploy-	VINNOVA	3,000 kSEK	2018-2021
ment: AutoDC			
ADMORPH: Towards Adaptively Morphing	EU – Horizon 2020	3,600 kSEK	2020-2022
Embedded Systems			

## Inter-University Cooperation within ELLIIT

The two partners in LiU and LU have had close cooperation, with regular project meetings and common research activities. Over the years, several joint publications have been generated in the area of control/embedded systems codesign (e.g., [Aminifar, 2018] and [Aminifar, 2013]). Recently, a concrete joint work in using the JitterTime and JitterBug tools, developed by the LU partner, to quantify the performance of control when using the 5G configured grant (CG) scheduling technique, developed by the LiU partner, has also been initiated. The LiU partner has also cooperated with Dr. Amir Aminifar, who has now been with the Department of Electrical and Information Technology at LU, in developing techniques for control-communication codesign of cyber-physical systems built with Ethernet networks, and using verifiable computation protocols for secure cloud control.

## Inter-Disciplinary Cooperation

One of the two partners of this project is in Computer Science and the other in Automatic Control; the cooperation is inter-disciplinary by nature.

## International Collaboration

Besides the international cooperation with General Motors, USA, described in the industrial cooperation section, the LiU partner had also close cooperation with Prof. Sudipta Chattopadhyay from Singapore University of Technology and Design (SUTD).

## Patent Applications, Open Source Software, and Contributions to Standards

Patent application: Eker, J., A. Heimerson, and K.-E. Årzén (2023). "Device and method for scaling microservices". Pat. WO2023048609A1 (WO). Telefonaktiebolaget LM Ericsson (Publ).

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### Exploitation and Cooperation with Industry and Institutes

Several LiU master thesis projects took place in collaboration with Ericsson, ABB, Infor AB, Volvo, and NIRA. Several LU master thesis projects took place together with Ericsson. Part of the project at LiU was done in collaboration with General Motors, USA, via Dr. Soheil Samii, who worked there for a long period of time.

### Contributions to Undergraduate/Graduate Education

Several research results have been incorporated into courses at the Master's and Ph.D. levels at LiU and LU, including the Master's level courses on "Advanced Computer Architecture and Real-Time Systems" at LiU. A new Ph.D. course on "Real-Time and Dependable Ethernet Communication with IEEE TSN standards" has been developed and taught at LiU.

### Keynotes, Plenaries and Academic Service

Researchers in the project have involved in the following activities:

- Petru Eles, Associate Editor of the IEEE Design and Test, the ACM Transactions on Embedded Computing Systems, and Real-Time Systems.
- Karl-Erik Årzén, Associate Editor for the journals Real-Time Systems Journal, Leibnitz Transactions on Embedded Systems (LITES), and ACM Transactions of Cyber-Physical Systems.
- Zebo Peng, Associate Editor for the Journal on Foundations and Trends in Electronic Design Automation.
- Petru Eles, General Chair, Embedded Systems Week (ESWeek), 2019.
- Zebo Peng, General Co-Chair for the 5th IEEE International Test Conference in Asia (ITC-Asia), 2021.
- Karl-Erik Årzén, Invited keynote, "Modeling, Control and Learning for Improved Cloud Predictability", IEEE Mobile Cloud 2022: The 10th International Conference on Mobile Cloud Computing, Services, and Engineering, August 17th, 2023
- Zebo Peng, Invited talk, "Temperature-Aware Design of Cyber-Physical Systems," at the IEEE International Symposium of EDA, Nanjing, China, May 8-11, 2023.

## 4.8 B7. Quality Assurance in Continuous Software Engineering

PI: Nauman bin Ali (BTH) Co-PI: Emelie Engström (LU)

## Objectives

Software quality assurance includes preventive, diagnostic, and corrective mechanisms to ensure the design and development of high-quality software systems. Technological advances, like cloud computing and modern toolchains for automated builds, testing, and deployment, have enabled organizations engaging in continuous software engineering to deploy a new system version ever more rapidly. This new way of working requires automation and puts new requirements in terms of the role and responsibilities of quality assurance. This project explores the interaction between automated and manual data analysis in the continuous software engineering contexts. We are investigating the use of data analytics and visualizations to help software engineers interpret the massive amount of data available due to activities like code analysis, version management, code reviews, testing, and product usage. Furthermore, to support integrating research activities and results in the industrial context, we work on improving the knowledge co-creation between industry and academia in the area of software quality assurance.

## Main Scientific Achievements

Over the last five years, the project extensively addressed challenges in quality assurance in the continuous software engineering context. The main achievements include new approaches for (i) research utilization [Engström, 2020], (ii) data-driven issue management [Laiq, 2023], (iii) optimization of anomaly detection in DevOps [Hrusto,

2023], (iv) regression test optimization [Ali, 2019], and (v) test case quality assessment [Tran 2021]. Moreover, we have achieved breakthroughs in the visualization of test data for decision support. Furthermore, the project has significantly contributed to the knowledge co-creation between academia and industry through the proposal and use of interactive rapid reviews.

#### Long-Term Impact

There are several ways in which this research collaboration provides a lasting impact. Outside academia impact is achieved directly through the long-term relations built with our industrial partners (for example, Ericsson, Axis, TestScouts, and Alstom) and indirectly through the research outputs and the undergraduate and graduate students bringing their results and knowledge to industry. Furthermore, our approaches for utilization of research and knowledge co-creation [Rico, 2023] help the broader research community to improve relevance and research communication within our field. Within academia lasting impact is achieved by providing constructs for theory building (such as taxonomy, models, and guidelines to support research) on emerging topics within quality assurance in continuous software engineering, such as testing of ML based systems [Song, 2022], testing of autonomous systems, managing IoT vulnerabilities [Rico, 2019], applying deep learning for anomaly detection, applying NLP for issue management [Laiq, 2022], and more. A recent example of impact is where our proposed taxonomy was independently evaluated in a case study at an automotive company to describe the regression testing challenge and to identify a relevant solution [Meyer 2023].

Another indicator of impact is that several students (supervised by the project B7 members) have defended their Licentiate and Doctoral theses, including Licentiate theses by [Tran 2022, Singh 2023, Hrusto 2022, Song 2022] and Ph.D. theses by [Minhas 2022, Irshad 2021, and Rico 2023].

#### Plans for 2024-2025

Our research agenda includes an exploration of the role of data and visual analytics in software quality assurance, with a specific emphasis on addressing current limitations. We intend to identify and consolidate key stakeholders' information needs through a design science approach and develop analytical solutions to meet those needs. The goal is to create an information model that decouples analytical solutions from data sources, ensuring effective and reusable data collection mechanisms. Additionally, we plan to delve into machine learning techniques to support various software engineering tasks and comprehensively review the literature on anomaly detection applied in practice. This multifaceted approach aligns with our commitment to advancing the field and exploring novel avenues for improving software development practices.

#### Awards and Recognitions

- Emelie Engström received the distinguished reviewer award at ICSE 2018, the premier global conference in software engineering. This recognition highlights expertise in software engineering, reflecting a significant contribution to advancing the field's research quality and technological progress.
- In an article of the Journal of Systems and Software, Vol 147 (2019), BTH was ranked 1st in Europe and 6th in the world based on publications in key journals in the area of systems and software engineering. Six of SERL Sweden's 21 researchers are ranked among the world-leading researchers in software engineering in their respective groups. ELLIIT researchers Kai Petersen and Claes Wohlin were ranked highly for their research productivity. Claes Wohlin was also ranked for impact in terms of citations.
- The paper "Search Strategy to Update Systematic Literature Reviews" by Emilia Mendes and Claes Wohlin (BTH) and co-authors Marcos Kalinowski and Katia Romero Felizardo from Brazil, received the best paper award at the Euromicro conference on Software Engineering and Advanced Application in Kallithea Halkidiki, Greece in August 2019.
- In 2019, the paper "A Comparison of Issues and Advantages in Agile and Incremental Development between State of the Art and an Industrial Case" by Kai Petersen and Claes Wohlin, both from BTH, were in the top three of the ten-year Most Influential Paper Award in the Journal of Systems and Software, i.e., for papers published in the journal in 2009.
- Claes Wohlin from Blekinge Institute of Technology (BTH) was appointed as a board member of the

Swedish Foundation for Strategic Research (SSF) in October 2020.

- Among the top 441 software engineering researchers worldwide, Claes Wohlin and Kai Petersen from BTH are ranked 53 and 263, respectively. The ranking is based on the citations their publications have received up to and including the year 2019 (see Six Researchers).
- In a ranking by the Swedish magazine Fokus based on publications in scientific journals between 2010 and 2015 and citations to these articles up to and including 2017, Kai Petersen (BTH) was number 62 among the 100 most cited researchers in the area "mathematics and technology" (see https://www.bth.se/eng/news/four-bth-researchers-on-the-top-100-list).
- According to a ranking published in the Journal of Systems and Software, Blekinge Institute of Technology (BTH) is ranked seventh worldwide and first in Europe for software engineering research based on the publications in selected venues during the years 2013-2020 and second worldwide. ELLIIT researchers Kai Petersen and Nauman bin Ali are among the researchers from BTH listed in various categories in the rankings (see https://doi.org/10.1016/j.jss.2021.111029 for further details).
- Muhammad Laiq, Ph.D. student at BTH/ Department of Software Engineering (with co-authors Nauman bin Ali/ BTH, Jürgen Börstler/ BTH, Emelie Engström/ LTH), received the best poster presentation award at PROFES 2022 for the paper "Early identification of invalid bug reports in industrial settings a case study."
- Umar Iftikhar, Nauman bin Ali, Jürgen Börstler, Muhammad Usman (BTH) received the best paper award for the paper, "A catalog of source code metrics a tertiary study" at Software Quality Days, 2023.

Project Name	Funding agency	Total Amount	Duration
		(kSEK)	
Decision Support for Component-Based Soft-	KK-stiftelsen	30 000	2015-2019
ware Engineering of Cyber-Physical Systems			
Open Collaborative Data as an Innovation Plat-	Vinnova	270	2018–2019
form for Machine Learning Applications			
Professionell Masterutbildning i Program-	KK-stiftelsen	13 000	2015-2020
varuteknik			
WASP (Academic Ph.D. student)	KAW	3 000	2016-2021
Handling Vulnerabilities in the Value Chain	Vinnova	4 000	2018-2021
Visualization of Test data for Decision Support	KK-stiftelsen	4 300	2019-2021
Software Engineering Rethought	KK-stiftelsen	48 000	2018-2027
ESS Data Lab	Vinnova	540	2020-2021
Professional Licentiate of Engineering School	KK-stiftelsen	8 400	2018-2022
Open Source Inspired Reuse	KK-stiftelsen	3 700	2020-2023
WASP (Academic Ph.D. student)	KAW	4 000	2020-2024
WASP (Industrial Ph.D. student)	KAW	800	2019-2024
Gaining Actionable Insights from Software	KK-stiftelsen	3 995	2023-2027
Testing			
WASP (Academic Ph.D. student)	KAW	4 000	2024-2028
Next Generation Communication and Com-	Vinnova	36 000	2024-2028
putational Infrastructures and Technologies			
(NextG2Com)			

### **External Funding Attracted**

#### Inter-University Cooperation within ELLIIT

BTH and LTH in this project are working like a virtual team. We have a weekly status meeting and an hour-long research meeting every two weeks. We also have separate supervision meetings for our co-supervised Ph.D. students every two weeks. The extensive cooperation is indicated by the following output:

• Emelie Engstrom (LTH) and Nauman bin Ali (BTH) have applied jointly for four grant applications.

- Contributed to each others grant application through internal reviews.
- Per Runesson (LTH) mentored Nauman bin Ali (BTH) from 2019 2023 for the VITS project (funded by the Knowledge Foundation).
- Formal (Muhammad Laiq, BTH) and informal (Sergio Rico, LTH) co-supervision of Ph.D. students.
- Several publications in top-tier software engineering publication venues.
- Joint industrial collaboration with Ericsson, Axis, TestScouts, and Alstom.

## Inter-Disciplinary Cooperation

We have had some inter-disciplinary cooperation in the project, for example;

- Elizabeth Bjarnason (LTH) collaborated with Carola Aili from the Faculty of Social Sciences on Work and Organization in the Digital Age, 2019.
- Kai Petersen, Jürgen Börstler and Nauman bin Ali (BTH) collaborated with Martin Svensson from the Industrial Economics department on investigating the role of theories and models for technology acceptance, 2021 2022.

## International Collaboration

We have had extensive collaboration with researchers from several universities outside Sweden on several topics. It includes collaboration with:

- The Open University, UK, on requirements-test alignment, 2018.
- University of Victoria, Canada, University of Bari, Italy, on software engineering research methodology and communication, 2018 2019.
- Technical University of Catalunya (UPC), Barcelona, Spain, Norwegian University of Science and Technology (NTNU), Norway, SCINTEF ICT, Norway and University of Adelaide, Australia, on system requirements and OSS component 2019.
- Pontifical Catholic University of Rio de Janeiro in Brazil and Federal Technological University of Paraná in Brazil on research methodology in software engineering, 2019.
- Queen's University Belfast in Northern Ireland, on using credible evidence in software engineering, 2019.
- Universidade Estadual de Campinas, Brazil (Breno França) on methodological guidelines for conducting simulation-based studies, 2019 2020.
- Universidade Estadual de Campinas, Brazil, University of Tartu, Estonia and Dalhousie University, Canada on ACM empirical standard for assessing the quality of simulation-based studies, 2020.
- University of Groningen, Netherlands, Pontifical Catholic University of Rio de Janeiro, Brazil, on coediting a book on the teaching of empirical research methods in Software Engineering, 2022 – ongoing.
- King's College, London, on evaluation of critical scenarios for testing of autonomous driving, 2023.
- University of Florence, Italy, and Vrije Universiteit Amsterdam, The Netherlands, on assessment of validity threats in software engineering research 2023 ongoing.
- University of Helsinki, Finland, on using monitoring data for anomaly detection. 2023 ongoing

## Patent Applications, Open Source Software, and Contributions to Standards

N/A

## Exploitation and Cooperation with Industry and Institutes

Since 2018, Emelie Engström has examined 15 M.Sc. theses and supervised 4 (including 2 ongoing) in collaboration with industry. (Axis Tetrapak, Sinch Sweden, Alstom, Sony, Danske Bank, Qlik, NordAxon, Telavox, Verisure Innovation, AppinMed, ICA Gruppen, SEB).

Between 2018 and 2023, we collaborated with RISE AB and prominent industry players such as Axis, Sony, Ericsson, and Alstom. These collaborations spanned a wide spectrum of activities, encompassing regression testing [Ericsson 2018 – 2020], software defect management [Ericsson 2019 – ongoing], visual and data analytics

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for decision support [Ericsson, Axis, TestScouts, Alstom 2019 - ongoing], and anomaly detection in operations [two anonymous companies 2020 - 2023]. The partnerships were characterized by a depth of involvement, including regular meetings, comprehensive data sharing, integration of academic research solutions into industry workflows, and the joint submission of grant applications to further their collaborative ventures.

## Contributions to Undergraduate/Graduate Education

We have significantly contributed to academic programs and courses at BTH and LTH. Our research findings have been further utilized in several master theses [2018 - ongoing]. We have also integrated our findings into software testing [2018 - 2020], requirements engineering [2018], and large-scale software engineering courses [2018]. Additionally, we have developed two doctoral courses, one on design science [2019 - 2020] and one on empirical methods for software engineering research. We have also developed and delivered courses for industry practitioners participating in a lifelong learning program [PROMPT 2018 - 2021] and a distance master's degree program at BTH [2022 - ongoing]. We have also supervised practitioners towards a licentiate degree in a research school at BTH (Professional Licentiate in Engineering Research, PLENG research school, 2018 - 2023).

## **Outreach Activities**

- Several researchers from BTH are participating in an outreach program where we are promoting software engineering as an education and a career choice at local high schools [2018, 2019].
- Elizabeth Bjarnason (LTH) held interactive presentations of research results at Axis Communication on the topic: "The impact of distances on collaboration between testing teams" A workshop on industry-academia collaboration with participants from several companies and researchers from both LTH and BTH, October 2018.
- We presented our work on test-case quality at the Swedish Association for Software Testing (SAST), a practitioner-centric conference, in October 2018.
- To continue competence building around software engineering and technology through the industryacademia ecosystem in southern Sweden, researchers LTH initiated a series of quarterly workshops. It is an open network driven by commitment from industry and academia partners who consider this competence provisioning to be important. The included presentations on recent or ongoing research, master thesis projects, and industry experiences, followed by discussions and matchmaking for collaborative actions, 2019.
- A common event was held at Axis Communications for 160 employees, where speakers from both LTH and Axis highlighted various collaboration projects within research and education.
- Per Runeson (LTH) gave a talk at nosad.se: Introduktion till öppen programvara och samspelet med öppna data, 2020.
- Per Runeson (LTH) gave a science and innovation talk: Beyond open source, Ericsson, Lund, 2020.
- Nauman bin Ali (BTH) represents the software engineering knowledge area in the local collaboration forum (samverkansforum) (2020 ongoing). This forum strategizes and coordinates collaboration activities between BTH and external entities.
- ELLIIT impact story, "Dialogue improves software development", 2021
- Vi Tran (BTH), ELLIIT tech talk, "Next-generation software technology", 2023.

## Keynotes, Plenaries and Academic Service

- Nauman bin Ali has served as a guest editor for a special issue on empirical software engineering in the Journal of Systems and Software, 2018.
- Emelie Engström was a member of the steering committee of Testing: Academia-Industry Collaboration, Practice and Research Techniques (TAIC PART), 2018 2020.
- Per Runesson is a member of the editorial board for two journals: Empirical Software Engineering and Software Testing Verification and Review, 2018 ongoing.
- Per Runesson served as co-chair for technical briefings at the 40th International Conference on Software

Engineering, ICSE 2018 in Gothenburg.

- Per Runesson organized the Software Technology Exchange Workshop, STEW 2018, in Malmö.
- Nauman bin Ali served as a reviewer in the "research methods and philosophy" track at the European Conference on Information Systems (ECIS), 2019.
- Nauman bin Ali also served as a program committee member for the Experimental Software Engineering track of the Ibero-American Conference on Software Engineering (CIbSE-ESELAW), 2019.
- Martin Höst organized Software Technology Exchange Workshop, STEW 2019, in Lund.
- Nauman bin Ali and Jürgen Börstler co-organized the 2019 ELLIIT workshop in Karlskrona.
- Claes Wohlin is an Emeritus Editor (honorary appointment) for the Journal of Information and Software Technology, 2019.
- Kai Petersen gave a tutorial for Sintef, Norway, on systematic reviews and mapping studies in 2019.
- Emelie Engström (LTH) was appointed associate editor of TOSEM (ACM Transactions on Software Engineering and Methodology) in April 2020 ongoing
- Kai Petersen was the chair for the agile method track at the 13th International Conference on the Quality of Information and Communications Technology, 2020.
- Claes Wohlin was invited to give a talk at the Faculty Winter Seminar for the Faculty of Computer Science at the Free University of Bozen-Bolzano, Italy, in January 2020.
- Deepika Badampudi (BTH) was the organizing chair for the 1st workshop on Ethics in Requirements Engineering Research and Practice (REthics), 2020.
- Deepika Badampudi (BTH) served on the program committee for the 15th International Conference on Global Software Engineering (ICGSE) and the International Conference on Software and Systems Process (ICSSP).
- Nauman bin Ali (BTH) was appointed as BTH representative to the International Software Engineering Research Network ISERN, 2020
- Nauman bin Ali (BTH) served as a program committee member for the "1st Workshop on DevOps and Software Engineering: new paradigms of continuous software development, inspection, integration and deployment" DevOps-SE '21
- Nauman bin Ali (BTH) served as a Program committee member for the Experimental Software Engineering track of the 2021 Ibero-American Conference on Software Engineering (CIbSE-ESELAW).
- Deepika Badampudi (BTH) co-organized the 2nd Workshop on Ethics in Software Engineering Research and Practice, held virtually in June 2021.
- Kai Petersen (BTH) will serve as co-chair for the new ideas track at the conference on "Evaluation and Assessment in Software Engineering" EASE'21 in Trondheim, Norway, in June 2021.
- Emelie Engström served as an external opponent for the licentiate thesis "Safety-Critical Software Test Coverage vs Remaining Faults" defended by Tech. Lic. Johan Sundell at Mälardalen University, 2022.
- Nauman bin Ali served as a doctoral committee member for the dissertation titled "Contributions to Improving Feedback and Trust in Automated Testing and Continuous Integration and Delivery" of the candidate Azeem Ahmed at Linköping University, 2022.
- Nauman bin Ali (BTH) served as a program committee member for the "17th International Symposium on Empirical Software Engineering and Measurement (ESEM)", 2023.
- Nauman bin Ali (BTH) served as a program committee member for the "International Conference on Evaluation and Assessment in Software Engineering (EASE)", 2023.
- Emelie Engström served as a program committee member for the International Conference on Software Engineering (ICSE), 2018–2019, 2021–2024.
- Emelie Engström served as a program committee member for Empirical Software Engineering and Measurement (ESEM) 2015–2016, 2022–2023.

# 4.9 B8. Cloud Tooling for Large-Scale Cyber-Physical System Model-Based Development

PI: Görel Hedin (LU) Co-PI: Adrian Pop (LiU)

## Objectives

By using high-level modeling languages, complex systems can be modeled in a compact and natural way, reusing libraries for different engineering domains. The project develops novel techniques for supporting cloud-based tooling for such languages. The Lund part of the project focuses on the generation of cloud components from high-level declarative specifications. The Linköping part of the project focuses on simulation-based verification of requirements using a combination of equation-based models and machine learning trained surrogate models, an easier-to-use and more expressive requirement language, and traceability in cloud-based development environments.

### Main Scientific Achievements

The ELLIIT support has been central to the development of the OpenModelica and JastAdd systems. Open-Modelica is an open-source Modelica-based modeling and simulation environment for Cyber-Physical Systems, supporting a wide range of applications. JastAdd is metacompilation system for language tooling generation based on declarative specifications (reference attribute grammars). Recent key achievements include a major overview article for the OpenModelica integrated environment [Fritzson, 2022], a new modular and extensible Modelica compiler framework in Julia [Tinnerholm 2022], a new technique, *property probes*, for cloud-based interactive exploration of program analysis results [Risberg Alaküla, 2022], and an extension to reference attribute grammars with relations to support continuous model validation [Mey, 2020]. To promote sustainability awareness and democratise the simulation, easier integration and analysis of Socio-Bio-Physical Systems we have developed a translator from System Dynamics to Modelica [Tinnerholm 2023].

#### Long-Term Impact

OpenModelica is widely used in both industry and academia (8000 downloads / month). Its long-term development is supported by the Open Source Modelica Consortium, a non-profit society that now has more than 55 member organisations from both the academic world and industry. Example uses include ABB Optimax (controlling 7.5 to 10% of German power generation), Bosch-Rexroth Control Edge Designer, Mike by DHI WEST Water Quality modeling and simulation environment and many others.

Reference attribute grammars and their implementation in the JastAdd system is being used both in academia and industry. Example industrial uses include a full Modelica and Optimica compiler developed by the company Modelon, and which is now a key part of their flagship product Modelon Impact for cloud-based Modelica development. Example academic uses include extensions of an extensible Java compiler implemented using JastAdd, as well as research in the Internet-of-Things area where JastAdd is used for implementing domain-specific languages.

#### Plans for 2024-2025

For the OpenModelica Julia-based compiler framework, we are working on improving various optimizations in the compiler such as matching and tearing in order to optimally distribute computation, which will allow faster model simulation, and support efficient verification of requirements in the cloud. As work in progress we are working on a Julia-based open-source optimization package that can be applied in different contexts in the project.

For property probes, we are investigating their use for robust white-box testing and for cloud-based code review. We are furthermore investigating the use of reference-attribute grammars and property probes within the OpenModelica tools. In particular, we have developed a Julia framework that will allow light-weight declarative program analysis within the Julia parts of the OpenModelica tools.

## Awards and Recognitions

ITEA Award of Excellence: The OPENCPS project coordinated by Saab and Linköping University received the ITEA award of excellence, September 2019. The major result of this project was the OpenModelica OMSimulator. The ITEA Vice-chairman, Philippe Letellier referred to it as "a milestone on the path of open and standardised co-design and simulation of complex systems, that delivers major results".

ITEA Award of Excellence: The EMPHYSIS project coordinated by Bosch in which Linköping University was a partner received ITEA award of excellence, September 2021. Jean-François Lavignon, ITEA Vice-chairman: "The EMPHYSIS project has achieved several outstanding results such as the automatic generation of efficient code for embedded devices. It shows the power of collaborative research projects to drive the adoption of a new standard and to generate significant productivity gains for the industry." Parts of the EMPHYSIS project results dealing with the equation code have been published in the 15th International Modelica Conference in 2023, and received best paper award: "Design proposal of a standardized Base Modelica language".

Best Demonstration Award for the demonstration Smart Bikes: Gradual Update of IoT Systems at the 2020 IEEE 24th International Enterprise Distributed Object Computing Conference (EDOC) [Nordahl, 2020]

Project Name	Funding agency	Total Amount	Duration
		(kSEK)	
OpenCPS – Open Cyber-Physical System	ITEA3/Vinnova	6000/63390	2015-2019
Model-Driven Certified Development			
Bloqqi – an open modular automation lan-	Vinnova	5000	2017-2020
guage			
WASP Ph.D. project. Adaptive software archi-	KAW	5000	2016-2020
tectures for autonomous systems			
EMPHYSIS – Embedded systems with physi-	ITEA3/Vinnova	2162/135220	2017-2020
cal models in the production code software			
WASP Ph.D. project. Explainable declarative	KAW	5000	2019-2024
program analysis			
LARGEDYN – Modeling and Simulation Tool	SSF	7036	2019-2023
for Very Large Systems with Possibly Dy-			
namic Structures			
EMBrACE – Environment for model-based	ITEA3/Vinnova	4632/54800	2019-2023
rigorous adaptive co-design and operation of			
CPS			

## **External Funding Attracted**

## Inter-University Cooperation within ELLIIT

Within the project, we have monthly meetings with senior researchers and Ph.D. students, and a yearly one-day workshop. Concrete collaboration points include the development of property probes (joint publication [Risberg Alaküla, 2022]), their application to OpenModelica, and the construction of a light-weight Julia library for reference attribute grammars.

## Inter-Disciplinary Cooperation

We have cross-disciplinary collaboration in a project on energy and sustainability mega-games ("Att vända strömmen – ett megaspel för ökad förståelse av energisystemet") where OpenModelica has been used to make future predictions via simulation from policies decided by the game participants. This is a collaboration between Linköping University with Jönköping University and Skövde Högskolan and is supported by the Swedish Energy Agency (Energimyndigheten).

#### International Collaboration

We have an ongoing collaboration with TU Dresden about using reference attribute grammars for tool building. During the last few years, we have met for joint one-day workshops with presentations and demonstrations. Our team has collaborated (via the Open Source Modelica Consortium) with Lawrence Berkeley National Laboratory on better supporting the Modelica Buildings library – a state-of-the art library for modeling and simulation of buildings and their energy consumption. We have also collaborated with ABB Germany on power plant modeling and simulation. Together with Politecnico di Milano we have collaborated on improving the modeling and simulation in Modelica [Tinnerholm 2022] and [Tinnerholm 2023] using our Julia-based OpenModelica.jl framework. We have also continued our collaboration with FH Bielefeld - University of Applied Sciences on improving the scalability and performance of the OpenModelica compiler backend. Together with EDF we have worked towards an open standard for requirements modeling (CRML) which we have presented at the 2023 Modelica Conference [Bouskela 2023].

#### Patent Applications, Open Source Software, and Contributions to Standards

Researchers in the project develop many open source systems. These are the most important ones.

- **[OpenModelica]** An advanced open-source CPS modeling, simulation, optimization and debugging framework that supports equation-based object-oriented languages based on the open standard Modelica.
- [**OpenModelica.jl**] A Julia-based experimental framework for exploring new paradigms and extensions for physical modeling languages.
- [OMSimulator] OMSimulator an open-source tool for co-simulation of composite models based of FMUs, supporting the FMI and SPP open standards.
- [CodeProber] A tool for source-code based exploration of program analysis results.

[JastAdd] A metacompiler that supports reference attribute grammars.

[ExtendJ] An extensible Java compiler, implemented using JastAdd.

Researchers in the project contribute to the following open standards:

- [Modelica] object-oriented equation-based declarative language to model Cyber-Physical Systems.
- [Functional Mock-up Interface (FMI)] exchange dynamic simulation models from tools (180+ tools support it).
- [Functional Mock-up Interface for Embedded Systems (eFMI)] open standard for model-driven development of advanced control functions for safety-critical and real-time targets.
- [System Structure and Parameterization (SSP)] tool independent open standard to define complete systems consisting of one or more Functional Mock-up Units (FMUs defined by the FMI standard) including its parameterization that can be transferred between simulation tools.

#### Exploitation and Cooperation with Industry and Institutes

Researchers in the project continuously supervise M.Sc. thesis projects in collaboration with industry and society. Recent examples include collaboration with, Modelon, Qlik, Neo4J, the Swedish Energy Agency, and Saab aeronautics. Examples of research collaboration partners include ABB Automation, Modelon, Cognibotics, Électricité de France, Réseau de Transport d'Électricité, Volvo Trucks, Santa Anna IT Research Institute, Research Institutes of Sweden, Swegon, Siemens Energy AB.

#### Contributions to Undergraduate/Graduate Education

We have incorporated our research results in several courses, primarily at the master level. Many of our Ph.D. students also take these courses, depending on background.

The JastAdd metacompiler has been used for many years in the EDAN65 Compilers course at Lund University, and has recently been put into use also in the EDAP15 Program Analysis course. The CodeProber tool has very recently been introduced into both courses. The students use it at lab assignments, to help in understanding example analyses, and to debug their own analyses. JastAdd and CodeProber are also used in our EDAN70

advanced project course. Furthermore, in the latter course, students often make use of our extensible Java compiler (ExtendJ) to build experimental language extensions or new tooling.

The OpenModelica environment is widely used in academia for both research and teaching. Locally at Linköping University in the course TNG022 Modeling and Simulation the students use the tool for exercises and demonstrations. As part of the compiler course TDDB44 we have discussed about optimization phases of OpenModelica. In the software design course TDDE45 we discuss OpenModelica in the part on domain-specific languages. Internationally, OpenModelica is used in courses in Italy (University of Pisa, Politecnico Di Milano), Germany (OTH Regensburg, TU Dresden, TU Hamburg, TU München), Netherlands (TU Delft) and as driver for cloud-based interactive books teaching Modelica such as Modelica by Example or Modelica Introduction and Applications.

### **Outreach Activities**

Starting in 2017, we have organized outreach activities to high school teachers to introduce programming in their math classes, jointly with Lund University Vattenhallen Science Center and financed by a Google CS4HS award. This was later followed by several outreach workshops for high school teachers and students, focusing on using programming for illustrating the UN global goals. This was a collaboration with Vattenhallen, the Department of Physical Geography and Ecosystem Science at Lund University, the Swedish Science Centers organization, and the Swedish National Space Agency.

In the fall of 2022, we gave an invited online technical talk at Gitlab's Vulnerability Research team (5-6 participants from Europe and SE Asia), and demonstrated CodeProber.

Since the project start, the Linköping University team has been running Modelica and CRML tutorials several times per year at workshops (ModProd) and conferences (Modelica, Asian Modelica Conference, American Modelica Conference). These tutorials also include a section to rise awareness on sustainability and allow researchers to run predictive scenarios simulations using System Dynamics World3 model.

## Keynotes, Plenaries and Academic Service

Some recent examples include:

- Görel Hedin served as chair for the [2022 AITO Dahl-Nygaard Award Committee]. This is an annual prize in the name of Ole-Johan Dahl and Kristen Nygaard, to honor their pioneering work on object-orientation.
- Martin Sjölund, Prof. Peter Fritzson, Lena Buffoni, Adrian Pop, Lennart Ochel served as Editors of Special Issue "[Selected Papers from Modelica Conference 2021]", [14th International Modelica Conference].
- Researchers from the Linköping team served as Chairs of the [OpenModelica Workshop 2019-2023] (Events → OpenModelica Workshop).

#### 4.10 B9. Collaborative Robotics

PI: Patrick Doherty (LiU) Co-PI: Elin Anna Topp (LU)

#### **Objectives**

The research areas of collaborative robotics, mixed initiative interaction and human-centered AI have reached the research forefront in recent years and encompass several of the strategically most important and industrially pressing issues in robotics. Dynamic and seamless interaction between collections of human and robotic agents in achieving complex common goals and information exchange is an essential component in collaborative robotics. In this context, distributive situation awareness is essential for supporting collective intelligence in teams of robots and human agents where it can be used for both individual and collective decision support. A major objective of this project is the scientifically grounded development of a distributed knowledge sharing framework for teams of human and robotic agents. A secondary objective is its integration with a distributed task-based framework used for collaborative planning capability.
#### Chapter 4. Call B

Another major objective is the development of frameworks for communication between teams of human and robotic agents based on the general mechanism of mixed-initiative interaction. This approach allows for a genuine two–way communication between agents which leverages access to the internal state of a system as well as intentional states of agents in order to assess and resolve ambiguous situations in interaction. This approach also serves as a basis to optimize use of the full capabilities of teams of agents in achieving complex goals. Additional active query interfaces combine both aspects of communication and plan generation into one cohesive system for collaborative goal achievement. The methodology used for achieving all project objectives is based on grounding all frameworks scientifically, both formally, experimentally, and algorithmically, and then testing the results through the development of prototype software systems. Field robotic experimentation with multiple robotic systems is then used to verify and validate both the science and the software prototypes.

#### Main Scientific Achievements

The participating groups in the project have been very successful in achieving the project objectives at this point in the project. The scientific articles generated, the software prototypes developed, and the ensuing field robotic experimentation, resulting in high level public demonstrations, have been targeted specifically to achieve the objectives and show their practical applicability. Much focus has been placed on publication of journal articles rather than shorter conference publications.

The article, Hastily Formed Knowledge Networks and Distributed Situation Awareness for Collaborative Robotics [Doherty, 2021], lays the conceptual basis for some of the ensuing work in the project. It provides a blueprint for both the distributed knowledge sharing framework for teams of human and robotic agents and its integration with a distributed task-based framework used for collaborative planning capability. The article, RGS+: RDF Graph Synchronization for Collaborative Robotics: accepted to the Journal of Autonomous Agents and Multi-Agent Systems [Berger, 2023], provides a detailed expose of the algorithms and empirical validation used in the distributed knowledge sharing framework. This work has generated some open source software referenced further in the report. Both of these articles provide the scientific and algorithmic basis for the prototype software system for distributed knowledge sharing used in our field experimentation. Two journal articles have recently been submitted in 2023 that are directly related to the project objectives. The article Leveraging Active Queries in Collaborative Robotic Missions has been submitted to a special issue in the Intelligence & Robotics journal [Berger, 2023]. This article develops mixed-initiative interfaces based on queries that often automatically generate collaborative plans to acquire information required to answer the query. This idea is quite novel and has also been integrated into the larger software framework and tested through field robotic experimentation. The article, Polygon Area Decomposition Using a Compactness Metric, submitted to the Applied Soft Computing journal [Wzorek, 2023], provides algorithms for partitioning polygonal areas into compact regions amenable for generation of distributed path plans for teams of UAVs tasked with 3D mapping of large land areas. Associated with this paper is an open-source software package that can parameterize and integrate the algorithms proposed, not only in the project context, but in other application areas.

Additionally, one of the project participants, Mariusz Wzorek successfully defended his Ph.D. thesis, *Selected functionalities for Autonomous Intelligent Systems In Public Safety Scenarios* [Wzorek, 2023]. Included in this thesis is the article, *Router and gateway node placement in wireless mesh networks for emergency rescue scenarios*: [Wzorek, 2021] published in the Journal of Autonomous Intelligent Systems. This article leverages the collaborative robotics framework and provides algorithms for optimally placing communication nodes in operational environments using UAVs with the express goal of generating ad-hoc communication networks for emergency rescue applications. A number of articles have been published in journals that are directly related to the project objectives in the sense that each agent is assumed to have a knowledge base or data repository associated with it. These articles provide insight into particular operations on such repositories that can be useful in the management and querying of such knowledge bases. The first article, *A landscape and implementation framework for probabilistic rough sets using PROBLOG*, published in the Information Sciences Journal [Doherty, 2022], develops a framework for reasoning about approximate knowledge with an associated implementation in PROBLOG, probabilistic logic programming. The second article, *Dual forgetting operators in the context of weakest sufficient and strongest necessary conditions* [Doherty, 2023], has been accepted for publication in the

Artificial Intelligence Journal. The paper proposes a framework for dealing with how one might appropriately *forget* information in knowledge bases in a principled manner while retaining maximal inferential power. A (short) paper has been published at ACM/IEEE HRI 2023 on a VR-based system for Human-Robot Collaboration, targeting SaR scenarios (main author Ayesha Jena). The system is based on eye-gaze and gesture tracking to capture user commands and the target of their attention.

# Long-Term Impact

We believe the project has the potential for long term impact due to the integrated mix of science, software prototyping and field robotics experimentation.

- Software systems and formal frameworks that have been developed within the project and based on published project articles are now being actively used in the WASP WARA Public Safety Arena by researchers and industrial partners. We expect this activity to continue, contribute to new research avenues and also be used as a basis for industrial products by the participating industries. The core systems architecture used to support all participants in WARA-PS, academic and industrial, is based on work done in this project and previous ELLIIT projects, among others.
- Activities in this, and other associated projects are actively being used in a new collaboration with Saab and its Brazilian partners under the auspices of the AuSSyS VINNOVA project, which is part of the Air Domain Studies (ADS) Framework. We believe it will have a long-term practical impact for the participating partners. This has already been shown in recent public demonstrations of integrated software systems developed by Brazil and the authors during the annual WASP WARA-PS workshops in 2022, and 2023.
- Scientifically, the development of the distributed knowledge sharing framework is novel and should contribute to new ways to process different types of data, information, and knowledge in a practical, scalable manner in multi-agent and robotic systems. Additionally, the use of active queries provides a new approach to distributed planning while at the same time hiding the details from human users by automating the process through queries.

# Plans for 2024-2025

The LiU team will continue the development of their systems for collaborative robotics in connection with this project and the WASP WARA-PS arena. Several outreach events/demonstrations are planned, including annual WARA-PS workshops (May and September) and international visits in connection to activities with Saab, among others. Three new scientific journal publications are being prepared related to the project objectives. One focuses on support for dealing with contingencies in multi-agent mission execution, where automated planning techniques are leveraged to generate and repair mission plans dynamically as robotic systems try to fulfill given mission goals. The second publication will describe the design and evaluation of an integrated system for maritime search and rescue scenarios, where the system leverages the use of the active query framework developed by the LiU team and a machine-learning framework developed by the Brazilian partners within the AuSSys VINNOVA project. The third publication will focus on distributed image processing execution, where remote processing sites are chosen optimally based on communication bandwidth/delays and available computational resources. The Lund team will continue work with a VR-interface, in addition to developing functionality to interpret human eye-gaze and gestures regarding underlying intentions of human operators using robotic teams. Scenarios developed for this aspect of the project will be integrated with WASP's WARA-PS tools for simulation and 3D visualization of the respective operational environment, where the LiU team is also heavily involved.

# Awards and Recognitions

- P. Doherty served as a Distinguished Guest Professor at Jinan University (Zhuhai campus), China (Fall 2018-Fall 2021) in addition to being appointed as an Honorable Dean of the School of Intelligent Systems and Engineering, Jinan University (Zhuhai campus), China for the same period.
- P. Doherty was elected a lifetime fellow of the Asia-Pacific Artificial Intelligence Association July 2023.

http://www.aaia-ai.org/.

• Elin A. Topp (Lund PI) has been accepted in 2022 into the pedagogical academy of the Faculty of Engineering, LTH, and now has the status of Excellent Teaching Practitioner.

# **External Funding Attracted**

Project Name	Funding agency	Total Amount	Duration
		(KSEK)	
Autonomous Search System - AuSSyS	Vinnova	2250	2022-2024
WASP WARA-PS Research Arena (LiU)	WASP	7000	2017-2024
Robot-Assisted Hastily Formed Knowledge Net-	SSF	27 000	2016-2021
works (RIT15-0097, LiU)			
Robotic Skill learning (LU)	WASP	5000	2019-2024
Semantic Mapping and Visual Navigation for	SSF	6000	2016-2022
Smart Robots (LU)			
SelectiCa (LU)	Vinnova/Eurostars	2600	2021-2023
AISA (AI powered tools for situation awareness	WASP	3000	2023-2025
in shared autonomy) (LU)			
Get a Grip - Accurate human-robot (tool) hand-	WASP	5000	2024-2028
overs			
WASP Industrial Ph.D. student (Saab Kockums)	WASP	3000	2023-2028
Next Generation Communication and Com-	Vinnova	36 000 (in total)	2024–2028
putational Infrastructures and Technologies			
(NextG2Com)			

# Inter-University Cooperation within ELLIIT

The LiU team has been informally co-advising two LU students, a master's student (Hicham Mohamad) and a Ph.D. student (Lara Laban), with both regular virtual and physical meetings throughout the 2021-2023 period. Additionally, a joint master's thesis on the topic of Simultaneous Localization and Mapping (SLAM) using laserand image-based sensors is being set up between the LiU team and the Learning for Autonomous Systems group at KTH. The project will start in January 2024. The LiU team has cooperated in this ELLIIT project with LU in the areas of human-robot interaction and robotics. The automatic control group at LU, previously led by Anders Robertsson, has cooperated with the LiU team specifically on leveraging LiU software frameworks for drone control.

# Inter-Disciplinary Cooperation

There are several areas where the project involves inter-disciplinary cooperation:

- Agriculture (LiU): work on interdisciplinary cooperation within precision agriculture in collaboration
  with Mahasarakham University, Thailand has taken place in 2023 with visits from three members of
  the LiU team. The initial project phase has focused on building 3D models of an experimental farm in
  Mahasarakham that is affiliated with Mahasarakham University. Some of the results of this cooperation
  have been integrated with systems used by both LiU and the WARA-PS participants. This is available
  online at https://cesium.waraps.org/ and widely available to researchers in Sweden.
- Control theory and robotic frameworks (LiU): the LiU team has started a collaboration within control
  theory applied to UAVs with Universidad Politecnica de Madrid, Spain. The topic of focus in the initial
  stages of the cooperation involves use of the open-source framework Aerostack2 https://github.com/
  aerostack2/aerostack2 and its integration with some of the software frameworks developed in this project.
- Political science studies (LU): the LU team (Elin A. Topp, project co-PI) has been involved in an interdisciplinary Study Group at the Pufendorf Institute for Advanced Studies at Lund University. The topic was Political Polarization on the Internet.

# International Collaboration

P. Doherty served as a Distinguished Guest Professor at Jinan University (Zhuhai campus), China (Fall 2018-Fall 2021) and has been a guest professor at Mahasarakham University, Thailand, from February 2023 - August 2023. The LiU team collaborates with several academic and research institutions in Brazil within the AuSSys VINNOVA project. These institutions include IANA Tecnologia Ltda., Centers of Reference in Innovative Technologies Foundation (CERTI), Instituto Tecnológico de Aeronáutica (ITA), Comando da Aeronáutica (COMAER). This has led to joint demonstrations with the Brazil team at the yearly WARA-Public Safety Arena national workshop in 2022 and 2023. More recently, the LiU team has begun collaboration with Professor Pascual Campoy's Lab at Universidad Politecnica de Madrid, Spain, where students will be exchanged in 2023-2024.

# Patent Applications, Open Source Software, and Contributions to Standards

The following open-source software projects, previously discussed, have been released:

- RGS+: RDF Graph Synchronization for Collaborative Robotics: https://gitlab.liu.se/lrs/kdb-gs-docker
- Polygon Decomposition Using Compactness Metrics: https://gitlab.com/cyloncore/Cartography/

# Exploitation and Cooperation with Industry and Institutes

The LiU team has had extensive collaboration with Saab, Saab-Combitech, and Saab Kockums in the context of the WASP WARA-Public Safety arena, where several software systems developed by the LiU team and related to this ELLIIT project have been integrated and used by these companies. The LiU team has been involved in two industrial master thesis projects where data collection using LiU's motion capture system was performed. Additionally, the computer science department and the automatic control department at Lund University have had (and still have) direct collaborations with Saab Kockums through WASP-funded industrial Ph.D. projects (one concluded in 2021 and one is still ongoing) and related M.Sc. projects. These activities have, in fact, resulted in a joint journal publication [Andersson, 2021] that includes both the PI and co-PI in this project, as well as employees for the mentioned companies as co-authors. Further, a new Ph.D. project supervised by the co-PI Elin A. Topp at LU has been started in fall 2023 in cooperation with the strongly application focused School of Aviation. This new project, run as an internal industrial Ph.D. project, has a direct connection to the current ELLIIT project, as the focus is on interfaces and situation awareness for supervision and remote control of Unmanned Aerial Vehicles / Systems.

# Contributions to Undergraduate/Graduate Education

Selected results of the project have been and continue to be disseminated in several courses at LiU, including Artificial Intelligence (TDDC17) and AI Robotics (TDDE05). The LiU team has been involved in planning, development and teaching for the WASP WARA-PS Summer School in June 2023. They are also currently involved in the supervision of several ongoing WASP WARA-PS Ph.D. project courses. LU has developed (2021/2022) a new undergraduate course which started in 2023: Advanced Applied Machine Learning (EDAP30). The project co-PI is responsible for this course. LU has also been involved in the coordination, development and delivery of a new WASP Course in 2022/2023: Interaction, Collaboration, Visualisation. The course was given for the first time in spring 2023. The project co-PI contributed regularly to the course Intelligent Autonomous Systems (started 2020), since 2021 with significant updates to incorporate aspects of interaction with autonomous systems to a larger extent than in the first course occasion. Application examples and project tasks for both these courses are or will be in many cases drawn from the research topics (robotics, knowledge representation, machine learning) that are pursued in the current ELLIIT project. The LU co-PI in this project has been a member of the WASP Graduate School Management group since 2019 and also joined the COMPUTE Graduate School steering group at Lund University in July 2021 (https://compute.lu.se).

# **Outreach Activities**

The LiU team has given several robot lab tours at their LiU Lab, given presentations to invited groups from industry, academia and society at large, and have set up live multi-agent robot demonstrations, during the duration of this project. These events include:

- A demonstration of the Spot quadruped ground robot for His Majesty the King's visit in May 2023 in Linköping, as part of the celebration of *Jubileumsåret 2023*.
- A demonstration of the Spot quadruped ground robot at the Business Europe Event 2022, Stockholm. This was done in collaboration with the LU team and included the release of a joint leaflet describing research activities at LiU and LU (https://bit.ly/3QkNiep). The brochure highlights the ELLIIT project.
- A robotics lab tour and demonstration of the Spot quadruped ground robot for Berzeliusskolan's students coordinated by *Teknikåttan* https://www.teknikattan.se/ in April 2023.
- Several robotics lab tours and demonstrations of the Spot quadruped ground robot and UAVs for 168 students during *Sommarveckan* in June 2023. This event was organized by LiU. (https://liu.se/artikel/sommarveckan).
- Several visits related to strategic Sweden-Brazil collaboration projects, May/November 2023. These included robotics lab tours, presentations, Spot quadruped ground robot demonstrations, in addition to UAV demonstrations.
- Visit from the AI strategy group at Region Östergötland, December 2022. This included a robotics lab tour, a presentation, and the Spot quadruped ground robot and UAV demonstrations.
- Exhibition during the *Populärvetenskapliga veckan* at LiU, October 2023. This included the Spot quadruped ground robot demonstrations and UAV demonstrations.

The LU team has been involved in the following outreach activities:

• The Lund team has been involved heavily and regularly in the European Robotics Week initiated by the EURobotics network, with lab demonstrations for school classes during one week in the Fall, run yearly since 2013 with adaptation to an online setting in Fall 2020. Several researchers from Lund, including the co-PI, have contributed with short portrait videos to the standing AI exhibition at LU's Science Center "Vattenhallen".

# Keynotes, Plenaries and Academic Service

- P. Doherty was Invited Speaker at the School of Mechanical Engineering, Zhejiang University. 110 Anniversary Event. Online Global Seminar Series. August 2021.
- P. Doherty continued serving as Editor-in-Chief of the Artificial Intelligence Journal (AIJ) in 2021-2022. His role as EinC finished at the end of 2022 after serving 8 years. The AIJ is considered to be one of the most prestigious journals in the area of AI.
- E.A. Topp was appointed Associate Editor for the ACM Transactions on Human Robot Interaction (THRI) in 2021, the flagship journal of the HRI community.
- E.A. Topp has served as local arrangement co-chair for the 2023 ACM/IEEE Conference on Human Robot Interaction, March 2023, Stockholm (with significant parts of the work load also being handled in 2022).

# 4.11 B10. Geometrically Constrained Learning for Vision

PI: Michael Felsberg (LiU) Co-PI: Anders Heyden (LU)

# Objectives

The project deals with the use of geometrical constraints for different vision tasks, such as navigation and map-making. In particular, we will look at using one or several homographies (describing the relation between corresponding feature points on planar surfaces), which is a very common situation in both man-made and natural environments. We will investigate incorporation of constraints obtained from homographies into different

deep-learning networks, such as convolutional neural networks and also investigate the underlying geometrical constraints imposed by one or several homographies under different conditions on the intrinsic camera parameters. There are several applications of the project within SLAM, UAVs etc.

## **Main Scientific Achievements**

The main scientific achievements in the project are related to new methods for geometric image matching [Edstedt, 2023], dataset for harmful content detection [Edstedt, 2022], few-shot learning of semantic segmentation [Johnander, 2022], and camera calibration for drones [Örnhag, 2022]. Two papers are accepted for the 3DV 2024 conference, one regarding local feature detection [Edstedt, 2024] and one about robust relative camera pose estimation (Astermark et al.). Two more papers are accepted, one for the WACV 2024 conference, regarding augmentation in transformer-based tracking [Zhao, 2024a], and one for NeurIPS 2023, regarding global scene flow [Zhang, 2024b].

## Long-Term Impact

The field of computer vision developed a powerful body of knowledge in the area of projective geometry during the decade before the deep learning revolution. Deep learning has since then been used to solve geometric problems in black-box approaches, which leaves room for synergies of the two fields. The results in this project lead to new insights, both in generating knowledge on geometric methods, and advances in machine learning. A particularly good example is the DKM-paper, showing that pose estimation from dense correspondences is superior to sparse feature point matching, sets a new state-of-the-art, and at the same time produces uncertainties in a transformer-based image warping. The results are highly relevant to several application domains and are useful for companies working on these applications, such as autonomous driving with its sub-tasks of self-localization as well as detecting and following objects, also in blind spots. The dense geometry estimation is also highly relevant in remote sensing and in the context of mitigation of climate change effects, for instance in the determination of risk areas for floods and landslides. Another good example is the combination of traditional minimal solvers for pose estimation based on feature correspondences with known relative depth and a convolutional neural networks that estimates the needed relative depths. The minimal solvers can be substantially simplified and the robustness and speed increased when an estimate of the relative depth is obtained.

#### Plans for 2024-2025

The core activities within the project are aiming at follow-up works, e.g. on the CVPR2023 and 3DV 2023 papers. For the year after, the planning of the Ph.D. defenses within the project is in the project focus. Also, a part of the project team is involved in an ELLIIT focus period in Autumn of 2024, with the topic of AI & Climate. A part of the team is involved in LiU's profile areas on Visual Digital Futures and Human in Systems of Systems (Connected Intelligent Systems). Another part of the team is involved in LU's profile area AI and digitalization.

#### Awards and Recognitions

M. Felsberg:

- Most cited paper and author IEEE Transactions on Signal Processing 2001 (exaly.com 2022),
- Best paper award at SSBA 2010,
- Honorable mention at Fusion 2011,
- Best paper award at Mobile Vision CVPR Workshop 2014,
- VOT challenge winner at VOT ECCV Workshop 2014,
- OpenCV Tracking challenge winner 2015,
- Best paper award at ICPR 2016,
- Highest ranked AI researcher in Sweden according to Vinnova AI report 2018,
- Best paper at VISAPP 2021,
- Honourable mention at DAGM-GCPR 2021,

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- Best paper award at SSBA 2022,
- Reviewer awards at ICML 2022 and ECAI 2023,

## J. Edstedt:

- DKM-paper was selected as highlight (top 2.5% of all submissions),
- In collaboration with Georg Bökman: winner of the SLAM challenge at IJCAI.

#### A. Heyden

- Invited speaker at SCIA 2013
- IAPR Fellow 2016
- Best paper award at WACV 2021
- Winner of Lund University Innovation Award 2022

M. Wadenbäck

• Best paper award at SSBA 2021.

## **External Funding Attracted**

Project Name	Funding agency	Total Amount	Duration
		(kSEK)	
Constrained Deep Spatio-Temporal Networks	WASP/KAW	4 000	2021-2026
NEST _main_	WASP/KAW	6 000	2022–2027
Industrial Ph.D.	WASP/KAW	4 000	2022–2027
Assistant Prof.	WASP/KAW	16 000	2022–2027
Future Airport Control	Vinnova	1 500	2022–2026
Uncertainties in Transformers	VR	3 700	2023–2027

# Inter-University Cooperation within ELLIIT

Due to the pandemic situation, project meetings were held via Zoom during 2021. Physical project meetings have been held in Linköping (May and October 2022) and in Lund (August 2022). The project team met during SSBA 2023 (Norrköping). Anders Heyden (LU) and Mårten Wadenbäck (LiU) have worked on UAV positions systems based on homographies and IMU-estimates of the gravitation vector together with Kalle Åström (LU), Patrik Persson (LU) and Marcus Valtonen-Örnhag (LU).

# Inter-Disciplinary Cooperation

In collaboration with Statens Medieråd and Luleå University, the dataset for the ICPR 2022 paper has been created. Furthermore, connections to the SFO Merge have been established, N. Kljun and M. Felsberg have been working on a joint Vinnova project and mutual invitations to present at Merge and ELLIIT (Focus Period) events have intensified the collaboration on AI for climate research.

# International Collaboration

M. Felsberg is part of the VOT committee organizing the yearly workshops and challenges on visual object tracking and segmentation together with delegates from several other European countries. Furthermore, M. Felsberg co-organized a visit of the ML-cluster (WASP) to Amsterdam, regarding the topic of geometry and deep learning. M. Felsberg is honorary professor at the University of Durban (South Africa). A. Heyden is a member of ECMI (European Concortium for Mathematics in Industry) Council.

# Patent Applications, Open Source Software, and Contributions to Standards

M. Felsberg is co-inventor in two patent application: Method for Surveillance and Analysis of Farm Animals and Arrangements for Such Surveillance and Analysis (P4885SE00) and a patent application together with Husqvarna AB. All code from papers is published on GitHub. A. Heyden is co-inventor of one patent application:

PREDICTION OF QUANTITATIVE CORONARY ANGIOGRAPHY VALUES USING MYOCARDIAL PERFUSION IMAGES (PCT/SE2021/051269)'.

# Exploitation and Cooperation with Industry and Institutes

Besides industrial Ph.D. students with Zenseact, Saab, and Husqvarna, we collaborate with Deep Forestry AB, Maxar Sweden, SICK IVP, IKEA, Arriver (Qualcomm), Trafikverket, Scania, Axis and Volvo Cars.

# Contributions to Undergraduate/Graduate Education

CVL supervises on average 26 theses each year, most of these with industry. Two master-level courses were designed in 2022 (Computer Vision for Video Analysis and 3D Computer Vision). A new master course on Deep Learning is currently under development together with Fredrik Lindsten and Marco Kuhlmann. CVML supervises on average 20 theses each year, most of these in collaboration with industry, such as Cellavision, Axis, Sony, Precise Biometrics, Volvo, etc. LTH has recently started an international master program in machine learning and automatic control.

# **Outreach Activities**

M. Felsberg gave an interview on Deep Fakes (August 2022 SVT-Play) and a presentation at "Pint of Science" 2022. In 2023, he presented at a popular scientific event in Norrköping, why learning vision is difficult, and has been interviewed about AI for the podcast Bildningskomplexet.

# Keynotes, Plenaries and Academic Service

M. Felsberg had been invited to give talks and keynotes at

- CVPR-WS Perception Beyond the Visible Spectrum 2020
- ISCMI 2020
- CVPR-WS Robust Video Scene Understanding 2021
- MAIN (Mathematics, AI, and Neuroscience) 2021
- CVPR-WS Anti-UAV challenge 2023
- Merge annual workshop 2023
- Qualcomm inspirational seminar series 2023

M. Felsberg is area editor for PLOS ONE and CVIU. He has been PC for SCIA 2019 and 2023 as well as AC for ECCV 2018, BMVC 2019 and 2021, CVPR 2020, 2022, and 2023, NeurIPS 2023, and WACV 2024. A. Heyden has been AC for BMVC 2022.

# 4.12 B11. Local Positioning Systems

PI: Kalle Åström (LU) Co-PI: Fredrik Gustafsson (LiU)

# Objectives

Mapping, positioning, and localization are key enabling technologies for a wide range of applications. Within EL-LIIT there are several strong research groups (math-LU, control-LiU, control-LU, EIT-LU) that do fundamental research within this area for many sensor modalities, e.g., vision, radio, audio, magnetometers, electromagnetic, radar, sonar and geophones. Within the project we use a dual strategy, (i) to conduct exceptional state-of-the-art research, and (ii) to engage in collaborative projects to ensure that the outcomes are applied in industry and society. Such collaborative projects provide inspiration from stakeholders that generate novel research questions. The overall goal is to develop and create technologies and fundamental knowledge for accurate positioning and localization with a variety of sensor modalities.

#### Main Scientific Achievements

The main scientific achievements over the last five years include, (i) new results on efficient algorithms for solving systems of polynomial equations exploiting Border bases, (ii) new algorithms for optimal trilateration [Larsson, 2019], (iii) new algorithms for sender-receiver node position estimation and calibration for massive MIMO utilizing multipath components, (iv) new algorithms for map merging enabling collaborative slam [Flood, 2020], (v) Gaussian process state-space models [Zhao, 2019], (vi) 3GPP Long Term Evolution (LTE) localization [Radnosrati, 2020], and (vii) 3D mapping [Zhu, 2022].

#### Long-Term Impact

There are several ways in which the research provides a lasting impact. Perhaps foremost is the impact through the undergraduate and graduate students that bring their results and knowledge to industry and public sector, where they with their skills have profound long-term impact. There are numerous examples here (ARM, Apple, Combain, Hövding, Sony, Ericsson, Volvo, Zenseact, Umansense, Spiideo), where we see such impact. Positioning and mapping are enabling technologies and we see how such methods are being used either as the core product of businesses (Combains global positioning system, Apples 3D maps) or as key components (motion analysis in Hövding or Umansense, tracking and positioning of players in Spiideo, mapping and positioning for Volvo or Zenseact, tracking of wildlife for Kolmården zoo, Ngulia Rhino Sanctuary). Within basic research, we have produced new results, e.g. on solving systems of polynomial equations [Larsson, 2017], massive MIMO localization [Li, 2019], particle filter for localization [Gustafsson, 2010], and novel features for camera localization [Sarlin, 2021]. These have already had a substantial impact both within and outside academia. Modelling expertise of the researchers in the project has also had an impact on understanding modelling of the COVID-19 pandemic intervention, [Soltesz, 2020].

#### Plans for 2024-2025

We have two Ph.D. students directly financed by the ELLIIT project (E. Tegler, G. Zetterqvist). In these two Ph.D. student projects, we will continue with research on both theory and applications. Examples of theoretical areas include research on, (i) algebraic geometry and its connection to mapping and localization, (ii) optimization techniques, (iii) estimation theory, (iv) sensor fusion, and (v) combinations of data-driven and model-based techniques. We will continue to work on a wide range of sensing modalities, e.g. vision, RGB-D, lidar, radar, sound, radio (in terms of UWB time of arrivals, WIFI signal strength, WIFI round-trip-time, 5G/B5G directional information and time of arrival), IMU and magnetometers. Each of these modalities provide research challenges on their own (how to make maps, how to estimate position, how to track), but also taken together in different combinations, e.g. using sensor fusion. An interesting theme going forward is to not only provide geometric understanding using these sensors, but to also start analyzing maps and motions in terms of semantic meaning.

#### Awards and Recognitions

Researchers within the projects have received the following awards and recognitions:

- Three master's theses got shared first and third prize in the "Radionavigeringsnämndens (RNNs) exjobbspris", 2019.
- Outstanding Student Paper Award at CCTA 2022, for the paper [Greiff, 2022]
- Best Student Paper (ICCV21) for the paper [Lindenberger, 2021]
- Best paper award, ACCV 2018 for the paper [Pritts, 2019]
- Fredrik Tufvesson was awarded IEEE fellow in 2017.
- IEEE Sweden VT-COM-IT Joint Chapter Best Student Journal Paper Award 2023 for the paper [Li, 2022]

Project Name	Funding agency	Total Amount	Duration
ADACOBSA Airborno data collection on		(KSEK) 4000	2020 2022
ADACORSA - Alloonie data conection on		4000	2020-2023
	005	(200	2016 2022
Semantic Mapping and Visual Navigation for	SSF	6200	2016-2022
Smart Robots			
Robust 3D Reconstruction with high-level	VR	1000	2024-2027
structures			
WASP (AcademicPh.D. student)	KAW	700	
WASP (Industrial Ph.D. student)	KAW, Combain	600	2016-2020
WASP (Industrial Ph.D. student)	KAW, Saab	600	2016-2020
WASP (Industrial Ph.D. student)	KAW, Ericsson	600	2016-2020
WASP (Industrial Ph.D. student)	KAW, ARM	600	2018-2022
WASP (Industrial Ph.D. student)	KAW, Sony	600	2018-2022
WASP (Industrial Ph.D. student)	KAW, Epiroc	600	2018-2022
WASP (Industrial Ph.D. student)	KAW, Combain	600	2022-2026
WASP (Industrial Ph.D. student)	KAW, Zenseact	600	2021-2026
WASP (Industrial Ph.D. student)	KAW, Zenseact	600	2023-2024
Link-Sic (Industrial Ph.D. student)	LINK-Sic	600	2018-2023
MIMO-Sensor for Positioning and Au-	Vinnova-FFI	5500	2019-2023
tonomous Drive			
AgTech 2030	Vinnova	20 000	2018-2030

#### **External Funding Attracted**

# Inter-University Cooperation within ELLIIT

The groups involved have substantial interuniversity interaction, and there are, in fact, many senior researchers from different departments and sites involved in this particular project beyond the PIs: G. Hendeby, Isaac Skoog (control-LiU); M. Oskarsson, V. Larsson (math-LU), F. Tufvesson (EIT-LU), B. Bernhardsson (control-LU). A key component here is a yearly workshops on localization and navigation. These are co-organized by this ELLIIT project and with the WASP cluster Smart Localization Systems. These meetings include participants from all over Sweden from academia, industry and organizations such as FOI.

- Localization workshop at Kolmården, joint WASP and ELLIIT workshop on local positioning systems, 29-30 August, 2018.
- Localization workshop at Gränsö Slott, joint WASP and ELLIIT workshop on local positioning systems, September 3-4, 2019.
- Nordic Navigation Workshop 2023 at Himmelsby, joint WASP and ELLIIT workshop on local positioning systems, 19-20 October, 2023.

We also have additional meetings, where the Ph.D. students and supervisors meet, either in Linköping or Lund or online. For example, in 2022 we met in Linköping and FOI, where we discussed research and made joint sound experiments.

# Inter-Disciplinary Cooperation

We have several areas in which the project does interdisciplinary cooperation:

- Farming Work on interdisciplinary cooperation within precision agriculture. Partners here are Hushållningssällskapet i Skåne och Östergötland, T-kartor, Agtech 2030, Region Östergötland.
- Forestry Collaborations on precision forestry, with KATAM.
- Biology ongoing collaborations with the biology department in Lund and with the Max Planck Institute for Ornithology,
- Wildlife protection ongoing collaboration with Kolmården zoo and with the Ngulia Rhino Sanctuary in

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Kenya.

• Medicine – Position and motion is used to detect stroke. Collaboration with a startup Umansense in Lund.

# International Collaboration

The project has extensive international cooperation, e.g. with Brown University, Aalto University, Vaasa University, Oulu University, TU Graz, Max Planck Institute of Ornitology, Ngulia Rhino Sanctuary, ETH.

# Patent Applications, Open Source Software, and Contributions to Standards

Patents:

- US Patent App. 16/329,891, Downlink synchronization signals.
- US Patent App. 16/171,976, Hearing system configured to localize a target sound source
- US Patent App. 16/210,365, Hearing device or system adapted for navigation.
- US Patent 10,362,414, Hearing assistance system comprising an EEG-recording and analysis system.
- US Patent 10,436,938, Control system for marine vibrators to reduce friction effects.
- US Patent 10,429,185, Indoor rotation sensor and directional sensor for determining the heading angle of portable device.

# Exploitation and Cooperation with Industry and Institutes

Within the project there have been numerous masters theses both at academia and also in cooperation with industry. There has also been significant technology transfer with startups, e.g. Spiideo, Terranet, Combain Mobile, and within joint research projects on e.g. satellite localization (Aalto University, and the University of Vaasa), global indoor positioning (Combain Mobile, Lund), autonomous drones (bitcraze, Malmö), indoor and outdoor RF-based tracking (Sony, Ericsson), localization (ARM), autonomous driving (Volvo Cars and Zenseact). In addition, there have also been numerous industrial Ph.D. student projects: Martin Larsson (Combain Mobile), Olivier Moliner (Sony), Axel Berg (ARM), Russ Whiton (Volvo cars), Junshi Chen (Terranet), Jens Gulin (Sony), and Malte Larsson (Combain).

# Contributions to Undergraduate/Graduate Education

We have developed new course material for the WASP course on Autonomous Systems, and new Ph.D.-courses in Multi-Target Tracking and Optimal Filtering. Bo Bernhardsson and Mikael Nilsson are the coordinators for a new international masters' program in Machine Learning, Systems and Control.

# **Outreach Activities**

Examples of outreach activities include:

- Talk on computer vision and machine learning, Volvo Cars, Lund.
- Kalle Åström gave a talk on artificial intelligence for 500 priests in January 2019 and collaborated with a workshop on artificial intelligence and theology.
- Kalle Åström participated in talks and panel discussions at the Sweden-India Innovation Partnership AI for All, in New Delhi, 2019.
- Kalle Åström held popular science presentations and participated in panel discussions at Almedalen 2019 and also in 2023.
- Kalle Åström, TV4 morning show participated in a segment on deep fakes, 22 June 2023.
- Well attended tutorials at IPIN 2021, Spain, and 2023, Germany, on Indoor Localization using Magnetic Fields (Gustaf Hendeby, Isaac Skog (LiU&UU), Manon Kok (TU Delft).
- Gustaf Hendeby held a tutorial on magnetic localization FOI, Linköping, 2022.
- Tutorial "The Art of Solving Minimal Problems" at CVPR 2019 Viktor Larsson, Zuzana Kukelova, Tomas Pajdla, Magnus Oskarsson, Kalle Åström & Janne Heikkila, 2019.
- Tutorial "Localization and Mapping for Augmented Reality" at ECCV 2022 Paul-Edouard Sarlin, Johannes

L Schönberger, Ondrej Miksik, Viktor Larsson, Mihai Dusmanu & Marc Pollefeys, 2022.

• Tutorial "Camera Geometry Problems in Computer Vision" at ICCV 2023 Viktor Larsson, Zuzana Kukelova, Tomas Pajdla, Daniel Barath & Torsten Sattler, 2023 Oct 2.

#### **Keynotes, Plenaries and Academic Service**

Examples include:

- Gustaf Hendeby is associate editor for IEEE Transactions on Aerospace and Electronics Systems.
- Gustaf Hendeby was elected to the board of International Society of Information Fusion, where Fredrik Gustafsson also is a board member.
- Keynote held at a workshop at IEEE Vehicular Technology Conference in Porto, June 2019 by Fredrik Tufvesson "Channel characteristics for cooperative ITS and positioning".
- Fredrik Gustafsson was co-chair for Fusion 2020-2021, held virtually 2020 and in hybrid format 2021 in South Africa.
- Kalle Åström and Viktor Larsson are organizing European Conference on Computer Vision in Malmö 2026.

#### 4.13 B12. Visual Feature Based Data Reduction

PI: Ingrid Hotz (LiU) Co-PI: Bo Bernhardsson (LU)

#### **Objectives**

This is a continuation of a previous project with the same title. While the previous project had a broader scope — combining the strengths of automatic data analysis, sparse data representations, and human expert knowledge to maximize data profits in several fields — this continuation project narrows its focus to one specific application domain: Sparse representations for visual exploration of brain data. Correspondingly the PI/co-PI constellation has also changed in the continuation project where Ingrid Hotz continues as main PI and Bo Bernhardsson has joined as new Co-PI.

Brain data, encompassing functional, structural, and EEG measurements, contains valuable insights into the brain's complex functions, with significant implications for various medical and technological applications. The data of interest typically presents a challenging mix of multi-source, high-dimensional spatio-temporal data with diverse characteristics. The goal of the research described herein is to distill semantic, sparse representations from structural and functional brain data. These representations will guide a visual exploration process to support the development of novel applications, such as EEG-based diagnoses or the advancement of brain-computer interfaces (BCIs).

This project approaches the challenge from multiple angles, including 1) Designing intelligent experiments to generate data that helps correlate observed patterns with semantic information; 2) Employing geometric and topological methods for automatic dimension reduction while preserving data characteristics; 3) Utilizing learning methods to classify the identified features; 4) Extracting information about the brain by investigating the layers of trained networks, for instance, identifying physical locations of activations in the brain.

#### Main Scientific Achievements

The "Visual Feature-Based Data Reduction" project focuses on data from large-scale scientific simulations and measurements, particularly brain-related data. Such data is often not only large but also increasingly complex, with a variety of output variables. Our contributions aim at the effective analysis of the data as an essential step in the scientific process. They complement and integrate other analytical approaches such as statistical and machine learning methods by including humans in the cycle. Our main contributions to date focus on (i) the generalization of successful visual analysis methods to more complex data types, (ii) the use of sparse representation for data reduction, and (iii) real-time capture and visualization of data via brain-computer interface systems.

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(i) We have extended some of the most popular scalar visualization and analysis methods to multi-field and tensor data. Specifically, this is the generalization of volume rendering and isosurface visualization to multivariate settings. An extension of this work enables the topological analysis of multivariate fields [Jankowai2023]. (ii) Novel methods have been developed that exploit sparse representation for data reduction and exploration. An example is sparse nonparametric bidirectional reflectance distribution functions (BRDF) [Tongbuasirilai2022]. (iii) A framework, BCI-HIL, has been developed for the real-time collection and visualization of data from Brain-Computer Interface (BCI) systems that utilize visual stimuli, incorporating a human-in-the-loop approach. This framework is described in the journal paper [Gemborn, 2023]. Additionally, an application of the BCI-HIL framework, which employs Bayesian optimization to enhance the performance of real-time BCI systems, is discussed in [Tufvesson, 2023]. This research also compares various feature extraction methods from EEG data, focusing on real-time processing and classification performance.

## Long-Term Impact

A better understanding of patient-specific structural and functional data of the brain offers diverse applications with great potential not only in medicine but also for general advances in neuroscience, particularly in understanding brain functions and neuronal patterns. Our current research focuses on diffusion magnetic resonance imaging (d-MRI) and EEG data, both of which play an essential role in the development of sophisticated diagnostic tools for neurological disorders. Improving the efficiency and accuracy of interpreting EEG data could revolutionize the field of brain-computer interfaces (BCIs), enabling more precise and user-friendly systems that have the potential to transform assistive technologies for individuals with mobility or communication impairments. However, in the long term, we see the greatest impact in combining these different types of data into an integrated analysis that offers new insights and methods for processing complex biological data. In a broader context, such advances could also contribute to the fields of artificial intelligence and machine learning.

#### Plans for 2024-2025

Building on initial promising results with sparse presentations, we want to further develop and deepen this topic in the next years. This also includes methods for fast and robust sparse sampling. Ongoing work deals with optimal sampling for BRDF Acquisition [paper under revision]. In the next steps, we aim to use similar representations for examining High-Angular Resolution Diffusion Imaging (HARDI) and EEG data. We also plan to integrate these results into a visualization framework that, on the one hand, enables better analysis of the data, but also enables a better understanding of the mechanism of sparse representations.

Ph.D. student Martin Gemborn Nilsson is planned to graduate during 2025. Ph.D. student Jochen Jankowai is planned to graduate during 2024.

#### Awards and Recognitions

- Ingrid Hotz was awarded the Dr. Ram Kumar IISc Distinguished Visiting Chair Professor position at the Indian Institute of Science for two years (August 2022-2024)
- Best paper award for the paper "Multi-field Visualisation via Trait-induced Merge Trees" [Jankowai2023] at IEEE VIS workshop 2023 "Topological Methods in Visualization".
- Best poster award "Sparse representations of HARDI Data towards visual exploration" [Lei2023] at the Eurographics Workshop on Visual Computing for Biology and Medicine (EG VCBM 2023).

# **External Funding Attracted**

Project Name	Funding agency	Total Amount (kSEK)	Duration
Visual Data Analytics in e-Science Applica- tions	Swedish e-Science research center (SeRC)	3 700	2015-2024 ongoing
Topological descriptors for tracking, compari- son and visual exploration of complex scien- tific data	VR grant 2019- 05487	850	2020-2024
Indo-Swedish joint network grant: Robust topological methods for analysis of dynamic large-scale data for modern material design	VR grant 2018- 07085	Total of 700	2020-2022 Extended until 2024
A topology-based approach to patterns in dy- namic network data for decision support	wasp, academic phd	1 000	2021-2024
HUDI: Huge Complex Diagnostic Imaging Data: Towards personalized models in the clin- ical workflow	WASP-DDLS	1 000	2023-2024
In-Situ Big Data Analysis for Flow and Cli- mate Simulations	SSF BD15-0082	900	2017-2021
Realtime Individualization of Brain Computer Interfaces (WASP)	KAW	2000	2020-2022
Optimizing the Next Generation Brain Com- puter Interfaces using Cloud Computing (WASP)	KAW	4000	2020
Learning Pharmacometric Model Structures from Data (WASP-DDLS)	KAW	2000	2021-2024
Joint Communication and Radar Sensing for Autonomous Systems (WASP)*	KAW	3200	2024-2028
Visual Data Analytics in e-Science Applica- tions	Swedish e-Science research center (SeRC)	3 700	2015-2024 ongoing
Topological descriptors for tracking, compari- son and visual exploration of complex scien- tific data	VR grant 2019- 05487	850	2020-2024
Indo-Swedish joint network grant: Robust topological methods for analysis of dynamic large-scale data for modern material design	VR grant 2018- 07085	Total of 700	2020-2022 Extended until 2024
A topology-based approach to patterns in dy- namic network data for decision support	WASP, academic phd	1 000	2021-2024
HUDI: Huge Complex Diagnostic Imaging Data: Towards personalized models in the clin- ical workflow	WASP-DDLS	1 000	2023-2024
In-Situ Big Data Analysis for Flow and Cli- mate Simulations	SSF BD15-0082	900	2017-2021

# Inter-University Cooperation within ELLIIT

Within ELLIIT there is an ongoing cooperation with Michael Doggett and Bo Bernhardsson from Lund University in relation to this ELLIIT project with regular online meetings. The work focusing on the utilization of EEG data for the development of innovative hearing aids and enhanced attention decoding is a collaborative effort involving Bernhardsson and Professors Martin Skoglund and Emina Alickovic at Linköping University.

## Inter-Disciplinary Cooperation

Visualization in nature is an interdisciplinary subject and thus most of the projects of the visualization group are either directly interdisciplinary or at least motivated by needs from other disciplines. There exist multiple collaborations nationally and internationally collaborations, see 7.10. For this project especially the collaboration with the Center for Medical Image Science and Visualization (CMIV) at Linköpng University and the collaboration with the Leibniz-Institute for Polymer Research, Dresden Germany) headed by Prof. Markus Stommel is of relevance.

# International Collaboration

The visualization group at LiU group has regular interactions with researchers from other countries 7.10. The main ongoing collaborations relevant to this project are related to the general topic of multi-field and tensor visualization with Prof Gerik Scheuermann from the University in Leipzig, Germany, and the Prof Bei Wang from the University of Utah. Professor at the Scientific Computing and Imaging Institute at the University of Utah.

# Patent Applications, Open Source Software, and Contributions to Standards

Open-source software development for visual analysis plays an important role in the visualization group. Of the developed software within the group Inviwo is most relevant for this project. It is an open-source Visualization System with Usage Abstraction Levels, and a software framework for rapid prototyping. It builds the basis for the development of novel visualization research and teaching in an increasing number of research groups in the world, with a growing number of application areas. Over the last years, we have been especially focusing on the integration of the open-source Topology Toolkit TTK in inviwo. The software has been presented during diverse tutorials at major visualization conferences.

In addition, the BCI-HIL framework mentioned before is open-sourced under MIT license at bci.lu.se.

# Exploitation and Cooperation with Industry and Institutes

Since the initiation of call B, seven master's thesis projects have been conducted in collaboration with hearing aid specialists at Oticon's Eriksholm Research Center. (The innovative use of EEG signal visualization in the advancement of hearing aid technology is presented in their "Groundbreaking new EEG research method," see this link.) A comprehensive list of the M.Sc. theses is available at the BCI Research at LU website, accessible here. Notably, one of these theses, authored by Wilroth (2023, to appear), has been accepted for journal publication. It explores the use of tensor decomposition techniques to identify efficient features for classification Furthermore, Tanveer's 2023 [M.Sc. thesis] employs a conditional variational autoencoder to discover latent variables that effectively represent EEG data, demonstrating that this approach can achieve state-of-the-art performance in EEG-based Attention Decoding.

# Contributions to Undergraduate/Graduate Education

Contributions from the scientific visualization group at LiU: An ongoing contribution to undergraduate education is the annual courses giving an introduction to scientific visualization mainly targeting computer sciences and media information technology students. The visualization course for physics students in Linköping has been held for the fifth time. A Ph.D. level course on "Mathematical foundations in visualization" was offered at LiU during fall 2022. The primary purpose of this course was to strengthen the knowledge of theoretical and mathematical concepts often used in data analysis and visualization processes. Over the last 6 years, we offered three summer schools for Ph.D. students and other interested researchers with varying topics related to visualization. The summer schools have all been attended by about 20 international researchers. • Introduction to visualization to people from application areas (2018). • Visual Storytelling (2021) • Topological data analysis in visualization (2023) • During Corona, we also co-organized a spring school on biomedical visualization online with more than 150 participants (2021).

# **Outreach Activities**

Ingrid Hotz participated in the sixth episode of ELLIIT tech talks about Big data and network science. The BCI-HIL framework has been demonstrated at the ELLIIT conference in 2022 and at Ericsson Research Days 2023. and a video describing the EEG-based BCI at LU research can be found here.

# Keynotes, Plenaries and Academic Service

In 2022 Ingrid Hotz was awarded the Dr Ram Kumar IISc Distinguished Visiting Chair Professor position at the Indian Institute of Science for two years, which included a two-month visit at IISC in Bangalore, India (Dec 22/Jan 23), a second visit is planned for 2024. Ingrid Hotz gave several invited talks and keynotes in different countries in Europe and India. Most importantly she gave an invited plenary talk at the Applied Topology workshop in Bedlewo, Poland 2022, a Keynote at the IPF colloquium "Digitalization in plastics and elastomer technology" at the Leibniz-Institute for Polymer Research Dresden, Germany (2022) and several invited talks at IISC Bangalore, India (IISC faculty, Centre for Brain Research An Autonomous Centre of IISC, IIIT-b). Recently, Ingrid Hotz co-chaired the annual workshop on EG Workshop on Visual Computing for Biology and Medicine, Sept 23, Norrköping, and organized a SeRC summer school on topological data analysis, Aug 23, Norrköping. In 2020 she was a Conference Co-Chair of the Eurographics & Eurovis Conference, 2020, Norrköping. Further, she is member of the Scientific Advisory Board of the Dioscuri Centre in Topological Data Analysis, Poland, supported by the MaxPlanck Society (since 2021), member of the Eurographics Executive Committee (since 2022), and member of the steering committee of the annual EG Symposium on Visual Computing for Biology and Medicine (since 2020). Since 2015 she has been the coordinator the Visualization Community of the Swedish e-Science Research Center SeRC, and member of the SeRC Management group, since 2018. She acts as associate editor for several journals and acts as reviewer for many journals, conferences, and funding agencies.

# 4.14 B13. Scalable Optimization for Learning in Control

PI: Anders Hansson (LiU) Co-PI: Anders Rantzer (LU)

# Objectives

Large-scale engineering applications put new demands on control theory, as most existing methods for analysis, design and verification do not scale well with increasing complexity. Furthermore, new powerful algorithms for machine learning are increasingly being used for control engineering purposes, further adding to the complexity of analysis and verification. To counteract this, there is a strong demand for scalable optimization methods and corresponding information interfaces. Important applications areas are autonomous transportation, networks for manufacturing and distribution, as well as robotics. The purpose of the proposed project is to address the complexity challenges by developing and exploiting new optimization algorithms suitable for parallel and/or distributed implementation.

# Main Scientific Achievements

We have developed efficient distributed optimization algorithms with applications to control of nonlinear systems, robust control and localization, [Ahmadi, 2023], We have developed efficient convex optimization methods for time-optimal tracking for cooperative manipulators, [Hagshenas, 2023], We have investigated conservative linear unbiased estimation under partially known covariances, [Forsling, 2022]. Several approaches to scalable closed loop learning have been investigated. High gain stabilizable systems have been treated using diagonal adaptive controllers and IQC analaysis targeted to neural networks was introduced in [Grönqvist, 2022]. A more general theory and computational methods for minimax adaptive controllers introduced by Rantzer at L4DC 2021 were further developed in [Cederberg, 2022]. Finally an important breakthrough was when [Rantzer, 2022] showed that (nonscalable) Riccati equations have scalable analogs for systems with linear cost and homogeneous constraints.

# Long-Term Impact

There are several ways in which the research provides a lasting impact. Learning based control is a very active research area and we have given fundamental contributions to the theory of learning in closed loop. This work, presented in major plenary lectures and publications, is likely to have a long term impact on the research field. Gradually, education of undergraduate and graduate students will bring results and knowledge to industry and public sector, where they with their skills have further long-term impact. Students involved in the project are now working at C3 AI, Munters, Nibe, AirForestry, and Saab. One of the students, involved in the project as a Master student, is currently pursuing a Ph.D. at Stanford University. Anders Hansson has together with Martin Andersen published the book "Optimization for Learning and Control" with Wiley, 2023.

# Plans for 2024-2025

We have two Ph.D. students directly financed by the ELLIIT project. One of them, Yuwei Ying, will start in May 2024. Several Ph.D. students in Lund, Fethi Benchreki, David Ohlin and Talitha Nauta have been partially funded by the project. The plan is to continue our work on distributed optimization with different applications to control in a wide sense, and specifically to system identification and closed loop learning. On the application side, we also plan to continue working on path tracking for cooperative manipulators, where we specifically will investigate internal forces.

## Awards and Recognitions

Researchers within the projects have received the following awards and recognitions:

• Linnea Persson, involved as co-author, was awarded WASP alumni in 2023.

Project Name	Funding agency	Total Amount	Duration
		(kSEK)	
WASP (Academic Ph.D. student)	KAW	4200	2022-2026
WASP Expedition Project	KAW	5000	2019-2020
WASP (Academic Ph.D. student)	KAW	4200	2016-2020
WASP Collaboration project	KAW	5000	2019-2024
WASP NEST project	KAW	5000	2019-2024
WASP (Academic Ph.D. student)	KAW	4200	2016-2020
ERC Advanced Grant	ERC	25000	2019-2025

## **External Funding Attracted**

#### Inter-University Cooperation within ELLIIT

The collaboration between Anders Hansson and Anders Rantzer has resulted in several joint publications in high ranking journals like IEEE Transactions on Automatic Control and high quality conferences like IEEE Conference on Decision and Control.

#### Inter-Disciplinary Cooperation

N/A

# International Collaboration

Daniel Cederberg carried out his Master's thesis under the supervision of Lieven Vandenberghe, UCLA, with Anders Hansson as examiner. Olle Kjellqvist spent the academic year 2021/22 as visiting Ph.D. student with John Doyle and Richard Murray at Caltech. Johan Olsson carried out his Master's thesis under the supervision of Li Na at Harvard with Anders Rantzer as examiner.

# Patent Applications, Open Source Software, and Contributions to Standards

N/A

# Exploitation and Cooperation with Industry and Institutes

Anders Rantzer's group was invited to join an industrial consortium investigating "Artificial intelligence techniques for GNC design, implementation, and verification" for the European Space Agency.

# Contributions to Undergraduate/Graduate Education

Anders Hansson has together with Martin Andersen published the book "Optimization for Learning and Control" with Wiley, 2023. This textbook is now used for a course at master level on optimal control at Linköping University. It is also used for a Ph.D. course on optimization for learning and control. Anders Rantzer developed a new advanced course on "Learning Based Control" for the engineering programs at LTH.

# **Outreach Activities**

Anders Rantzer gave a popular science lecture organized by the Royal Physiographic Society of Lund, targeting a general academic audience.

# Keynotes, Plenaries and Academic Service

Examples include:

- Anders Hansson is the Swedish representative in the European Control Association.
- Anders Hansson co-organized the ELLIIT Focus Period Hybrid AI Where data-driven and model-based methods meet.
- Anders Hansson is member of the IEEE Control System Society Technical Committee on Robust and Complex Systems
- Anders Hansson is member of the IFAC Technical Committee on Robust Control
- Anders Rantzer gave a plenary lecture "Quadratic Inequalities in Learning for Control" at 17th IEEE International Conference on Control and Automation, Neaples June 29, 2022.
- Anders Rantzer gave a plenary lecture "Towards Robust and Adaptive Control for Large-scale Systems" at 10th IFAC Symposium on Robust Control Design ROCOND 2022, Kyoto, Japan, September 1, 2022.
- Anders Rantzer was invited to give a semi-plenary lecture "Dual Control Revisited" at the 62nd IEEE Conference on Decision and Control in Singapore, December 14, 2023.
- Anders Rantzer is member of the steering committee for the International Symposium on Mathematical Theory of Networks and Systems
- Anders Rantzer is a member of the Editorial Board for the journal Annual Reviews in Control
- In 2022 he was member of review panel for completed projects funded by the European Research Council.
- Anders Rantzer was member of the IEEE Control Systems Award Committee for three years
- Anders Rantzer was chairman of the IFAC Fellow Selection Committee, then chairman of the IFAC Fellow Search Committee
- Anders Rantzer was a member of organizing committee for IEEE CSS Workshop on Control for Societal Challenges 2021
- Anders Rantzer was a member of the IEEE Control Systems Society Fellow Evaluating Committee
- Anders Rantzer is member of the IEEE Control System Society Technical Committee on Nonlinear Systems and Control
- Anders Rantzer is member of the IFAC Technical Committee on Nonlinear Systems
- Anders Rantzer is member of the Int. Program Committee for L4DC Conference on Learning for Decision and Control
- Anders Rantzer is General Co-chair for the organization of European Control Conferenence 2024 in Stockholm

# 4.15 B14. Autonomous Force-Aware Swift Motion Control

PI: Björn Olofsson (LU) Co-PI: Lars Nielsen (LiU)

#### Objectives

The research program for this project has a number of steps for moving autonomous force-aware swift motion control forward. Our recently derived novel methods for at-the-limit maneuvering will be extended to new scenarios, where previously non-dynamic kinematic models (with non-holonomic motion constraints) have been used under, sometimes highly restrictive, assumptions on limited slip and upper-bounded velocities. For example, maneuvering in highway driving at higher speeds (typically 70 km/h and higher) implies that consideration of the forces involved is of importance. This means that the dynamic behavior is important, e.g., if heavy-duty vehicles with their inherent roll sensitivity or mobile platforms with heavy manipulators onboard are considered. The new force-aware dynamic perspective has a high potential to lead to new significant results concerning planning and control strategies for a wide range of vehicle-maneuvering and robotic manipulation scenarios, and will also treat scenarios with multiple vehicles and moving robots, in traffic or on work sites. The core of the project is scientific questions in swift motion control that is safe, resilient, and efficient.

#### Main Scientific Achievements

The main scientific achievements so far in the project are along two lines of research: 1) force-centric control principles for autonomous vehicle maneuvering in safety-critical situations and 2) complex decision-making in multi-vehicle traffic situations with multi-modal uncertainties in the motion of surrounding vehicles. Forcecentric control principles for autonomous vehicle maneuvering: A particular overall focus in this line of research is on how autonomy can be used in the best possible way for increased vehicle safety. More specifically, this means how to use optimal steering and braking patterns observed in autonomous vehicle maneuvers computed using optimization, for the purpose of feedback control design applicable for real-time execution. A central aspect of autonomous vehicle maneuvering at the limit of tire friction is how the available force potential between the tire and the road is used in the best possible way for dynamic control of the vehicle, for example, to avoid obstacles suddenly appearing on the road. Research on so-called attainable forces in the considered safety-critical maneuvers has been performed. More specifically, the concept of attainable force volumes developed as a tool for visualizing and analyzing the forces and moments on the vehicle during an autonomous optimal maneuver has been further leveraged. The results related to attainable force volumes have been published in Vehicle System Dynamics [Fors, 2019]. Research leveraging on the previous results from optimization of vehicle maneuvers in this project led to new interesting research results regarding how to actually control the vehicle online with real-time constraints and inherent uncertainty on the tire friction. Handling critical situations is an important part of the architecture of an autonomous vehicle. Based on a wary strategy to perform the maneuver that is feasible with the least tire-road friction, a controller for autonomous collision avoidance has been developed. The controller uses an acceleration reference obtained from optimal control of a friction-limited particle, whose applicability is verified by using numerical optimization on a full-vehicle model. Employing an analytical tire model of the tire-road friction limit to determine references for steering and body-slip control, results in a controller where the computation of its output is explicit and independent of the actual tire-road friction. When evaluated in real-time on a high-fidelity simulation model, the developed controller performs close to that achieved by offline numerical optimization. The results have been published in IEEE Transactions on Intelligent Vehicles [Fors, 2021a]. The wary control algorithm has been implemented by the Dynamic Design Lab at Stanford University, and it has performed well in real experiments at Thunderhill Raceway Park. Research on how to extend the force-centric control design to the cases of at-the-limit maneuvers with moving obstacles has also been performed. A solution was developed that leverages previous ELLIIT research in terms of planning based on a friction-limited particle model and a subsequent acceleration-following controller, and it employs a receding-horizon control strategy. The results have been published in ASME Journal of Dynamic Systems, Measurements and Control [Fors, 2021b].

Integrated traffic-environment prediction and model predictive control: This line of research investigates an integrated traffic environment modeling and model predictive control (MPC) system to realize interaction-aware dynamic motion planning of an autonomous vehicle with multiple surrounding vehicles. The Interaction-Aware Interacting Multiple Model Kalman Filter (IAIMM-KF) from the literature was used to hierarchically predict maneuvers and trajectories of surrounding vehicles and to compute safe targets for the ego vehicle. The targets are terminal speed and reference lane, which are updated at each time step. Then, an MPC controller was designed for the ego vehicle to generate an optimal trajectory by following the moving targets and including the prediction results to formulate collision-free constraints. The proposed interaction-aware planning method has a proactive planning ability and can avoid collisions by non-local replanning. The advantages and effectiveness of the approach have been evaluated in highway lane-change simulation scenarios. The research was presented at the European Control Conference (ECC) in London, UK [Zhou, 2022]. This line of research continued during the later part of 2022, where a particular focus was to extend the controller to explicitly address the uncertainty in the maneuvers of surrounding vehicles. The multi-modal prediction uncertainties, containing both the maneuver and trajectory uncertainties of surrounding vehicles, are considered in the method for resilient motion planning of the ego vehicle. Based on the prediction of the surrounding vehicles, an optimal reference trajectory of the ego vehicle is computed by model predictive control (MPC) to follow the time-varying reference targets and avoid collisions with obstacles. A trade-off between the performance and robustness of the method is achieved by tuning a safety-awareness parameter in the MPC. The proposed method was evaluated in simulations of challenging highway driving scenarios and a scenario from recorded real traffic data. The research was presented in an accepted article in IEEE Transactions on Intelligent Vehicles [Zhou, 2023].

#### Long-Term Impact

In addition to the major scientific contributions from the project in terms of novel approaches to autonomous vehicle maneuvering, as described in the previous section, a fundamental question is what the long-term effects of implementation of such strategies in vehicles are. This has been investigated within the project through the research question What is the Potential Benefit of Autonomy in Terms of Saved Lives?. Research on estimating the potential benefits of optimal autonomous vehicle maneuvers with respect to injury reductions in lane-departure accidents has therefore been performed. In order to effectively estimate the number of accidents that would have been possible to avoid or mitigate by autonomous handling, a framework combining available historical data, in the form of crash databases and statistical methods has been developed. It builds on our approach of using the criterion "maximize entry speed" for a maneuver instead of the more common "minimum-time criterion". Thus, our recent developments in obtaining optimal maneuvers, usually applied in autonomous vehicle handling, are now utilized to determine the limits of vehicle behavior. The result is quantitative measures based on real data for the potential of saved lives by using autonomous vehicle maneuvers, and as a specific example, the developed method was applied to lane-departure accidents. The results have been published in IEEE Transactions on Intelligent Transportation Systems [Olofsson, 2021]. The analysis in the paper shows that 197 of the 233 studied lane-departure accidents with fatal or severe outcomes could have been avoided by autonomous control. This indicates great potential in such methods and is of course very encouraging for the development and implementation of autonomous safety maneuvers as developed in this project.

#### Plans for 2024-2025

The research regarding traffic environment modeling and prediction in multi-vehicle scenarios will be further investigated. A particular aspect that will be addressed is how the uncertainty of the motion of surrounding vehicles explicitly can be quantified online using data-driven methods and subsequently incorporated into a model-predictive control design. Here, integration of research from the ELLIIT project A9 is planned, where data-driven prediction methods of traffic environments can be combined with advanced control techniques. The research on force-centric path-tracking control for mobile manipulators will continue, by extending the results obtained so far to the case where the simultaneous motion of the mobile platform and the robot arm is considered, and thus there are interaction forces also between the platform and the ground. Experimental evaluations are planned in the ELLIIT infrastructure Joint Autonomous Systems Lab at LiU and LU.

# Chapter 4. Call B

# Awards and Recognitions

The PI was Finalist for the Best Student Paper Award at the IEEE International Conference on Automation Science and Engineering, 2015.

# **External Funding Attracted**

Project Name	Funding	Total Amount	Duration
	agency	(kSEK)	
SelectiCa	Eurostars	1 000	2021-2022
Semantic Mapping and Visual Navigation for Smart Robots	SSF	6 000	2016-2022
KAW project	KAW	2 000	2018-2022
KAW project	KAW	3 000	2023-2024
WASP Ph.D. student	KAW	5 000	2023-2028
WASP Ind. Ph.D. student	KAW	3 000	2023-2028

# Inter-University Cooperation within ELLIIT

Significant joint research has been performed between Div. Vehicular Systems, LiU and Dept. Automatic Control, LU. Björn Olofsson (LU, affiliated with LiU) is sharing time between the two ELLIIT nodes in this project. The Ph.D. students Theodor Westny and Jian Zhou are active in the project (with Björn Olofsson as co-supervisor). Lars Nielsen (LiU) is a co-supervisor for Ph.D. student Zheng Jia at Lund University. This organization of staff and supervision establishes a very strong connection between the two research groups.

# Inter-Disciplinary Cooperation

N/A

# International Collaboration

LiU collaborates with Stanford University. The former ELLIIT Ph.D. student Victor Fors is now a postdoc there, and they are implementing algorithms developed in ELLIIT research projects. Lars Nielsen has taken part in their experimental evaluations at Thunderhill Raceway Park during the fall of 2022 and the spring of 2023.

# Patent Applications, Open Source Software, and Contributions to Standards

- Interaction-Aware Motion Planning for Autonomous Vehicles with Multi-Modal Obstacle Uncertainty Predictions https://github.com/JianZhou1212/interaction-safety-aware-motion-planning
- MTP-GO: Graph-Based Probabilistic Multi-Agent Trajectory Prediction with Neural ODEs (https://github.com/westny/mtp-go)

# Exploitation and Cooperation with Industry and Institutes

Supervision of Master Thesis projects in collaboration with industry:

- Toyota Material Handling (Master's thesis project)
- OMotion AB (Master's thesis projects)
- Aimpoint AB (Master's thesis projects)
- BorgWarner AB (Master's thesis projects)
- Saab Kockums AB (Master's thesis projects)
- Axis AB (Master's thesis projects)
- Cognibotics AB (Master's thesis projects)
- FOI (Master's thesis project)
- MAX IV Laboratory (Master's thesis project)

# Contributions to Undergraduate/Graduate Education

The 2nd cycle course "Autonomous vehicles — planning, control, and learning systems" at LiU was developed by Erik Frisk, Björn Olofsson, and Jan Åslund at Div. Vehicular Systems, LiU. It has been given since 2019. Results from this ELLIIT project are used in the course and this new course is thus an excellent dissemination platform for making the research in ELLIIT accessible to Master's students in the engineering educational programs. The elective course attracted more than 100 students and received excellent grades in course evaluations. Björn Olofsson was responsible for the 2nd cycle course "Applied Robotics" during the fall semesters 2022 & 2023, given within the undergraduate education at LU. The content of this course also has strong connections with the research in this ELLIIT project.

Building on the Ph.D. courses on Motion Planning and Control, given at LiU in 2016 and LU in 2017, a further developed edition of the course named "*ELLIIT Ph.D. Course on Motion Planning and Control*", 6+3 hp was given during the spring semester of 2021. The course had participants within ELLIIT both from Linköping University and Lund University. The course stimulated interesting discussions among the course participants, and the course was concluded with impressive projects performed by the participants on different topics related to the subject matter of the course.

A new graduate course "*Optimal Vehicle Maneuvers*" on 6 hp was developed and given for the first time in the spring of 2023. The teachers were Lars Nielsen and Björn Olofsson. The examination included hand-in exercises and mini-projects, which in some cases now are seeds for research.

# **Outreach Activities**

RobotLab LTH at LU is a research platform for industrial, mobile, and aerial robotics, which also is used extensively in education at both undergraduate and graduate levels. It has become a good forum to expose ongoing research and the lab regularly receives visiting groups, with an interest in robotics as well as in more general engineering and technology. Since 2011, RobotLab LTH has annually arranged scheduled one-hour-long visits for school classes (from elementary grade 4 to high school and college students) in conjunction with the EU Robotics Week. During the EU Robotics Weeks, several school classes and company representatives will visit the lab and experience demos of ongoing research. In these presentations, parts of the research results demonstrated were obtained within this ELLIIT project. There were also additional activities co-organized by DIGIT@LTH & AI Lund aimed at industry, the public sector, and colleagues at Lund University.

# Keynotes, Plenaries and Academic Service

Based on the results achieved in this ELLIIT project, Lars Nielsen was invited to give a plenary lecture at the 3rd IAVSD Workshop on Dynamics of Road Vehicles — Connected and Automated Vehicles in Ann Arbor, Michigan, USA, in April 2019, where the University of Michigan is the leading automotive university in the area around Detroit which is the center of the automotive industry in the USA. The title of the talk was "Using optimization for obtaining and analyzing at-the-limit maneuvers". It presented research from this project in ELLIIT and the lecture gained significant attention among the audience consisting of world-leading researchers on vehicle autonomy from academia, representatives from major automotive companies, and important policymakers. Lars Nielsen was a plenary speaker at IFAC AAC 2022 (IFAC Conference on Advances in Automotive Control), Columbus Ohio in August 2022, giving a talk on the subject "Force-centric perspectives on autonomous safety maneuvers". Lars Nielsen was the first speaker of the IAVSD conference (International Association for Vehicle Systems Dynamics) in Ottawa, August, 2023, giving a presentation titled "Architectures for Emergency Actions in Autonomous Driving not using Friction Knowledge". These occasions provided excellent opportunities for disseminating the research performed within this project.

#### 4.16 B15. Information Handling in Industrial IoT

PI: Nikolaos Pappas (LiU) Co-PI: Emma Fitzgerald (LU)

#### Objectives

This project aims to jointly consider information generation, processing, transmission, and reconstruction in beyond 5G (B5G) massive and mission-critical IoT networks by considering the semantics of information. The importance and usefulness of the generated and transmitted information is ignored in the current systems. This project develops theoretical and algorithmic foundations of goal-oriented, data-importance-aware communication to depart from the separated and conventional content-agnostic paradigm. The solutions we design will be further transformed into functioning protocols and implemented in real-world testbeds.

#### Main Scientific Achievements

In [Nikkhah, 2023] we proposed a new metric to capture the actuation of information in addition to its timeliness, called the Age of Actuation, this is important since it extends Age of Information towards goal-oriented communications. In [Kutsevol, 2023], we propose a novel relevance- and network-aware transport layer (TL) scheme for WNCSs. The proposed scheme admits the most important measurements for the control process into the network while considering current network conditions. Moreover, we propose a mechanism for the scheme parameters adaptation in dynamic scenarios with unknown network statistics. Unlike the conventional TL mechanisms failing to provide adequate control performance due to either congestion in the network or inefficient utilization of available resources, our method prevents network congestion while keeping the control performance high. We argue that relevance- and network-awareness are critical components of network protocol design to avoid control performance degradation in practice. From this paper we submitted also a demo which won the best demo award at the IEEE SECON 2023. Furthermore, in another set of works [Salimnejad, 2023] we have proposed a set of semantics-aware metrics for goal-oriented communications regarding real-time tracking of Markov Chains for the purpose of actuation and we have proposed open-loop and closed-loop optimization problems to solve them.

In Lund we have developed a testbed for measuring one-way delay in networks. The testbed has endpoints synchronised to a high degree of precision using the PTP protocol. Between the endpoints can be placed different network setups that implement different types of industrial control scenarios, including both wired and wireless (via our 5G base station in our lab) links and one or more network emulators to add delays, packet losses, or other disturbances that can affect the Age of Information and related metrics. Using the testbed, we have obtained measurement sets for the Age of Information (AoI) between a controlled process and a cloud-based controller, and the Age of Actuation (AoA) at the plant. Initial measurements with a comparison of transport protocols are published in [Peng, 2023], and we are currently preparing a paper together with the team at LiU with the AoI and AoA analysis of our measurement data. We have also implemented and tested, in both simulations and our testbed, different mechanisms for mitigating the effects of network disturbances from the perspective of the value and age of the information transmitted for industrial control. For example, we have developed a method for compensating for different types of delays in cloud-based control, which has been published in [Peng, 2021].

#### Long-Term Impact

Much of the work thus far on AoI and semantics of information has been theoretical. In this project, we are demonstrating the relevance of these metrics and the feasibility of mechanisms based on them in real network scenarios. It is not enough for future networks to be simply a "data pipe" blindly transporting bits, but rather we aim to show that semantics-aware networking concepts must be included in the design of future network protocols in order to handle the enormous volume of data produced by the IoT, as well as stringent requirements on energy usage, latency, scalability, and reliability of future devices and applications. Below we include a set of high impact publications on topics relevant to this project. More specifically, two books published on AoI [Pappas, 2023] and [Kosta, 2017]. In addition, there are three vision and overview articles [Popovski, 2022],

[Kountouris, 2021], [Abd-Elmagid, 2019].

## Plans for 2024-2025

Much of the time in the project thus far for the Lund team has been spent on the development and implementation of our testbed. Now that we have it in place, we will move to focus more on collecting data and testing different mechanisms related to AoI and other metrics for semantic-aware networking. We will compare our measurements to the analysis done in Linköping, and implement the algorithms developed there to test their performance under realistic network conditions. The co-PI, E. Fitzgerald, will leave Lund University in early 2024 and the project will be handed over to a new co-PI. A decision has not been made yet but it is likely it will be William Tärneberg, who is the co-supervisor for S. Sadikhov and thus already involved in the research work in the project. This will allow for a smooth continuity in the project.

# Awards and Recognitions

- 2021-2023 N. Pappas listed in the Top 2% scientists list, single year impact, in the area of Networking and Telecommunications
- 2023 Göran Lind prize in electrical engineering, Royal Physiographical Society in Lund (E. Fitzgerald)
- 2023 Best Demo Award IEEE SECON 2023 (N. Pappas in collaboration with TUM, Germany)
- 2022 Best Student Conference Paper Award in Swedish Communication Technologies Workshop (Swe-CTW 2022) (N. Pappas with his previous student E. Fountoulakis)
- 2022 IEEE/KICS Journal of Communications and Networks (JCN) Best Paper Award (N. Pappas with his previous student A. Kosta)
- 2021 Best Student Journal Paper Award in Swedish Communication Technologies Workshop (Swe-CTW 2021) (N. Pappas with his previous student A. Kosta)

Project Name	Funding agency	Total Amount	Duration
		(kSEK)	
Next Generation Communication and Computational	Vinnova	36 000 (in total)	2024–2028
Infrastructures and Technologies (NEXTG2COM)			
Quality of Service for IoT Applications Using Large	National Science	1170	2020-2023
Scale Antenna Arrays	Centre, Poland		
ROBUST-6G - SmaRt, AutOmated, and ReliaBle	Horizon Europe 6G-	2700	2024-2026
SecUrity Service PlaTform for 6G (N. Pappas)	SNS 2023		
SOVEREIGN - distributed ledger technologies and	Horizon Europe	2400	2024-2027
user-driven automation towards self-sovereign mo-	MSCA		
bile data access in beyond 5G networks (N. Pappas)			
ELIXIRION - rEaLIzing healthcare 4.0 eXploIting	Horizon Europe	3400	2023-2027
the 6G netwoRk evolutION (N. Pappas)	MSCA-DN		
ETHER - sElf-evolving terrestrial/non-Terrestrial Hy-	Horizon Europe 6G-	3000	2023-2025
brid nEtwoRks (N. Pappas)	SNS 2022		
Semantics-Empowered Communication for Net-	Swedish Research	3800	2022-2025
worked Intelligent Systems (N. Pappas)	Council (VR)		
Low Latency Communications for Wireless Net-	Zenith previous	2700	2018-2024
works: Exploiting Traffic Characteristics (N. Pappas)	CENIIT		
Physical Layer Secrecy for IoT Networks with Het-	Swedish Research	700	2020-2022
erogeneous Traffic (N. Pappas)	Council (VR)		

# **External Funding Attracted**

# Inter-University Cooperation within ELLIIT

During the course of the project we have had both regular online meetings and on-site visits between the teams in Lund and Linköping. The on-site visits include:

- November 2023: Visit by Lund team to Linköping
- November 2023: Visit by M. Salimnejad to Lund
- September 2022: Participation by S. Sadikhov in 6G Summer School in Linköping
- October 2021: Visit by N. Pappas to Lund

We have also planned some visits during spring and summer of 2024 to both sites.

We have the following ongoing collaborations between Lund University and Linköping University:

- AoI and AoA analysis of measurement data collected in the testbed in Lund (E. Fitzgerald, S. Sadikhov, N. Pappas, W. Tärnerberg). Conference manuscript in preparation, to be submitted December 2023/January 2024.
- Theoretical analysis of AoI and AoA for the scenario used for collecting the measurement data (N. Pappas, M. Salimnejad, E. Fitzgerald). Conference manuscript in preparation, to be submitted January 2024.
- Stochastic geometry-based analysis of full-duplex cellular IoT setup (M. Salimnejad, N. Pappas, E. Fitzgerald). Journal paper manuscript in preparation, to be submitted end of December 2023/January 2024. A shorter version is expected to be submitted for a conference publication.

Furthermore, we have identified other directions that we plan to investigate the next two years.

# Inter-Disciplinary Cooperation

Through the EU project ELIXIRION, N. Pappas collaborates with healthcare researchers to investigate the impact of the age of information and semantics on the decision-making process and early detection from medical data. In addition, through the same project, collaboration with a company that manufactures wearable devices will implement the ideas from semantics and goal-oriented communications to increase energy efficiency in their devices. E. Fitzgerald, through her other projects, has collaborations with researchers studying energy-neutral and low-energy devices, positioning, and control theory, among others. These aspects are highly relevant for IoT and the use cases and scenarios we are working on in this project.

# International Collaboration

E. Fitzgerald has collaborations with researchers at KU Leuven, Belgium, Warsaw University of Technology, Poland, and TU Graz, Austria, among others. Between 2018 and 2021 she was employed as an adjunct researcher at Warsaw University of Technology.

N. Pappas has established collaborations with Aalto - Finland, Aalborg University - Denmark, TUM - Germany, Virginia Tech. - USA, King's College London - UK, CUHK - Hong Kong, University of Maryland - USA, EURECOM - France, ENSEA - France, Zhejiang University - China, SUTD - Singapore, several IITs in India, to name a few. The collaborations have produced a good number of papers and also joint projects. Several students and faculty have visited the group of N. Pappas for periods spanning from a few weeks to a year.

# Patent Applications, Open Source Software, and Contributions to Standards

E. Fitzgerald is a main contributor to LISsim, a simulator for large intelligent surfaces. Parts of this project are already available as open-source software, and a full open-source release will occur once all parts of the simulator have reached a complete and stable first version. She is also a contributor to the open source project DFSS, which provides a format and tools for experimental data sets.

N. Pappas is actively involved in the standardization of the Tactile Internet, more specifically he is a voting member at the at the IEEE Working Group P1918.1 - Tactile Internet: Application Scenarios, Definitions and Terminology, Architecture, Functions, and Technical Assumptions and among the leading members regarding the network architecture. In addition, he is serving as vice-chair for the IEEE Tactile Internet Technical Committee.

# Exploitation and Cooperation with Industry and Institutes

E. Fitzgerald has contacts and collaborations with, among others, Tetra Pak, Volvo Cars, Volvo Construction Equipment, and Sensative, giving her good insight into how IoT, and specifically IIoT, are used in industry. Since the start of the project she has supervised a Masters thesis project at Axis Communications.

N. Pappas actively collaborates with Ericsson, Qualcomm, and Combitech, including several master theses jointly supervised. Since September 2023, N. Pappas has been collaborating with Ericsson Kista, co-supervising an industrial WASP Ph.D. student. In addition, through his Horizon Europe ongoing projects, he is collaborating with ORANGE, Sateliot, Collins Aerospace, and MCS-Datalabs.

# Contributions to Undergraduate/Graduate Education

E. Fitzgerald was a lecturer at the Erasmus Blended Intensive Program "Sustainable Energy in an IoT world" for Masters and Ph.D. students at KU Leuven in Ghent, March 2023, on the topic of Mission Critical IoT. She has also incorporated results from this project and other research activities into her undergraduate course Computer Communications. She is also the deputy program manager for the computer science program at Lund University, and is currently conducting a review of networking specialisations for this program, based in part on her research and collaborations with industry.

N. Pappas has developed two Ph.D. courses that were given during 2023. The courses are i) Analysis of Communication Networks and ii) Age of Information: Foundations and Applications. Furthermore, he has presented several tutorials at major IEEE conferences, as listed in the service section. Several research results were presented in the Ph.D. courses and the tutorials.

# **Outreach Activities**

E. Fitzgerald was a participating expert on the BBC World Service program The Inquiry in April 2023.

# Keynotes, Plenaries and Academic Service

N. Pappas has the following editorial duties

- Area Editor, IEEE Open Journal of Communications Society (2022 )
- Editor, IEEE Transactions on Machine Learning in Communications and Networking (2022 )
- Expert Editor for Invited Papers, IEEE Communications Letters (2021 )
- Editor, IEEE/KICS Journal of Communications and Networks (2018 )
- Editor, IEEE Transactions on Communications (2018 2023)
- Editor, IEEE Open Journal of Communications Society (2019 2022)

N. Pappas has involvement as a guest editor or leading guest editor in several journals including the IEEE Internet of Things Journal, IEEE Network, IEEE IoT Magazine on topics related to this project. In addition, he has be serving as chair/co-chair of workshops related to AoI and semantics of information in the IEEE ICC, IEEE GLOBECOM, IEEE ICASSP, IEEE SPAWC, IEEE INFOCOM to name a few. During 2022, he served as a symposium co-chair for the IEEE ICC and IEEE WCNC.

Selected invited talks

- N.Pappas gave an invited talk on Semantics of Information beyond AoI in a special session of the ACM Mobihoc 2023.
- N. Pappas gave a talk on "From Information Freshness to Semantics of Information and Goal-oriented Communications" in the Distinguished Speaker Series organized by Apple, USA on November 2023.

# N. Pappas presented the following tutorials:

• IEEE GLOBECOM 2023: Task-oriented and Semantics-aware Communications and Networking for 6G.

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- NetSys 2023: Age of information (AoI) A new performance metric for measuring freshness of information.
- IEEE ICC 2023: Task-oriented and Semantic-aware Communications and Networking for 6G.
- IEEE WCNC 2023: Task-oriented communications and networks.
- IEEE SPS EURASIP summer school on "Defining 6G: Theory, Applications, and Enabling Technologies", Goal-oriented and semantic communications.
- IEEE/CIC ICCC 2022: Age of Information Optimizations in Wireless Networks: Theories, Applications, and Beyond.
- IEEE ICC 2022: Age of Information in Wireless Networks: Fundamentals and Applications.
- Digicosme Spring School 2022: Emerging and future communication networks: technologies, architectures, and tools: Semantics Communications for Future Wireless Communications.
- IEEE SPAWC 2021: Goal-Oriented Communication for Networked Intelligent Systems.
- IEEE GLOBECOM 2020: Age of Information: Theory, Applications, and Testbed Implementation.
- IEEE/CIC ICCC 2020: Age of Information as a New Data Freshness Metric in the IoT Era: From Theory to Implementation.

N. Pappas gave the following keynotes

- Goal Oriented and Semantic Communications Event at INRIA GdR ISIS Nov. 2023
- International Workshop on Learning and Information Theory (WOLIT'23) July 2023
- IEEE ICASSP 2023 workshop on "6G Ubiquitous Space Ground Integrated Communications" June 2023

E. Fitzgerald is a member of the board for the Department of Electrical and Information Technology, Lund University, and between 2018 and 2021 was also the department's Equal Opportunity Representative.



# 5.1 Overview

The ELLIIT SG decided in September 2020 to allocate up to 20 MSEK per year during five years for new Ph.D. student projects to commence in the spring of 2021. An open call ("Call C") was issued and in total, 44 applications were submitted. 9 Ph.D. projects were funded. These projects will run from 2021 to 2025.

# 5.2 C1. Dynamics of Complex Socio-Technological Network Systems

PI: Claudio Altafini (LiU) Co-PI: Emma Tegling (LU)

# Objectives

This project investigates how opinions and beliefs propagate on "social networks", i.e., on networks of individuals interacting over socio-technological media and influencing each other through social ties. The main scientific goal is to use data and dynamical models in order to understand the mechanisms by which sociologically relevant macroscopic collective behaviors can emerge from microscopic (i.e., individual-level) interactions.

# Main Scientific Achievements

**Multiagent dynamics on signed graphs.** We have studied several possible types of dynamics on signed graphs, i.e., networks in which the agents collaborate but also compete with each other. In particular, we have investigated how for commonly used multiagent models with sigmoidal nonlinearities the notion of frustration (from Statistical Physics) can influence the collective decision process: a network with higher frustration might take a longer time to reach a decision. The idea was also applied to a concrete dataset we compiled, dealing with a question from Political Sciences, namely the process of forming a government in parliamentary democracies, where the decision is voting for or against a candidate government cabinet. We showed that there is a rather strong correlation between the frustration of the "parliamentary networks" (in which political parties are considered as rivals of each other) and the duration of the negotiation phase necessary to form a government (data from 29 European Countries).

Considering emerging global dynamical properties, the project has developed a complete classification of Laplacians on signed graphs, investigating their convergence to consensus, in both time-invariant and time varying case. The main properties that allow this classification have to do with a particular extension of Perron-Frobenius theory to signed matrices, the so-called eventual positivity property and its variants, see [Fontan, 2023]. Discrete-time versions of the results have also been obtained, extending results valid for stochastic matrices (and inhomogeneous Markov chains).



A signed network perspective on the government formation process in parliamentary democracies, see [Fontan, 2021].

#### Plans for 2024-2025

For what concerns opinion dynamics, we are currently investigating extensions of the signed graph approach to other opinion dynamics models such as the so-called Friedkin-Johnsen model. The peculiarity (and originality) of this model is that even though it obeys an averaging rule, it may not behave as an averaging model, in the sense that the end-point opinion need not belong to the convex hull of the initial conditions. This feature makes it interesting for describing phenomena like cleavage and polarization on social networks.

We are also investigating a novel opinion dynamical model aimed at capturing the interaction between exposure to news or opinions through social networks and the perceived accuracy. The uniqueness of this model is that individuals' attention span is limited. It is our belief that this model may capture, for example, the increased distrust in mainstream media in favor of niche sources. We will strive to validate models with empirical data.

On another research direction, we plan to develop mathematical methods for investigating the controllability properties of temporal networks, i.e., networks represented as time-varying linear systems. Empirical evidence has shown that, with respect to their static counterparts, temporal networks (i) are often endowed with larger controllable subspaces and (ii) require less control energy when steered towards an arbitrary target state. However, to date, theoretical conditions guaranteeing that these properties are fulfilled are missing, and only numerical analysis has been carried out.

#### Awards and Recognitions

N/A

# **External Funding Attracted**

Project Name	Funding agency	Total Amount (kSEK)	Duration
Multiagent dynamics and collective decisions on signed graphs	Vetenskapsrådet	4.300	2021-25
Multi-resolution dynamical modeling of mul- tiple sclerosis	SSF	28.000	2017-22
Learning in Networks: Structure, Dynamics and Control	WASP (KAW)	25.000	2022-26

# Inter-University Cooperation within ELLIIT

The two PIs of this project have co-organized an ELLIIT Focus period in the Fall of 2023 in Linköping, see this web page. The Focus period was entitled "Network Dynamics and Control" and its main goal was to stimulate the interaction between scientists working on network dynamics and control from different perspectives, representing the various fields in which networks and "network thinking" is of relevance, such as social sciences, economical sciences, biology, ecology, and engineering. The focus period was extremely well received and planted seeds for many new collaborations.

# Inter-Disciplinary Cooperation

The PI collaborated with various groups at Physics and Medical Faculty at LiU, in the framework of a joint SSF sponsored project called "Multi-resolution dynamical modeling of multiple sclerosis". Data-driven models that are somewhat related to the topics we are developing in this project were published in a few journal papers.

Our work on climate negotiation was done in collaboration with climate change scientists at LiU's Department of Thematic Studies (Tema).

The Co-PI participates in the Lund University Focus Area on Natural and Artificial Cognition, which includes researchers from humanities and social sciences as well as math and engineering. There, research related to this project will be presented at an interdisciplinary workshop in the Spring of 2024 titled "*N*-body society: Power and Democracy in the Modern World."

# International Collaboration

We have collaborated with the University of Sydney, Chinese Academy of Science, Tongji University in Shanghai, and the University of Sannio, Benevento, Italy. There are also an ongoing collaboration with the Institute of Data, Systems, and Society at the Massachussetts Institute of Technology (MIT).

# Contributions to Undergraduate/Graduate Education

The PI of the project has developed a new Ph.D. course entitled "Opinion Dynamics on Social Networks" which was delivered at LiU in the Fall of 2022. In the Fall of 2023, the PI also hosted another Ph.D. course, within the framework of the ELLIIT Focus period "Network Dynamics and Control". The Ph.D. course was entitled "Theory and Applications of Contracting Dynamical Systems" and the lecturer was Francesco Bullo from University of California, Santa Barbara. The course was attended by around 20 Ph.D. students from all Swedish Universities.

# **Outreach Activities**

Or research on political networks was the subject of the LiU news article, see "Forming a government – how long will it take?".

Also our research on climate negotiations was highlighted in a LiU news article entitled "A mathematical model may give more efficient climate talks", which was picked up by various international news outlets.

# Keynotes, Plenaries and Academic Service

The PI served as Associate Editor for Automatica and for IEEE Transactions on Control of Network Systems. He was also Guest Editor for a special Issue on on "Dynamics and Behavior in Social Networks" also for the IEEE Transactions on Control of Network Systems, published in 2022 (see [Altafini 2022]). He was on the program committee of the 11th and 12th Int. Conference on Complex Networks and Their Applications, of the 9th IFAC Workshop on Distributed Estimation and Control of Networked Systems (NecSys'22) and of the 21st International Conference on Computational Methods in Systems Biology (CMSB 2023).

The Co-PI is active in the academic community by serving on the program committee for IFAC Workshop on Distributed Estimation and Control in Networked Systems (Necsys), International Symposium on Mathematical Theory of Networks and Systems (MTNS) 2022, IEEE International Conf. on Communications, Control, and Computing Technologies for Smart Grids (SmartGridComm) 2022, IFAC Symposium on Nonlinear Control Systems (Nolcos) 2022. She is also the Secretary of the European Control Association, Chair of Chapter Activities at the IEEE Control Systems Society. She serves as Social Media Chair for the IEEE Conference on Decision and Control (CDC) 2023 and Publicity Chair for European Control Conference 2024. She is the incoming (as of 2024) Deputy Head of Department at the Department of Automatic Control in Lund. Since the start of the Call C project, she has given three invited conference talks and research seminars.

We wish to remark that the Co-PI was on parental leave for most of 2021.

# 5.3 C2. Developing Core–Technologies for Tree-Based Models

PI: Krzysztof Bartoszek (LiU) Co-PI: Niklas Wahlberg (LU)

# Objectives

We aim to develop new learning algorithms for tree-structured graphs, motivated by phylogenetics but with potential use in other network-based applications, e.g., discovery and analysis of gene–regulatory networks and epidemiology. We hope for improving network discovery algorithms from a collection of trees. In the longer run we would like to contribute to the development of probabilistic programming languages (PPLs) and associated inference algorithms. Our project seeks to resolve computational problems in the area of Big data and network science, and in probabilistic modelling in general. We aim to take advantage of the massive increase in whole genome data for large numbers of non-model species to test the methods that are developed during this project.

# Main Scientific Achievements

We have developed a fast Bayesian approach to estimate parameters of branching Gaussian processes. The R code for this is on GitHub. We are at the moment beginning a manuscript on this. We have also compiled a large empirical dataset based on genomes of butterflies and moths (more than 400 species), with which we aim to test the new methods. We have been working with both developing statistical understanding of the models behind multivariate branching Gaussian processes ([Bartoszek 2023a], [Bartoszek 2023b]), and studying properties of random trees ([Bartoszek 2021]). We also connected our work to the problem of the spread of SARS–CoV–2 (Kiang 2022). Our empirical work on butterflies and moths has shown that there are limitations of modern methods when dealing with large datasets of unclear ancestry ([Rota 2022]).

# Plans for 2024-2025

We plan to develop methods for missing data imputation for tree-structured data, with the aim of network inference. We plan to write up a manuscript concerning Bayesian estimation methods for branching Gaussian processes. We also plan to combine our work with that concerning random fields, not necessarily Gaussian ones, and how that theory can be used to make inferences for branching stochastic processes. We will use our empirical dataset, comprising thousands of gene sequences from hundreds of species, to test the methods.

# Awards and Recognitions

Best poster award at 29<sup>th</sup> Nordic Conference in Mathematical Statistics, NORDSTAT 2023 (Göteborg) for Hao Chi Kiang (PI's Ph.D. student). Best poster award at BLAM, Lund University, spring 2022, for Etka Yapar (the Co-PI's Ph.D. student).

# **External Funding Attracted**

N/A

# Inter-University Cooperation within ELLIIT

We are starting a collaboration with Doc. Jonas Walin (Dept. Stat., Lund Univ.) on using the theory of random fields for inference of branching stochastic (non necessarily Gaussian) processes. The PI's Ph.D. student, Bayu Beta Brahmantio, is also establishing scientific contacts with other members of the Co-PI's department, e.g., Dr. Masahito Tsuboi.

# Inter-Disciplinary Cooperation

N/A

# International Collaboration

We are working with Prof. Paweł Dłotko's group (Dioscuri Centre in Topological Data Analysis, Institute of Mathematics, Polish Academy of Sciences) on missing data imputation for tree-structured data with the aim of network structure inference. We are working with Dr. Jason Pienaar's group (Florida International University) on applying branching Gaussian models to biological data. We have also initiated collaboration with the Darwin Tree of Life project in the UK (Wellcome Sanger Institute), that is sequencing reference quality genomes for all species occurring on the British Isles. This collaboration will provide us with high quality butterfly and moth genomes as they are produced, placing us at the cutting edge of phylogenomics. The data will be an integral part of the thesis work of the co-PI's Ph.D. student, Etka Yapar.

# Patent Applications, Open Source Software, and Contributions to Standards

During the past years the PI has been developing (with collaborators) the **mvSLOUCH** (inference for multivariate branching Ornstein–Uhlenbeck processes) and **RMaCzek** (software for creating Czekanowski's diagram) R packages (on CRAN). With his Ph.D. students they are currently developing R packages for calculating confidence intervals for branching Gaussian processes (**glinvci** on CRAN), and for Bayesian inference for branching Gaussian processes (on GitHub).

# Exploitation and Cooperation with Industry and Institutes

The PI is the examiner and supervisor for a number of master theses that are done in collaboration with industry.

# Contributions to Undergraduate/Graduate Education

- 1. At the Division of Statistics, Linköping University, in March 2023 we hosted the YUIMA stochastic differential equations with R school and conference. It attracted about 25 Ph.D. students and other researchers. The classes were held by lecturers from the Universities of Tokyo, Kyoto and Neuchatel.
- 2. For spring 2024 the PI has prepared a Ph.D. level course in Stochastic processes to be run at IDA, LiU.
- 3. The Co-PI has included lectures on phylogenomics in the Master's level program Evolutionary Biology at Lund University.

# **Outreach Activities**

# Keynotes, Plenaries and Academic Service

- 1. Since fall 2023 the PI is a member of the Scientific Committee of the National Conference on Applications of Mathematics to Biology and Medicine.
- 2. 1 September 2023 the PI was a reserve on the Ph.D. committee for Gustav Lindwall's defence at the Division of Mathematical Statistics, Department of Mathematical Sciences, Chalmers University of Technology and University of Gothenburg. The title of the Ph.D. thesis: Statistical inference on interacting particle systems with applications to cancer biology; supervisor Prof. Philipe Gerlee.
- The PI: 29<sup>th</sup> Nordic Conference in Mathematical Statistics, Session Chair: Special topics in Statistics 2. Göteborg (Sweden), June 2023.
- 4. 1 June 2023 the PI was a reserve on the Ph.D. committee for Denise Uwamariya's defence at the Department of Mathematics, Linköping University. The title of the Ph.D. thesis is Large deviations of condition numbers and extremal eigenvalues of random matrices, thesis supervisor Doc. Xiangfeng Yang.
- 5. 31 May 2023 the PI was a member on the Ph.D. committee for Harald Hannerz's defence at the Dept. of Statistics, School of Economics and Management, Lund University. The title of the thesis: A new family of survival functions and a method for measuring risk inequalities; supervisor Prof. Krzysztof Podgórski.
- 6. CIBB 2023, 18<sup>th</sup> International Meeting on Computational Intelligence Methods for Bioinformatics and Biostatistics. Padova (Italy), Sept. 2023. The PI was on the programme committee, reviewed one article for the conference.
- 7. The PI: The National and International Network Retreat in AI and Medicine. Presentation of STIMA: Coordinate teaching in AI/ML courses and program. Umeå (Sweden), May 2023.
- 8. The PI: NordicMathCovid Research Conference. Participation by invitation, talk: Investigating Czechia, Poland and Sweden: developing visualization methods. Oslo (Norway), Feb. 2023.
- 9. 2022/23 The PI was an external reviewer of the Ph.D. thesis of Łukasz Tomasz Bielak (Department of Applied Mathematics, Faculty of Pure and Applied Mathematics, Wrocław University of Science and Technology). The thesis title is Application of stochastic processes for modelling market risk factors in a mining company, thesis supervisors Dr. Agnieszka Wyłomańska and Dr. Joanna Janczura. The defence took place in Wrocław on 11 May 2023 (I participated virtually).
- 10. The PI: ELLIIT Annual Workshop 2022. Talk (by invitation): RMaCzek: An Old Technique for New Data. Linköping (Sweden), Oct. 2022.
- 11. 4 October 2022 the PI was the chairman of Caroline Svahn's Ph.D. defence at the Department of Computer and Information Science, Linköping University. The thesis title is Prediction Methods for High Dimensional Data with Censored Covariates, thesis supervisor Doc. Oleg Sysoev, Ph.D..
- 12. The PI: NordicMathCovid Research Conference. Participation by invitation, talk: Some comparative thoughts around COVID19. Sigtuna (Sweden), Sept. 2021.
- 13. 18 August 2022 The PI was the opponent at Caroline Svahn's full time seminar at the Department of Computer and Information Science, Linköping University. Her thesis supervisor is Doc. Oleg Sysoev.
- 14. CIBB 2021, 17<sup>th</sup> International Meeting on Computational Intelligence Methods for Bioinformatics and Biostatistics. Online (due to COVID–19 restrictions), Nov. 2021. The PI was on the programme committee, reviewed one article for the conference and co–authored one contribution.
- 15. 22 March 2021 The PI was a "vocal" at the Ph.D. defence of Tomás Martìnez Coronado at the University of the Balearic Islands (Doctoral Programme of Information and Communication Technology). The thesis title is New results on old and new balance indices, thesis supervisor Dr. Francesc Andreu Rosselló Llompart. Participation in the defence was virtual.
- 16. The Co-PI was an opponent and reviewer for the licenciate thesis of Meri Lähteenaro, the Swedish Museum of Natural History, Stockholm in May 2023
- 17. The Co-PI was an external reviewer for the Ph.D. thesis of Athulya Girish K, National Centre for Biological Sciences, Tata Institute of Fundamental Research, Bangalore, India in August 2023
- 18. The Co-PI was an external reviewer and rapporteur for the Ph.D. thesis of Eliette Reboud, University of Montpellier, France in December 2023.
- 19. The Co-PI is a member of the review panel for the Olof Berggren Fund of the Royal Physiographic Society, Lund (2021, 2022 and 2023).

# 5.4 C3. Real-Time Realistic Pixel Synthesis using Deep Learning for Augmented and Virtual Reality

PI: Michael Doggett (LU) Co-PI: Karl Johan Lundin Palmerius (LiU)

# Objectives

This project aims to solve the challenges of generating the realistic images necessary to ensure the level of immersion to make XR platforms essential. By using high quality physical accurate resources, combined with the latest techniques in Deep Learning combined with Real-Time Rendering, we will address the challenges of immersive realistic imagery for Augmented and Virtual Reality.

# Main Scientific Achievements

We have created a novel system to capture the lighting in a scene using a separate camera and raspberry Pi, that communicates data to the a Microsoft HoloLens 2 head set. The camera and raspberry Pi are mounted on the HoloLens allowing accurate direction capture. The lighting is processed using white balancing and stored in an adaptive two dimensional quad tree that is progressively updated as new data is captured. Once an object is placed in the scene this data is accessed and interpolated to light objects in the scene making them blend more naturally into their surroundings, particularly when complex lighting situations are encountered. This paper has recently been submitted for GRAPP 2024.

Other research results have improved the ability to reconstruct scenes, which is an essential component of any Augmented Reality system that requires an understanding of the objects in the physical world that are being interacted with. This research has advanced differentiable rendering, which aims to use highly realistic path tracing to estimate the objects in a scene. If the scene contains highly glossy surfaces, it can be difficult to reconstruct the underlying geometry of the surface. By using a technique called antithetic sampling, we are able to reduce the variance when reconstructing glossy surfaces. This research was presented at the highly prestigious SIGGRAPH conference.

During 2021 research continued on using Real-Time Ray Tracing hardware in modern GPUs to produce advanced lighting effects, in particular caustics [Moreau22]. Caustics occur when light is concentrated via transparent objects. Our approach combines bi-directional tracing of light and view paths with the BVH hardware acceleration to store and access the light as it travels through the scene. By using hardware acceleration we are able to achieve real-time frame rates for complex reflections and refractions. Michael Doggett's Ph.D. student Pierre Moreau, successfully defended his thesis, Towards Fully Dynamic Surface Illumination in Real-Time Rendering using Acceleration Data Structures in 2022.

We have also created a new method for modelling plasma in order to use plasma as a light source in 3D rendering. This new method is based on traditional Computational Fluid Dynamics techniques, but instead of working with fluid, considers the movement of charged particles inside the forces of a magnetic field.

In collaboration with an ARM we have created new techniques for the use of Opactiy Micromaps. These are a new feature of Real Time Ray Tracing hardware. We have focused on the construction and compression of Mircomaps. We are working towards two publications from this research.

We have also combined Neural Radiance Fields (NeRF) with Real-Time Raytracing Hardware to improve performance of NeRF rendering, and are currently working to publish the results.

# Plans for 2024-2025

We have recently recruited a graduate student, Shreyas Shivakumara, for studying the application of deep learning in immersive realistic imagery for augmented and virtual reality, at LiU from 2023-12-01 and onwards. Initially our focus in this area will be on exploring current methods for real-time texture and imagery synthesis, primarily with respect to realism and geometric stability, and how these can be made to make use of the data collected and classified in related projects at LiU on twin city model generation from aerial and drone imagery.

We will investigate different approaches to machine learning including up-scaling and improving quality of already available city model textures and model data, and view rendering and improvement methods.

At LU we plan to continue work on NeRF rendering and working with the Neural image synthesis work at LiU.

# Awards and Recognitions

Pierre Moreau, Michael's recent PhD graduate, now at Nvidia, did research into many-light direct illumination, which is cited as the motivation for the very successful follow on ReSTIR algorithm, which has led to a growing number of research papers in the area of real-time ray tracing using many-lights.

# **External Funding Attracted**

Project Name	Funding agency	Total Amount	Duration
		(kSEK)	
Efficient GPU Programming for Visual and	KWA WASP-AS	3500	2018 - 2022
Autonomous Systems			
GAIA	FORMAS	154	2023–2025
Visual Sweden City Platform	FORMAS	3700	2023–2025

# Inter-University Cooperation within ELLIIT

Due to a longer sick leave by one of the original PIs the project, after initial meetings in the beginning of 2023, had one-sided start, and it is only recently that both parts are at a stage when collaborations can be fruitful. For the spring of 2024 we have planned several meetings and a workshop to work on inclusion of ray tracing paradigms in the Visual Sweden City Platform.

# Inter-Disciplinary Cooperation

The LiU research group participates in a series of projects on the topic of city modelling using machine learning, some including cross disciplinary aspects. This is executed in collaboration with other research groups at LiU, Visual Sweden and NVAB (Norrköping visualiseringscenter C). Most recently, the communication project around the Visual City aims to spread knowledge about the possible use of digital twins of city structures, by demonstration of a variety of examples.

# International Collaboration

Michael Doggett collaborates with a group as part of the EUGLOH project. This has resulted in the 2023 Summer School, future work is on-going for a future Summer School in 2024, and a joint European Masters programme. Michael is working with António Coelho from University of Porto on teaching and research collaborations between Porto and Lund. He also collaborates with Cheng Zhang and Zhou Dong at Meta Reality Labs, Seattle, and Shuang Zhao at the University of California, Irvine, on Differentiable Rendering.

# Patent Applications, Open Source Software, and Contributions to Standards

The code from the GRAPP paper, [Moreau22] is available on Github.

Michael Doggett was a member of the Khronos Working Group for the Open Standard API for Graphics called Vulkan, where he worked on the new Ray Tracing extension.

# Exploitation and Cooperation with Industry and Institutes

Michael Doggett collaborates with Calle Lejdfors, AMD, on a Masters project titled, Dynamic Diffuse Global Illumination Using Probes and Surfels, with student Elmer Dellson. Michael also supervised Master Thesis in collaboration with industrial partners. A project entitled, Enhancing Satellite Images Using Super-Resolution,

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with student Nils Olén, and collaborators at Tactel, Jonas Bondesson and Tobias Leksell. A project titled, Improving Artificial Validation Data Using Scene Analysis, with students Gustav Klotz and Kristina Patrikson, and collaborators at AXIS, Linus Jacobson and Mikael Murstam. Michael Doggett and Gustaf Waldemarson, a WASP Industrial Ph.D. student, collaborate with ARM in Lund, Sweden.

The communication project Visual City, mentioned above under the inter-disciplinary cooperation section, includes cooperation with the Norrköping visualization institute as well as with municipalities around Sweden.

#### Contributions to Undergraduate/Graduate Education

The research drives and is used in collaborations with Masters projects in Real-Time Ray Tracing with industrial partner from AMD, Calle Lejdfors. In 2022 a student project titled, "Colour Correction of Augmented Reality Objects Using Spherical Harmonic Lighting" was a follow on project from Rikard's AR work. In 2023 a Masters project has started that is looking into high-performance Neural Networks using low-level hardware GPU coding.

#### **Outreach Activities**

The LiU research group is, through the Simstad project and together with NVAB (Norrköping visualiseringscenter C), developing an exhibit for the public spaces, with inauguration in February 2024. This interactive exhibit uses a projector to render statistical and real-time data on a 3D printed model of Norrköping, forming a multi user, non-invasive type of augmented reality (AR). Visitors will be able to control the information layers and learn both about the municipality and about important aspects of the projects, such as the use of machine learning.

Also, the communication project Visual City aims to spread knowledge to municipalities in Sweden about use of digital twins of city structures, by demonstrating best practise.

#### Keynotes, Plenaries and Academic Service

Michael Doggett gave invited Lectures at EUGLOH Summer School in July, 2023 in Hamburg, was General chair for 2022 ACM I3D, and Paper chair for 2023 ACM I3D. He is also an Associate Editor for Computers and Graphics, and IPC member for ACM/EuroGraphics High-Performance Graphics 2021, 2022, 2023. He has been involved in the following Ph.D. review committees :

- Mark Bo Jensen, "Virtual Reality-Based Visualization of Large Geometric Data", 2022-12-07, Technical University of Denmark (DTU)
- Wito Engelke, "Exploring the Invisible: Finding Structure in Scientific Data", 2022-04-29, Linköping University
- Dan Dolonius, "On sparse voxel DAGs, and memory efficient compression of surface attributes, for real-time scenarios", 2022-03-25, Chalmers University of Technology
- Joakim Jönsson, "MultiScattering : Computational light transport in turbid media", 2021-06-17, Division of Combustion Physics, LTH

#### 5.5 C4. Brain-Based Monitoring of Sound

PI: Martin Enqvist (LiU) Co-PI: Maria Sandsten (LU)

#### Objectives

The outcome of this project will be a set of optimized methods to continuously monitor recorded electroencephalogram (EEG) measurements from the brain in order to estimate and track sound processing in the brain. The increasing requirements on audio products for hearing aids (HAs), together with recent invention of EEG electrodes that fit in the ear will call for robust methods with high time and spatial resolution of the EEG. In this project, we intend to attack the problem of complex listening environments (e.g., the cocktail party problem) and we will provide a better understanding for how the sound is processed at different stages in the brain for both normal-hearing (NH) and hearing-impaired (HI) listeners, opening up for future advanced HA solutions. Experiments and technical solutions will be on the scientific frontier through the collaboration with researchers at Eriksholm Research Center (part of the world-leading HA manufacturer Oticon A/S).

#### Main Scientific Achievements

The main scientific achievements until now include (i) a novel method for robust multi-channel phase difference estimation of oscillating transient signals in high noise levels which has been presented at EUSIPCO2022 [Keding, 2022] and (ii) novel methods for robust coherence estimation, especially for estimating coupling between EEG and speech envelope. Several conference papers within this scope have been presented at EUSIPCO 2023 [Keding, 2023] and INTERSPEECH 2023 [Keding, 2023]. This work is also expanded into a journal manuscript (submitted). Furthermore, (iii) a novel domain adaptation framework for EEG-based auditory attention classification has been developed and published in the Journal of Neural Engineering paper [Wilroth, 2023] and (iv) the neuro-current response function (NCRF) method has been adapted to handle EEG data, which enables that source-localized linear filters can be estimated directly from EEG measurements. These results are available in the IFAC World Congress 2023 paper [Wilroth, 2023]. Finally, (v) a novel method for nonlinearity detection and compensation, based on an adaptive binning approach, has been developed and a paper has been submitted to ICASSP 2024.

#### Plans for 2024-2025

The plans for 2024 include carrying out experiments at Eriksholm Research Center with approximately 30 test persons. The exact details of these experiments are still not finalized, but the main objective is to take a novel experimental step towards more realistic environments while building on the previous results from this project. Furthermore, both of the Ph.D. students in the project plan to write and present licentiate's theses during 2024. The plans beyond that include a research visit or internship at a leading neuroscience research environment, for example in the USA.

#### Awards and Recognitions

In 2020, Johanna Wilroth was awarded the prize "LTHs Jubileumsstipendium" for the best master's thesis at LTH. In this work, Wilroth studied novel algorithms for improving the performance of hearing aids using EEG signals, which is also the overall objective of the current ELLIIT project.

#### **External Funding Attracted**

Project Name	Funding agency	Total Amount	Duration
		(kSEK)	
Competence center SEDDIT (Sensor Informat-	Vinnova	57 000	2023-2028
ics and Decision-making for the Digital Trans-			
formation) [M. Enqvist co-applicant]			
Competence Center in Integrated Sensors and	Vinnova	36 000	2023-2026
Adaptive Technology for Sustainable Products			
and Manufacturing [M. Sandsten co-applicant]			
Active learning for active control and monitor-	Vinnova	1 100	2023–2024
ing [M. Sandsten co-applicant]			
Adaptive system for active control and moni-	Vinnova	3 700	2023-2026
toring of biobased lubricants for smart manu-			
facturing [M. Sandsten co-applicant]			
Soundscape analysis using AI [M. Sandsten	SSF	2 000	2022–2025
co-applicant]			
Vibration monitoring and passive seismic ex-	BeFo	3 500	2022-2023
ploration of rock mass via fiber optic sensing,			
[M. Sandsten co-applicant]			

#### Inter-University Cooperation within ELLIIT

All participants meet regularly every month, usually on Teams. The two Ph.D. students (one from LiU and one from LU) collaborate more frequently and have also visited Eriksholm Research Center at several occasions. The two Ph.D. students have the same co-supervisors from Eriksholm to ease collaboration and align common interest. Doctoral students and supervisors participated in CHSCOM 2022 in Linköping and in the ELLIIT workshops in 2021 and 2022, in Lund and Linköping, respectively.

#### Inter-Disciplinary Cooperation

The project is clearly interdisciplinary, both thanks to the collaboration between control researchers from LiU and mathematical statistics researchers from LU and thanks to the collaboration with researchers at Eriksholm with expertise in speech processing and EEG.

#### International Collaboration

The project involves extensive international collaboration with Eriksholm Research Center and Oticon A/S in Denmark. In 2022, researchers in the project participated in Coghear, Washington DC, USA, where they met and collaborated with several internationally recognized researchers.

#### Patent Applications, Open Source Software, and Contributions to Standards

The implemented methods from the Journal of Neural Engineering paper [Wilroth, 2023] are available on GitHub.

#### Exploitation and Cooperation with Industry and Institutes

Within the project there is extensive collaboration with Eriksholm Research Center and Oticon A/S and the two Ph.D. students in the project have given talks and presented posters at several internal symposia at Eriksholm. Several master's thesis projects have been also been performed together with Eriksholm Research Center. Joint research in the area of bio-acoustics is also performed with RISE deep learning group, Gothenburg. Other industry related master's thesis projects within related areas are regularly performed together with local companies such as Acconeer, ABB, Axis, ASSA Abloy, Saab, Sinch, Tetra-pak and Trygg-Hansa.

#### Contributions to Undergraduate/Graduate Education

Student projects have been performed with methods and data that are related to the project in the advanced course *Stationary and Non-stationary Spectral Analysis*, 7.5 hp, at LU.

#### **Outreach Activities**

N/A

#### **Keynotes, Plenaries and Academic Service**

Martin Enqvist has been an associate editor for IEEE Control Systems Letters during the two first years of this project and has previously been an associate editor for Automatica. Maria Sandsten has previously been an associate editor for IEEE Transactions on Signal Processing. Johanna Wilroth will be a volunteer at the 2024 European Control Conference.

#### 5.6 C5. GPAI — General Purpose AI Computing

PI: Håkan Grahn (BTH) Co-PI: Jörn Janneck (LU) and Christoph Kessler (LiU)

#### Objectives

AI hardware accelerators are starting to be commonplace today and we foresee they will evolve by integrating more general purpose friendly features, similar to the way GPUs evolved into GPGPUs more than a decade ago. Contemporary accelerators are highly parallel, specialized, and often limited-precision devices with higher performance per Watt than general CPUs and they are targeting a relatively narrow application domain, i.e., neural networks (deep learning) processing. The objective is to address the challenges involved when using these AI accelerators for more general processing by (i) novel hardware and system software techniques, (ii) suitable computational models, and (iii) domain-specific programming models, languages and tools.

#### Main Scientific Achievements

Initial work in the project included a survey on low-power AI accelerators [Åleskog, 2022], from both academia and industry, in order to provide an understanding of contemporary AI accelerator design. A followup study evaluates different simulation and evaluation frameworks for accelerator design, in order to identify suitable candidates to be used as evaluation platforms in the project. Furthermore, work has been done to advance the state-of-the-art of high-level mapping and scheduling techniques for stream programs designed to operate across heterogeneous AI hardware platforms. A conference paper has been published [Boulasikis, 2023, to appear] with another currently undergoing the review process. In addition, we have done initial studies on how to implement some numerical analysis methods aimed at solving partial differential equations using AI/ML frameworks like Google's TensorFlow, in order to understand how numerical applications can be executed on AI/ML hardware. Some work has also been done to identify important application areas [Lundberg, 2022].

We have performed an analysis of computational patterns in deep convolutional neural networks and several other domains, and extended the pattern-based programming framework SkePU with the missing constructs and with a programming interface at a similar abstraction level as Keras and PyTorch, aiming at a portable high-level programming framework that can seamlessly express and deploy applications spanning multiple (AI+X) domains. A paper on this work is currently in preparation. In a journal article [Ernstsson, 2023], LiU contributed an evaluation of the performance portability of SkePU. LiU has also cooperated with LU on a joint paper on packet-type aware optimized deployment of streaming computations on multicore target systems, and contributed to an article on co-optimization of heterogeneous CPU multi-core architecture configuration with application mapping and scheduling for best energy efficiency of soft-realtime streaming computations [Litzinger, 2022].

#### Plans for 2024-2025

LU intends to further strengthen current partnerships and establish new connections with academic institutions focused on scientific computing, numerical analysis, and simulations. The primary objective is to systematically delineate the intricacies and hurdles associated with the utilization of AI hardware for general-purpose computations, for example issues related to data transfer and arithmetic precision, through both qualitative and quantitative assessments. The ultimate aspiration is the development of a high-level framework that facilitates the generation of efficient and usable codes, harnessing the computational capabilities of AI accelerators. LiU will complete and evaluate the extension of the SkePU framework towards a mixed AI+X multi-domain specific programming framework. Together with a planned SkePU backend for a forthcoming GPAI accelerator hardware design, this will allow to provide a first prototype of a high-level programming toolchain for GPAI. In a longer perspective, LiU aims to eliminate the restrictions inherent to the SkePU framework design by gradually substituting SkePU-based code generation for GPAI with an adaptation of leading compiler framework technology such as LLVM MLIR. Finally, at BTH the work will continue to focus on accelerator design and the interface to the software layers above.

#### Awards and Recognitions

- One of the Top 10 most downloaded articles from the journal Evolving Systems in 2022, [Nordahl, 2022].
- [Nordahl, 2023] was ranked as one of **Top-3 best papers** at the *36th Canadian Conference on Artificial Intelligence (Canadian AI 2023)*.

Project Name	Funding agency	Total Amount	Duration
		(kSEK)	
Green Clouds - Load Prediction and Optimiza-	Knowledge Founda-	4,172	2023-2026
tion in Private Cloud Systems	tion		
Recruitments-22, Senior lecturer in computer	Knowledge Founda-	2,600	2023-2027
science	tion		
Adaptive Software for the Heterogeneous	SSF	30,000	2022-2027
Edge-Cloud Continuum (ASTECC)			

#### **External Funding Attracted**

#### Inter-University Cooperation within ELLIIT

Within the project we have monthly meetings to discuss process, status of ongoing work, and present interesting topics. In addition, we have at least one physical meeting each semester. We are also working on joint papers. For example, LU and LiU cooperated on a joint paper on packet-type aware optimized deployment of streaming computations on multicore target systems. A significant part of the research for this paper was developed during Michail Boulasikis' research visit from LU to LiU.

#### Inter-Disciplinary Cooperation

We have established a productive collaboration with the Fluid Mechanics division within the Department of Energy at LTH, in conjunction with researcher Robert-Zoltán Szász. The Fluid Mechanics division possesses specialized knowledge in numerics and the integration of partial differential equations. This expertise is instrumental in steering the project towards practical applications and methods that hold relevance for both academic and industrial utilization. LU has also engaged in talks with researchers working on the DUNE framework for numerical analysis.

#### International Collaboration

LU has contact with and is collaborating with the Nordic IoT Hub. In a joint paper, LU and LiU cooperated with the group of Prof. Jörg Keller from FernUniversität in Hagen, Germany, on packet-type aware optimized

deployment of moldable streaming computations on multicore target systems, which is currently submitted. The joint article [Litzinger, 2022] by LiU and FU Hagen presented a method for the co-optimization of design space exploration for heterogeneous multi-core CPU architecture configuration with scheduling and DVFS scaling for moldable streaming computations. August Ernstsson, postdoc at LiU and associated with this project, is working as a guest researcher at the University of Münster, Germany, during 2023. The article [Ernstsson, 2023] on SkePU performance portability evaluation is joint work by LiU (2022) with a researcher from PUCRS University of Porto Allegre, Brasil. BTH has a collaboration with Hasso Plattner Institute (HPI), Potsdam, Germany, since more than 15 years, including joint course development, double-diploma education, long-term research collaboration, visits, and access to the FutureSoc Lab, a high-performance computing facility. For example, we have developed and gave three online courses together with HPI, Tor Vergata University, Rome, Italy, and Sapienza University, Rome, Italy during 2019-2022. In addition, we have guest edited a special issue for the journal *Big Data Research* together [Lundberg, 2021].

#### Patent Applications, Open Source Software, and Contributions to Standards

In the GPAI project activities, LiU uses, and also extends, its pattern-based open-source high-level programming framework SkePU [SkePU, 2023] for heterogeneous parallel systems. We plan to finally integrate project-developed prototype functionality into the publically distributed version of the SkePU framework.

#### Exploitation and Cooperation with Industry and Institutes

The Ph.D. level course "Advanced Compiler Construction" held at LiU in spring 2023 has been attended also by a group of engineers from the Ericsson compiler team in Kista and Linköping (remotely), and the Ericsson team also contributed to the course with a guest lecture. In related projects, we have ongoing collaborations with, e.g., Ericsson, Telenor Sverige, Cleura, Noda Intelligent Systems, and Saab. Therefore, we have several dissemination channels of our results, and we can also get feedback on the relevance and applicability of our work. In addition, Håkan Grahn (BTH/CS) is currently supervisor for four industrial Ph.D. students.

#### Contributions to Undergraduate/Graduate Education

Two Ph.D. courses have been given in the project, i.e., "Advanced Computer Architecture" at BTH and "Advanced Compiler Construction" at LiU. A new master course was developed at BTH in 2021 on multiprocessor programming. The course covers both traditional thread-based programming as well as GPU programming using CUDA. Further, activities of this project have initiated talks of developing a new GPGPU programming course at LU.

A master thesis project supervised at LiU about a FPGA backend for the pattern-based programming framework SkePU resulted in a research paper that is currently submitted for journal publication.

#### **Outreach Activities**

N/A

#### Keynotes, Plenaries and Academic Service

Christoph Kessler (LiU/IDA) held a keynote presentation about high-level portable programming of heterogeneous parallel systems at the PDP-2021 conference, and an invited presentation at the ScienceCloud'21 workshop. Three SkePU programming tutorials have been held: at ACM PPoPP-2021 (the most prestigious conference in parallel programming), at the IEEE e-Science 2021 conference, and at a joint workshop with international participants from groups involved in two European projects.

Håkan Grahn (BTH/CS) was guest editor, together with L. Lundberg, V. Cardellini, A. Polze, and S. Shirinbab) for a special issue on "Big Data in Industrial and Commercial Applications" in the journal *Big Data Research*, Vol. 26, 2021.

Examples of tasks as expert evaluator, etc.:

- Evaluation of Assistant and Associate Professorships, Halmstad University, 2021.
- Evaluation of Assistant Professorship in Machine Learning, Luleå Tekniska Universitet, 2022.
- Evaluation committee for Master program in Computer Science, Kristianstad University, 2022.
- Opponent for Jakob Danielsson's Ph.D. defense, Mälardalen University, 2021.

Ph.D. grading committees:

- Lorenzo Chelini, TU Eindhoven, Netherlands, "Abstraction Raising in General-Purpose Compilers," 2021.
- Shiraz Farouq, Halmstad University, "Towards conformal methods for large-scale monitoring of district heating substations," 2022.
- Hannaneh Najdataei, Chalmers, "Efficient Data Streaming Analytic Designs for Parallel and Distributed Processing", 2022.
- Rodothea Tsoupidi, KTH, "Generating Optimized and Secure Binary Code," 2023.

BTH arranged SAIS-2023, the 35th Swedish Artificial Intelligence Society annual workshop, where Håkan Grahn served as program co-chair and member of the organizing committee.

Examples of program committee memberships:

- AAAI Conf. on Artificial Intelligence (AAAI-2021, 2022, 2023, and 2024).
- Int'l Conf. on Computer Vision Theory and Applications (VISAPP 2021 and 2022).
- Euromicro Int'l Conf. on Parallel, Distributed, and Network-Based Processing (PDP 2021, 2022, 2023, and 2024).
- Int'l Joint Conf. on Artificial Intelligence (IJCAI-ECAI 2022 and 2023).
- Int'l Symposium on High-Level Parallel Programming and Applications (HLPP 2021, 2022, and 2023).
- Int'l Conf. for High Performance Computing, Networking, Storage, and Analysis (Supercomputing 2021).
- ACM Int. Conf. on Compiler Construction (CC 2022).
- Int'l Conf. on Computational Science (ICCS 2021, 2022, and 2023).

#### 5.7 C6. In situ Real-Time Characterization of Large 5G and Beyond Antenna Systems

PI: Mats Gustafsson (LU)

Co-PI: Magnus Berggren (LiU) and Isak Engquist (LiU)

#### Objectives

This project produces a technique for in situ measurements of mm-wave devices enabling rapid verification and testing of 5G-and-beyond systems with inexpensive and accessible measurement equipment. The technique relies on a non-invasive/intrusive metasurface designed to convert mm-wave radiation into heat, detectable by an infrared camera. This innovative approach allows the measurement of very low incident power density levels, representative of those utilized in consumer products. The use of printed electronic inks in these metasurfaces is expected to yield increased knowledge about the combined physical and electronic properties of these materials in the GHz range.

#### Main Scientific Achievements

We simulated and designed resistive metasurfaces which, utilizing screen printing technology, successfully have been manufactured. Collaborating with industry partners, we conducted near-field measurements on a mm-wave satellite. The results serve as an initial validation of the feasibility of metasurface-based non-destructive evaluation. Ongoing efforts include spectral measurements of infrared emissivity of metasurface materials. Additionally, we devised algorithms for array processing for metasurface IR images. Preliminary feasibility tests indicate the viability of 3D-printed antenna structures.

#### Plans for 2024-2025

Enhancing system sensitivity involves fine-tuning the multiphysics tradeoff among the electromagnetic, thermal, and infrared properties of the metasurface. In continuing collaborative efforts with industrial partners, as well as in-house efforts, we will further validate the technology with a specific focus on the near-field distribution around mm-wave array antennas. This ongoing work allows us to develop algorithms for array calibration and measurement methodologies applicable in diverse environments and for various quantities. Our research will extend to exploring a variety of substrates, printing inks, geometry, and material inclusions aiming to improve emissivity while minimizing thermal conductivity. Simultaneously, we will actively explore 3D printing techniques to enhance the manufacturing flexibility of the surfaces.

#### Awards and Recognitions

- Teacher of the Year, awarded by the student union F-guild to Johan Lundgren (2023)
- Teknologkåren's Pedagogical Prize, awarded by the student union of the faculty to Johan Lundgren (2023)
- Best poster award, Van Chinh Tran, European Conference of Molecular Electronics, Bari, Italy, October 2023
- Norrköping Municipality's honorary medal Honoris Causa, the St. Olof's medal, awarded to Magnus Berggren (Feb 2023)
- Young Scientist Award, URSI AT-RASC 2022, Niklas Wingren.

#### **Project Name Funding agency Total Amount** Duration (kSEK) ICONIC EU 5546 2024-2028 Tryckta komplementära OECT-kretsar Vinnova 994 2024-2025 WWSC (PI Magnus Berggren) KAW 380 000 2022-2026 PI Magnus Berggren Önnesjö-stiftelsen 1000 2022-2023 PI Magnus Berggren KAW 270 000 2022-2024 PI Magnus Berggren VINNOVA 10 000 2021-2022 PI Magnus Berggren EU 31 840 2021-2025 Fast and Efficient ElectroMagnetic Solvers 500 2023 Vinnova (FE2MS) EKAS-3D Vinnova 480 2023-2024

#### **External Funding Attracted**

#### Inter-University Cooperation within ELLIIT

Bi-weekly meetings on Zoom have been arranged, providing a forum for discussions and coordination between the partners. The project group met physically at the ELLIIT workshops and have organized project meetings in conjunction with the workshop focusing on the collaborative aspects and reviewing manufacturing options. Several design ideas have been discussed between the universities, with mutual exchanges of experiences of design, material choices, manufacturing, *etc.* We plan to increase the collaboration within ELLIIT by using the metasurface to measure mm-wave massive MIMO antennas.

#### Inter-Disciplinary Cooperation

The project is interdisciplinary in the sense that the partner at LU focuses on design and algorithms and the partner at LiU focuses on materials and manufacturing technology.

#### International Collaboration

**Synthesis, spectroscopy and characterization of organic electronic materials:** Profs. G Hadziioannou (U. Bordeaux, FR), I McCulloch (KAUST, SA), A Facchetti (NW U., USA), JW Andreasen, (DTU Energy, DK), M.

#### Chapter 5. Call C

Mas-Torrent (ICMAB-CSIC, ES), A. Salleo (Stanford, USA); **Paper electronics:** (displays and identification): J. Reynolds (Georgia Tech, USA); **Antenna measurements:** Samel Arslanagic (DTU Space, DK), **Antenna design:** Anja Skrivervik (EPFL, CH); **Optimal design:** Miloslav Capek (CTU, CZ), Lukas Jelinek (CTU, CZ), Kurt Schab (SCU, US)

#### Patent Applications, Open Source Software, and Contributions to Standards

- Absorption sheet, system and method for performing radiation characterization, PRV 2051181-2
- An absorption sheet for absorbing power from an electromagnetic wave, system for performing a radiation characterization, method for measuring an electromagnetic radiative near field using the same, PCT/EP2021/077704
- Patent application "An antenna arrangement", SE 2200055-8, Alexandros Pallaris, Daniel Sjöberg, Bengt Svensson, Anders Höök, Glenn Sjöberg.
- Open source hybrid finite element-boundary integral method code FE2MS, published at GitHub

#### Exploitation and Cooperation with Industry and Institutes

We conducted measurements on an mm-wave array antenna in collaboration with ReQuTech, confirming the efficacy of the metasurface in imaging the radiated near field and detecting radiation from individual antenna elements. Additionally, we are currently in discussions and planning stages for joint measurements with Ericsson AB to assess and validate the metasurface for Electromagnetic Field (EMF) applications. Simultaneously, our collaboration with RISE in Norrköping, particularly with the Printed Electronics Arena and the Swedish Research Lab for Printed Electronics, continues to progress. We are actively engaged in exploring screen printing inks and techniques. Furthermore, ongoing collaboration with DP Patterning, Norrköping, is focused on evaluating the potential use of their patterned metal films as antennas in the later stages of the project. A startup company named Mxwaves has been initiated as part of this endeavor.

#### Contributions to Undergraduate/Graduate Education

- M. Gustafsson taught a short course on 'Optimal inverse design' at APS 2022 in Denver, 'Matrix Formalism for Optimal Computational Design' at APS 2023 in Portland, and 'Optimal Inverse Design of Antennas' at EuCAP in Florence 2023.
- M. Gustafsson and J. Lundgren supervised the 'BirdFeeder Collective Team' in the IEEE APS student design contest (3rd place) in Denver 2022
- Johan Lundgren supervised the 'RICE-BOX GROUP team' in the IEEE APS student design contest (1st place) in Portland 2023
- Summer student project by Erik Waldemarson, "Temporal and spatial evolution of electromagnetic heating and infrared photon generation in metasurfaces from mmWave excitations", 7.5 ECTS.
- M. Gustafsson taught in European School of Antennas, compressing sensing in electromagnetics 2023 and 2021 in Trento, Antenna Systems for 5G Communications 2021

#### **Outreach Activities**

- A transistor made of wood popular science reports in New Scientist, Nature Materials, Physics World and IEEE Spectrum (Isak Engquist, May and June 2023)
- "Mobil kommunikation och radiovågor teknik och hälsa": Brochure on biological effects from electromagnetic fields, published by the Swedish National Committee of Radio Science, Wilén, J., Estenberg, J., Mild, K. H., Ljunggren, T., Mattsson, M.-O., Sjöberg, D., Törnevik, C., http://snrv.se/SNRV/Publikationer/Mobil kommunikation.pdf

#### Keynotes, Plenaries and Academic Service

- M. Gustafsson was a keynote speaker at Singapore Workshop on Antennas 2022
- M. Gustafsson co-organized a workshop 'Functional Electromagnetic Structures Workshop' together with

Saab and IEEE, May 5 2022

- M. Gustafsson, IEEE Antennas and Propagation best paper award committee member 2019-2021.
- M. Gustafsson, European Research Council (ERC) advanced grant panel member (PE7), 2022.
- M. Berggren, Chair of the board, SSF (2022-)
- M. Berggren, Director, the Wallenberg Initiative Materials Science for Sustainability (WISE) (2022-)
- D. Sjöberg, Chair Swedish National Committee of Radio Science
- D. Sjöberg, Commission B tutorial at URSI-GASS 2021 in Rome, "Physical Bounds for Functional Surfaces and Materials"

#### 5.8 C7. The DiaVoc Project: Diagnosing Vocal Characteristics to Track Patients' Health

PI: Andreas Jakobsson (LU) Co-PI: Johan Sanmartin Berglund (BTH)

#### Objectives

This project focuses on the diagnosis and tracking of health conditions that affect patients' voices, such as Neurocognitive disorders (NCDs) (cognitive decline), pulmonary disorder (COPD), and heart failure conditions (HF). Using longitudinal voice recording, matched with medical information, the project aims to identify vocal features and machine learning techniques suitable for tracking and classifying relevant vocal changes related to specific disorders. As an outcome of this project, the goal is to develop a system that can be used to support the clinical decision-making process toward quicker diagnosis and better treatment.

The project has an additional objective of enhancing scientific understanding through the integration of a cross-disciplinary approach. To achieve this, project teams have been established, comprising members with diverse academic backgrounds. Niloofar Momeni (LU) and Alper Idrisoglu (BTH), both Ph.D. students, have been enlisted and provided assistance by these teams in their research endeavors.

#### **Main Scientific Achievements**

In 2022 and 2023, Alper Idrisoglu carried out a systematic literature review (SLR) covering the period from 2012 to the entire year of 2022, with the aim of exploring the current state-of-the-art machine-learning techniques used in the diagnosis or monitoring of voice affecting disorders from the perspective of applied health technology. The SLR process involved screening 2220 articles from three databases, out of which 145 articles were deemed suitable for synthesis. The study selection was performed together with Ana Luiza Dallora, Ph.D. (supervisor). The SLR analyzed the trends in the research and successfully identified gaps in the literature of the area that ground the work that will come next. The findings have been published in the Journal of Medical Internet Research (JMIR) in 2023. In parallel with the SLR process, the BTH team has initiated the collection of voice data through the VoiceDiagnostic application. The team has obtained more than 2000 recordings from over 70 participants across four groups, namely Parkinson's Disease (PD), Cardiovascular Disorder (CD), Chronic Obstructive Pulmonary Disease (COPD), and a Healthy Control Group (HC). The development of a Swedish COPD classification dataset consisting of vocal features and evaluation of possible use for the classification of COPD employing machine learning was collected during 2023. A manuscript detailing the experiment is currently being prepared for submission by the end of 2023 or the beginning of 2024. The team at LU has worked primarily on voice features as well as motion analysis of patients suffering from Parkinson's disease (PD). The latter is in the form of a close collaboration with researchers in neurology, and have resulted in two M.Sc. thesis projects on this topic (by Gustaf von Grothusen and by Marlon Almström and Hoa Tran), as well as journal papers published in Neuropharmacology and in Frontiers in Neuroscience, as well as the initial work on a joint publication of the classification of motion patterns for PD patients. We have also worked together with speech therapists in determining vocal patterns for PD patients and for persons suffering from gender dysphoria, work that will continue into 2024. This work has resulted in one M.Sc. thesis project (by Mira Kjellin). There has also been work on the classification of children suffering from a cleft-pallet using vocal data, resulting in one M.Sc. thesis on this topic (by Rebecca Svensson).

#### Plans for 2024-2025

During 2024, the LU group plans to finalize initial work on the classification of PD based on voice data. For this, the group is utilizing data from the public mPower data set as well as own recordings gathered in collaboration with neurologists at LU as well as the BTH team. A collaboration with speech therapists at LU and in Linköping is also ongoing for studies on both PD patients and persons suffering from gender dysphoria. The group is investigating possibilities to provide personalized speech therapy for the latter group (initially), investigating connections between key vocal aspects and treatments. It is our hope that we can also finalize an initial work on this study during 2024.

Apart from the publication of the project on the Development and Evaluation of a Voice Dataset for Automated Classification of Chronic Obstructive Pulmonary Disease, the BTH team will conduct a research project to investigate if there are regions in a vowel phonation that contain more information for better classification accuracy. We aim to identify patterns that are explicitly related to COPD and enhance the classification accuracy. Additionally, The BTH team is actively planning new studies and experiments where some of the feature studies have the possibility to be presented at international conferences, and the recruitment of new participants will continue.

#### Awards and Recognitions

N/A

#### **External Funding Attracted**

N/A

#### Inter-University Cooperation within ELLIIT

As part of the collaboration on cleft-pallet children's voices, the group at LU has collaborated with Karolinska University, and for the vocal features also with the Åbo academy in Finland. Given that the project is a collaborative effort between LU and BTH, there exists an information exchange wherein LU provides guidance and supervision for Ph.D. students involved in projects at BTH.

#### Inter-Disciplinary Cooperation

The LU group has since 2022 extensively collaborated with speech therapist and neurologist, the latter related to both speech and motions. The latter collaboration has resulted in joint publications in *Neuropharmacology* and in *Frontiers in Neuroscience*, focusing on how different motion patterns for PD and tremor patients may be determined using a worn mobile phone. Similarly, the BTH team has initiated a multidisciplinary collaboration by including members in the project team with backgrounds from different disciplines, namely, data science, machine learning, big data, mathematics, and medicine. Team members supervising Ph.D. student Alper at BTH are Ph.D. Ana Luiza Dallora in Applied Health Technology, Associate Professor (Docent) Abbas Chedat in Computer Science, prof. Peter Anderberg is in Applied Health Technology, Prof. Andreas Jakobsson is in mathematical statistics, and Prof. MD Johan Sanmartin Berglund is in health science. Alper himself has an education in M.Sc. in computer engineering and digital media technology.

#### International Collaboration

Åbo academy and Aalto university, both in Finland.

#### Patent Applications, Open Source Software, and Contributions to Standards

N/A

#### Exploitation and Cooperation with Industry and Institutes

The group at LU has during the entire project collaborated closely with the start-up VoiceDiagnostic Sweden AB on the analysis and recording of voices.

#### Contributions to Undergraduate/Graduate Education

Illustrative examples based on research: the course Time series analysis, LU, Undergraduate (4th/5th year). Several M.Sc. theses.

#### **Outreach Activities**

Prof. Jakobsson has given several popular science presentations, at universities, schools, and large libraries. In these, he commonly refers to this ongoing project to illustrate the potential in AI research. In 2022, Alper Idrisoglu attended the ELLIIT workshop held at Linköping University and plans to participate in the ELLIIT workshop to be held in 2023 at Lund University. Additionally, Alper presented the project as a guest lecturer in courses (Electronics with Applications in Measurement Systems and the project course in Electrical Engineering with emphasis on IoT), in workshops, and at conferences at the annual BTH Ph.D. workshop and the annual Department of Health (TIHA) conference. Apart from the presented activities, Alper has participated at the National Graduate School on Aging and Health (SWEAH) conference (without presenting) in Norrköping and introduced the project during the discussion with other participants. Additionally, Professor Berglund has participated in a Podcast highlighting the potential of a voice-based decision support system.

#### Keynotes, Plenaries and Academic Service

Prof. Jakobsson acts as an Associate Editor for Elsevier Signal Processing.

#### 5.9 C8. Situation Aware Perception for Safe Autonomous Robotics Systems

PI: Volker Krueger (LU) Co-PI: Per-Erik Forssén (LiU)

#### Objectives

This project addresses the areas of sensing, analytics and learning. We develop a modular adaptable situationaware approach for perception, such that autonomous robotic systems (ARS), e.g., autonomous cars or robots, can decide in each situation how to sense. Consider the famous first accident of an autonomously driving Tesla, where the perception system missed a white trailer in front of a bright horizon because the sensing system was not able to adapt. Adaptability of sensing will make ARS safer, more robust to situation changes, and reduce costs and time for network training, programming and testing, thus making robots more accessible to SMEs. This will require advances in probabilistic modelling of perceptual outcomes and will use latent space learning and latent space tracking to adapt the perception to the situation. Scientific progress will be evaluated in an agile manner under realistic scenarios on our robot platforms (robotic arms and mobile robots, autonomous model cars, in/outdoors).

#### Main Scientific Achievements

Already in 2022, Simon Lind had implemented the normalizing flow-based out-of-distribution detection on the Heron robot (see Project S1) to investigate the performance of the normalizing flow in a robotics context. It turned out that the COCO image database is considerably different from the usual robotics applications. While COCO has mostly long focal-length images with everyday objects scattered in different locations whereas the robotics applications have usually wide-angle views with potentially different illumination conditions in different parts of the image. While the work in 2022 computed the normalizing flows (NF) for the whole image the work in 2023 has focused on investigating how the NF can be computed locally. For this, Simon has developed a novel

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approach, the *normalizing flow gradient*. The approach allows to identify the out-of-distribution probability on a per-pixel basis. This allowed to process the robotics image data. The results have been submitted to the International Conference on Robotics and Automation (ICRA). The paper is under review.

The Ph.D. student Ziliang Xiong started in September 2022, and has been working on addressing overconfidence in CNNs for robotic applications. An initial presentation on the work plan was given at the ELLIIT workshop in Linköping, October 2022. A paper has been written on the test case of horizon line estimation (which is geometrically equivalent to a camera up-vector estimation). By having the CNN output full probability distributions for the estimated parameters (aka. Regression by classification), it is possible to express uncertainty as a less peaked distribution, and ambiguity in input as a multi-modal distribution. This however requires that the training is set up in the correct way and uses a suitable loss function. How to set up the training, and how to quantify the quality of the output uncertainty is the focus of the paper.

The work was recently also applied to the task of stereo disparity estimation where aleatoric uncertainty is present, e.g. at occlusion boundaries. An extension of the horizon line paper has been done, where the behaviour is further analyzed on a synthetic dataset, and on the disparity task. This was recently submitted to the International Conference on Computer Vision and Pattern Recognition (CVPR) for review.

#### Plans for 2024-2025

We have plans for a joint paper on uncertainty assessment in the project. We have already had some preliminary discussions, but most of the work still remains to be done.

CVL has recruited two internal master's students that will be working on uncertainty quantification for object detection in the spring of 2024. We are also looking at collaboration with the Ph.D. student Bao Long Tran, who is working on *dorsal stream robot vision* in a project funded by the Swedish Research Council (VR). ELLIIT has local infrastructure in Linköping that could be useful for robotics applications in the intersection of dorsal stream robot vision and safe robotics systems.

#### Awards and Recognitions

N/A

#### **External Funding Attracted**

Project Name	Funding agency	Total Amount	Duration
		(kSEK)	
Dorsal Stream Robot Vision (LiU)	VR	3 600	2023-2026
TwinGenerator (LiU)	Vinnova	843	2023-2025
Visual Sweden City Platform (LiU)	Formas	616	2023-2025
Next Generation Communication and Com-	Vinnova	36 000 (in total)	2024-2028
putational Infrastructures and Technologies			
(NextG2Com)			

#### Inter-University Cooperation within ELLIIT

Ther collaboration between LU and LiU has been somewhat limited due to the leaving of the LiU Ph.D. student. LiU hired a new Ph.D. student in October 2022, and we have since met over video, somewhat regularly. We also consider having the occasional on-site meeting when this is called for. In the autumn of 2024 we plan to have a project where LiU students test the SkiROS system developed in Lund, on the Heron robot which is now available in Linköping (see ELLIIT Projects S1 and S4). This was initially planned for autumn 2023, but had to be postponed as the LiU robot was not fully functional.

#### Inter-Disciplinary Cooperation

#### International Collaboration

Simon Lind's reserach is done in collaboration with Rudolf Triebel from DLR, the German Space Agency. DR. Triebel became recently processor at the Karlsruhe Inst. of Technology (KIT).

#### Patent Applications, Open Source Software, and Contributions to Standards

N/A

#### Exploitation and Cooperation with Industry and Institutes

LU is collaborating with Tetra Pak towards the use of autonomous robots for quality inspection where image processing reliability is of high priority. Simon Lind's results are of importance here.

#### Contributions to Undergraduate/Graduate Education

N/A

#### **Outreach Activities**

Per-Erik Forssén gave the popular science talk: "3D-seende hos självkörande bilar och människor, October 27, 2022.

#### Keynotes, Plenaries and Academic Service

N/A

#### 5.10 C9. Data Sharing for Industry 4.0 Machine Learning

PI: Per Runeson (LU) Co-PI: Christian Kowalkowski (LiU)

#### Objectives

With the emergence of machine learning (ML) techniques into Industry 4.0 applications, increasing volumes of data are required to train ML applications. This project explores novel business models for business-to-business (B2B) data sharing, and designs new methods and tools to govern data sharing. We aim to 1) explore how mutual benefit of pooling data from multiple organizations may be balanced with their business values, and 2) design technical solutions to support versioning, encryption, differential privacy, licensing, maintaining and collaborating around shared data sets.

The objectives are hence partly descriptive and partly prescriptive. The descriptive part explores current practices and tools, and current and foreseen challenges in relation to B2B data sharing. Through empirical studies in industry we get an understanding of the phenomena, link them to existing research both from a business and a technical engineering perspective. In the prescriptive part, we aim to derive recommendations for industry on business models and guidance on feasible tool support for inter-organizational data sharing processes.

#### Main Scientific Achievements

Since the project is a true cross-disciplinary undertaking, getting to know the literature on both sides is a major challenge for the two Ph.D. students. On the business side, contributions by Christian Kowalkowski and colleagues in Industrial Marketing on servitization underpin the project, e.g. [Trondvoll, 2020]. On the engineering side, contributions by the Per Runeson and colleagues in Software Engineering constitutes the foundation, e.g. [Runeson, 2021]. Based on these, the scientific work has primarily focused on a joint exploration of *inter-organizational data sharing processes*. In a qualitative survey of industry practices, we have interviewed

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representatives of six organizations – large companies, an SME and a large research facility – on their practices, experiences and challenges of data sharing.

The findings, currently submitted for review at an international conference, comprise 1) business matters – why and with whom to collaborate, data quality, and data ownership issues; 2) technical matters – what data to share and how to do it, and how to maintain the data over time; and 3) challenges – comprising privacy concerns, supply of sufficient data volumes, geopolitical restrictions, and costs related to data collection, analysis, storage and sharing.

On the analytical side, we have analyzed instances on open data ecosystems in relation to Elinor Ostrom's design principles for Common Pool Resources and derived empirically-based recommendations for practice [Linåker, 2022].

#### Plans for 2024-2025

The plans for the continued work have three main elements. Firstly, we aim to continue the qualitative survey and add more cases from industry to increase the understanding of practices and challenges with data sharing, trying to find patterns across or within domains. Secondly, we intend to study one or a few cases of inter-organizational data sharing in depth as a case study. Thereby we aim to understand factors related to the business models of the involved organizations, which are at play, hindering or catalyzing data sharing practices. Thirdly, we plan to explore technical needs and design data sharing platform features and characteristics to support inter-organizational data sharing. The latter will be conducted in collaboration with the WARA-Ops (WASP Research Arena on operations data, https://www.wara-ops.org).

#### Awards and Recognitions

Christian Kowalkowski is recognized as Highly Cited Researcher in the field of Economics and Business 2022 and 2023 by Clarivate.

Project Name	Funding agency	Total Amount	Duration
		(kSEK)	
Myndighetsdriven Datadelning och Sam-	Triple F (Trafikver-	4 920	2023-2028
verkan för Effektivare Godstransporter	ket)		
Next Generation Communication and Com-	Vinnova	36 000	2024–2028
putational Infrastructures and Technologies			
(NextG2Com)			

#### **External Funding Attracted**

The first project is a Ph.D. student project funded by Trafikverket (Swedish Transport Administration) on data sharing between public authorities and private transportation firms. The second project is a Vinnova Competence Center with multiple actors from industry and public sectors, covering a the broad field of communication and computational infrastructures and technologies. One of the six project areas within the center is Integrated Data Engineering and Machine Learning, aiming to provide models, methods and tools for data supply and quality assurance, thus making it align to this project.

#### Inter-University Cooperation within ELLIIT

The cooperation between the two university partners in the project has firstly provided competence in two different research domains, Industrial Marketing and Software Engineering. Further, the university partners have provided their respective industry networks, which is highly relevant for an empirically based project, like this. Meeting in person has taken place in conjunction with ELLIIT workshops, while most cooperation takes place via digital communication.

#### Inter-Disciplinary Cooperation

The project is inter-disciplinary by design, representing Industrial Marketing and Software engineering, i.e. one discipline from Business/Economy and one from the Engineering/Technology domain. However, both disciplines are based on empirical studies, dominantly case studies, which is a common denominator.

#### International Collaboration

Related to the topic of the project, the Per Runeson has collaborated with Delft University of Technology (Anneke Zuijderwijk) and OpenUK (Amanda Brook) particluarly on a special issue of IEEE Software on collaborative aspects of open data [Linåker, 2022].

#### Patent Applications, Open Source Software, and Contributions to Standards

#### Exploitation and Cooperation with Industry and Institutes

Since the research work is empirical, the research conduct as such involves communication and networking to find feasible interviewees. Further, the Ph.D. student at LU has a co-supervisor, Dr. Johan Linåker, who is primarily employed at RISE (Research Institutes of Sweden), thereby further extending the industry contact network.

In the ongoing transfer towards open science at universities in Sweden and Europe, the findings from the project on data sharing is relevant for universities and researchers as well. Per Runeson has a role as chairman of the Lund University Expert group on FAIR research data, with responsibilities internally to promote FAIR/open data practices, and externally represent the university of national (SUHF) and international collaboration fora (EOSC).

#### **Outreach Activities**

Per Runeson was invited to several conferences as a keynote to talk about various aspects of data sharing and open data to audiences outside academia: Network Open Source and Data, Graz Symposium Virtual Vehicle, Swedsoft TEchnology Workshop, and Internetdagarna. Both Per Runeson and Christian Kowalkowski contributed to the ELLIIT Tech Talk #11 on Digital business models and legal aspects.

#### Keynotes, Plenaries and Academic Service

Per Runeson was invited as a keynote speaker at the Swedish Workshop on Data Science. In his role as chairman of the Lund University Expert group on FAIR research data, he gave a talk at a SUHF webinar. He was program co-chair for the 2023 edition of the IEEE/ACM conference on Empirical Software Engineering and Measurement (ESEM), he is a member of the editorial board of IEEE Transactions on Software and Software Testing Verification and Reliability (Wiley).



#### 6.1 Overview

The ELLIIT Steering Group (SG) decided to finance new Ph.D. student projects to commence early 2023. An open call ("Call D") was launched in May 2022. This call focused on projects with clear energy efficiency, trustworthiness, or resilience aspects.

In the first step of the application process, 48 applications were received. 20 of these were invited to submit a detailed proposal in a second step. 12 applications were selected for funding. These projects are funded with 1 MSEK/year per PI, for five years (2023–2027).

#### 6.2 D1. Protocol Security Verification Using Dynamic Key Structures

PI: Mikael Asplund (LiU) Co-PI: Christian Gehrmann (LU)

Probably secure communication solutions will be needed for the continued trust in future digital services. In this project, it is proposed a new approach to taming the inherent computational complexity of protocol security analysis by providing the means and the tools to leverage model structures (e.g., dynamic key dependencies) in models of security mechanisms and to use these structures to automate security analysis. The project is composed of three main tasks (i) automated model structure analysis, (ii) developing a theory on dependency relations, and (iii) modular protocol specification and verification. The research group leverages previous and ongoing work in secure protocol analysis with two recently started industry-oriented research projects involving Sectra, Ericsson and Saab.

#### Aspects of Energy Efficiency, Trustworthiness, and/or Resilience

This project is centred around trustworthiness and resilience of the next generation communication protocols. Enabling provably secure interaction protocols will be of great value to provide system level security as is greatly needed by Swedish industry today.

## 6.3 D2. Integrated reactive motion planning and motion control

PI: Daniel Axehill (LiU) Co-PI: Björn Olofsson (LU)

The objective with the proposed research is to significantly extend the recent work by the PI's former Ph.D. students Oskar Ljungqvist and Kristoffer Bergman in the area of optimization-based motion planning and control. The proposed work considers optimal motion planning, where motions that are optimal in terms of a user-defined (e.g., energy) performance measure are computed. Overall, several novel research directions are proposed with the overarching goal to obtain an efficient integrated motion-planning algorithm with the benefits that Bergman's method has, but extended to also be able to reliably work in a reactive setup implementing optimal control in feedback form for problems containing disturbances and dynamic obstacles. To reach that goal, research with the aim to significantly advance the computational efficiency of the employed algorithms is proposed. Furthermore, this development also needs to go hand-in-hand with control theory, to exploit the available margins but also to be able to guarantee not to break them.

#### Aspects of Energy Efficiency, Trustworthiness, and/or Resilience

The proposed research relates to energy efficiency from at least three perspectives: first, optimal motion planning can, e.g., be used to find minium energy solutions. Second, the proposed lower-level control strategy will be able to exploit helpful disturbances which translates to energy efficiency of the controlled platform if that is the selected performance measure. Third, the proposed research aims at increasing the computational efficiency, which translates to energy consumption of the control system which might be critical for battery powered mobile systems. The fast re-planning and proposed optimal feedback will make the system resilient with respect to disturbances, moving obstacles and model errors.

#### 6.4 D3: ACRE - Approximate Computing Reducing Energy

PI: Oscar Gustafsson (LiU) Co-PI: Joachim Rodrigues (LU)

Trading energy for accuracy is a promising approach to reduce the computing energy dissipation. Especially, for classes of applications with inherent resiliency, including AI/ML, significant reductions can be obtained. We focus on the novel and visionary area of modifying exact arithmetic operators to also perform more complex operations approximately with a focus on floating-point representations. This brings energy savings from approximate computing into general purpose processors.

#### Aspects of Energy Efficiency, Trustworthiness, and/or Resilience

Energy efficiency is at the core here, both enabling reduced memory bandwidth from shorter word lengths and reduced computational power from AC. We expect to move the energy-accuracy pareto front significantly. Resilience is primarily at the application level, but AC systems require a degree of resilience to manage increased approximation errors.

#### 6.5 D4: Visual Analytics of Large and Complex Multilayer Technological Networks

PI: Andreas Kerren (LiU) Co-PI: Richard Pates (LU)

Multilayer networks are a relatively new way to model complex real-world systems that demand novel and efficient solutions for their analysis. Especially when regarding large and heterogeneous data typically used

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in power systems control, the use of multilayer networks for data representation, modeling, and analysis is promising.

To explore such multilayer technological networks and to incorporate the human perspective into the analysis process for increasing the trust into the results, interactive visualization approaches are key. This project will be performed in an interdisciplinary team which will study and develop novel visual analytics approaches for the exploration and analysis of multilayer technological networks. This is not only highly relevant for the field of visual analytics, but also for the energy efficiency of power systems.

## Aspects of Energy Efficiency, Trustworthiness, and/or Resilience

The project will greatly improve aspects of trustworthiness into the analytical results during and after the



analysis process. Interactive visualization and visual analytics allow for the creation of human insights into complex phenomena that are connected with huge and complex data sets. It is a way to improve the understand-ability, interpretability, and reproducibility of any complex data analysis task and, hence, establishes trust for data analysts. Furthermore, this project will directly impact several aspects of energy efficiency. The integration of renewable energy into grids is a key ingredient when addressing climate change, but requires the underlying control challenges to be addressed. Our visualizations will contribute to help understand many aspects of this process. This is especially important when analyzing many large, complex, and heterogeneous networks in combination as considered in this project.

#### 6.6 D5: Discrete Optimisation for Automatic Decision-Making in Large-Scale Complex Systems

PI: Elina Rönnberg (LiU) Co-PI: Susanna F. de Rezende (LU)

Improved methods for solving discrete optimisation problems have a great potential to contribute to sustainability and energy efficiency, as well as to trustworthiness of systems. The goal of this project is to push the limits for which scheduling and resource allocation problems can be successfully solved. Both the mathematical programming and computer science communities have long and strong traditions of developing optimisation methods for such problems, but with limited interaction. The core novelty of this project is in hybridising methods from these communities and integrating them into decomposition frameworks.

#### Aspects of Energy Efficiency, Trustworthiness, and/or Resilience

Careful planning is essential to make efficient use of resources and applying optimisation often has a great impact on energy efficiency.

An important research direction for the group at LiU is to contribute to sustainability, which — in the context of methods for scheduling and resource allocation — often is related to energy efficiency. In addition to this, the research group has an interest in optimisation as part of systems engineering. When optimisation is part of system design it can contribute to trustworthiness of systems, as in the case of avionics scheduling. These research interests are reflected in the group's choice of applied



projects and industry collaborations, while at the same time we have projects that aim for more generic method development for larger classes of optimisation problems. At the core, we have an interaction between fundamental research projects and applied projects: the latter provides relevant problem formulations (or even more general problem structures) of relevance for general method design, while the former pushes the limits for which practically relevant problems we can solve. In this project, such interaction will make the proposed research contribute to energy efficiency and trustworthiness.

#### 6.7 D6: FL4IoT: Energy-Efficient Federated Learning for Internet of Things (IoT) Systems

#### PI: Amir Aminifar (LU)

Co-PIs: Christoph Kessler (LiU) and Petru Eles (LiU)

The new generation of artificial intelligence (AI) and machine learning (ML) techniques have recently been shown to require non-negligible energy for both training and inference.

FL4IoT will focus on developing efficient machine learning techniques to overcome their energy overheads, by taking advantage of the inherent heterogeneity of the Internet of Things (IoT) platforms, towards a new generation of sustainable AI/ML techniques.

This project is highly relevant for key industry players, including Ericsson, with collaboration/exchange possibilities, particularly in connection with the recent SSF project "Adaptive Software for the Heterogeneous Edge-Cloud Continuum."



# Aspects of Energy Efficiency, Trustworthiness, and/or Resilience

The project proposal mainly focuses on the energy efficiency aspect in relation to modern machine learning models and the challenges in terms of sustainability. In particular, recent studies have shown that the energy overheads of training and inference on modern machine learning models are certainly non-negligible when it comes to sustainability and can pose environmental threats. On the other hand, federated learning enables decentralized processing of the data, without data leaving patient/user's devices, hence reducing the concerns in relation to privacy. In this regard, we plan to create synergies with the PI's recent Swedish Research Council (VR) Starting Grant project "Privacy-Preserving Edge Machine Learning on Internet of Things (IoT) Systems with Extreme Resource Constraints."

#### 6.8 D7: DDoS detection in 5G/6G networks

PI: Christian Gehrmann (LU) Co-PI: Mikael Asplund (LiU)

The huge amount of cellular connected devices can be used to launch Distributed Denial of Service (DDoS) attacks which are a severe threat against telecommunication infrastructures and services. The new analytic function introduced by 3GPP in 5G, Network Data Analytics Function (NWDAF), supports anomaly detection, the first step towards DDoS blocking even if few such functions have so far been introduced. In general, relatively little research work addresses next generation cellular network, machine learning, DDoS detection. In this project we investigate different anomaly detection strategies with focus on resource allocation and mobility-oriented attacks as well as low-rate DDoS. The research is directed towards obtaining appropriate data for these attack

classes and, in the next step, identification of appropriate machine learning detection principles for these classes. The research is built upon and extends a recently started research cooperation with Ericsson Research.



#### Aspects of Energy Efficiency, Trustworthiness, and/or Resilience

The whole project is devoted to make cellular systems more trustworthy and resilient. As machine learning approaches now are about to be introduced in the core networks, attacks on such methods will almost certain happen. This can severely disturb the mobile services which are consider critical to the society. All the new methods we propose in this research project will be evaluated with respect to computing performance and energy efficiency.

#### 6.9 D8: Revisiting Data Associations in Large-Scale Mapping

PI: Viktor Larsson (LU)

Co-PIs: Mårten Wadenbäck (LiU) and Michael Felsberg (LiU)

This project concerns 3D mapping methods which are used to enable re-localization and navigation in large-scale environments. In particular, the project focus on sparse reconstruction methods where the input is a set of images, which can be passively acquired from autonomous agents. In the scope of the project we will significantly improve the robustness and accuracy of the current pipelines by proposing novel methods for adaptively updating the data associations used in the estimation pipeline.



#### Aspects of Energy Efficiency, Trustworthiness, and/or Resilience

The project directly targets the robustness of sparse mapping systems which are used in the back-end of many autonomous navigation and localization pipelines. Therefore, the project is very relevant for the resilience of engineering systems, in particular in the context of autonomous agents.

#### 6.10 D9: Efficient Mid-range Wireless Power Transfer with Intelligent Surfaces (EMPTIS)

PI: Buon Kiong Lau (LU) Co-PI: Alireza Saberkari (LiU)

Today, small devices can only be charged efficiently by wire connection or short-range, magnetic coupling based wireless power transfer (WPT), which is inconvenient to users.



Long-range WPT has been attempted, but high efficiency will require impractically large antennas. The project EMPTIS aims to leverage the widely-deployed large intelligent surfaces (LISs) envisioned for 6G to realize mid-range WPT with drastically improved efficiency, while ensuring safe operation for future green Internet-of-Things (IoT) devices and applications. In EMPTIS, we will focus on LISs that consist of active antenna elements (ca. hundreds to thousands) with associated electronics widely spread on surfaces like walls, to meet 6G requirements.

# Aspects of Energy Efficiency, Trustworthiness, and/or Resilience

The project is crucial to realize high enough end-toend WPT efficiency (beyond a few percent to >10%) to enable large-scale adoption and deployment of mid-range WPT. Today, the only commercial technology that can wirelessly power a remote device, i.e., passive RFID, transmits at less than or equal 1W, with only a few uW's available at the tag (less than or equal 6m range), i.e., efficiency of approximately 0.0001%. We can expect many more IoT devices than the 25 billions forecasted by the 6G rollout in 2030 (dataprot.net/statistics) due to the resulting smaller/cheaper devices and operation/maintenance (with small batteries that do not need to be changed), leading to huge overall power/cost savings.

### 6.11 D10: Optimal Estimation and Control at Scale

PI: Richard Pates (LU) Co-PI: Anders Hansson (LiU)

Many classical optimal methods for estimation and control have provable robustness and performance guarantees that can enhance the sustainability and resilience of engineering systems. However, their implementation typically requires all-to-all communication of sensor measurements, making them an infeasible choice for many practical applications. The aim of the project is to improve efficiency and resilience in network applications, through scalable linear algebra based implementations of centralized estimation and control algorithms. In particular, the project aims to exploit techniques from sparse linear algebra to reduce the communication burden of classical optimal estimation and control methods.

Reducing the need for communication will allow these methods to be applied in important sensor rich application areas, such as autonomous vehicles, transportation networks, and power grids. This has the potential to greatly



improve energy efficiency and resilience in these applications, where suboptimal design approaches, that typically provide no formal guarantees, must currently be used for reasons of system scale.

#### Aspects of Energy Efficiency, Trustworthiness, and/or Resilience

Many optimal estimation and control methods have highly desirable performance and robustness guarantees that can enhance energy efficiency and resilience of engineering systems. This project aims to unlock the benefits of these approaches for important sensor rich application areas, where heavy communication requirements have previously prevented their application. The project will have a focus on application areas where energy efficiency is of paramount importance, such as power systems and transportation networks.

#### 6.12 D11: Near Memory Computing for Data-Centric Architectures

PI: Joachim Rodrigues (LU) Co-PI: Oscar Gustafsson (LiU)

A promising technique to boost performance and energy efficiency in data-centric computing architectures is the integration of computation logic in the near proximity of on-chip memory.

In this project, it is proposed hardware/software co-optimized near memory computing (NMC) techniques, having the advantage of being scalable for various architectures and applications (for instance, ML/AI or baseband processing). The techniques will improve computation speed by several orders of magnitude at a negligible hardware cost, increase energy efficiency, be validated by hardware/software co-verification in a virtual platform, and will be confirmed with measurements of a RISC-V processor based silicon realization.

#### Aspects of Energy Efficiency, Trustworthiness, and/or Resilience



Conceptual illustration of NMC in beyond

von Neumann.

Serial processing of massive data in traditional von

Neumann-based platforms has identified severe performance bottlenecks, and data management dramatically degrades energy efficiency. We will propose HW-accelerators integrated as co-processor on cache level, and thereby, dramatically reduce the number of repetitive memory accesses as well as data handling of the data buses.

#### 6.13 D12: Static Analysis of Energy Usage in Software

PI: Wojciech Mostowski (HH) Co-PI: Christoph Reichenbach (LU)

This project focuses on developing new methods in static analysis to achieve verifiable energy efficiency of software. Research on energy efficiency typically focuses on hardware, but a lavishly designed or buggy program can easily waste the hardware design efforts by being unaware of the energy consumption intricacies of the execution platform. To help capture energy consumption requirements and guarantees for software, we will develop specific program annotations in design-by-contract style that take into account power consumption of the underlying program constructs, from single statement up to complete procedures. We then propose two different static analysis methods of different precision, working in separation or combination, to help in (i) verifying the annotations, and in (ii) proposing candidate annotations.

When verification succeeds, power consumption annotations give quantified statements about energy efficiency. When verification fails, the failure can point to power consumption related bugs, e.g., so-called resource leaks. Combined with platform-specific power consumption models, we can then derive absolute statements about power consumption (on platform X the program uses at most Y power), or relative statements (program A is more energy efficient than program B). One of the prerequisites for such analysis is a suitable power profile of the execution platform to be developed early in the project. Our research will be supported by suitable and realistic case studies where appropriate.



#### Aspects of Energy Efficiency, Trustworthiness, and/or Resilience

This project directly addresses the aspect of energy efficiency by explicitly developing static analysis techniques to validate power related behaviour of programs. Trustworthiness and resilience are transitively supported by this work, namely, our static program analysis techniques target software reliability in general, and can be used to show that the software meets different kinds of functional and non-functional requirements, including robustness and security properties.



# **Recruited Faculty**

## 7. Recruited Faculty

#### 7.1 Andreas Kerren, Professor in Information Visualization

Andreas Kerren is a full professor of information visualization with the Department of Science and Technology, Linköping University (LiU), Norrköping Campus, Sweden, and with the Department of Computer Science and Media Technology, Linnaeus University (LNU), Växjö, Sweden.



He holds the Chair of Information Visualization (iVis group) at LiU and is head of the ISOVIS research group at LNU. In addition, he is an ELLIIT professor supported by the Excellence Center at Linköping–Lund in Information Technology since 2021 and key researcher of the Linnaeus University Centre for Data Intensive Sciences and Applications since 2017. Since 2022, he also leads the LNU-node of the National Research Infrastructure for Data Visualization (InfraVis). Prof Andreas Kerren received his Ph.D. degree in Computer Science from Saarland University, Saarbrücken, Germany, in 2002. Afterwards, he held temporary positions as university assistant (equivalent

to assistant professor) at Vienna University of Technology, Austria, and as senior researcher at Kaiserslautern University of Technology, Germany. In 2007, he moved to Sweden after accepting a senior lecturer position at Växjö University (now LNU) where he achieved his habilitation (docent competence) in 2008 and got promoted to full professor in 2009. End of 2020, he received and accepted the offer from Linköping University to chair the information visualization unit in Norrköping.

Prof Kerren has published more than 200 peer-reviewed papers, articles, and book chapters; and his main research interests include several areas of information visualization and visual analytics, especially visual network analytics [Zimmer et al., 2017], text visualization [Kucher et al., 2020], the use of visual analytics for explainable AI [Chatzimparmpas et al., 2020] and [Chatzimparmpas et al., 2022], and embeddings in visual analytics [Witschard et al., 2022].

#### **Description of Research Group**

The iVis group at Linköping University (https://ivis.itn.liu.se) focuses on the explorative analysis and visualization of typically large and complex information spaces, for example in environmental research, transportation systems, social sciences, or artificial intelligence. Our vision is to attack the big data challenge by a combination of

human-centered data analysis and interactive visualization for deriving meaning from the data and final decision making. Our research is highly relevant for academia and economy as both science and industry make increasing use of data-intensive technologies. We take a human-centered and problem-oriented visualization approach: human-centered visualization deals with the development of interactive visualization techniques in consideration of user- and task-related information to explore and analyze complex data sets efficiently. This course of action combines aspects of different research fields, such as information visualization, human-computer interaction, information design, cognition, but also the particular application field. The purpose of research in these areas is to develop novel methods and tools that are able to efficiently support analysts from various data domains. Our new visualization techniques enable them to solve difficult analytical problems and to identify and extract meaningful information from the data while improving the speed, accuracy, and completeness of their understanding. We are engaged in a wide range of research aspects which encompass the development of new algorithmic approaches for the extraction of patterns and relationships in data, the visual and auditory representation of these features, the use of machine learning approaches in visualization and vice versa, as well as the study of perceptual mechanisms and novel evaluation methodologies. Currently, iVis counts 19 members incl. 7 Ph.D. students and 3 postdoctoral researchers.

The ISOVIS research group at Linnaeus University (https://cs.lnu.se/isovis/) largely addresses the same research problems as iVis and consists of currently 9 people incl. 2 Ph.D. students. Members of the group are also involved in the National Research Infrastructure for Data Visualization (InfraVis, https://infravis.se).

#### Plans for the Next Five Years

In the coming five years, I plan to consolidate my research groups even more and try to attract more external research funding in form of larger project environments, such as WASP NESTs, VR research environments, etc. This would even pave the way for a more intensive inter-university cooperation within the ELLIIT environment. From a research perspective, I will further expand our activities in the areas of multidimensional and temporal data visualization, network visualization, visual text analytics, and explainable ML/AI with the help of visualization. Especially the latter one is of increasing importance as several challenges—but also opportunities—remain for visual analysis in relation to (X)AI, but also for human-in-the-loop AI/ML where humans play an interactive and iterative role in the model development for improving machine-learning outcomes. Open questions are for instance: what should the visual analytics research community learn from other researchers in (X)AI coming with different perspectives, how should the role of visualization be positioned and communicated, and how should the long-term collaboration with other communities of researchers and practitioners of (X)AI look like? When, where, and to what extend should humans become involved in the machine learning pipeline? Or, where should visualization research focus on in a world of rapidly changing AI/ML methods?

I also would like to expand our research to further applications domains that were not in our focus so far, such as data analytic challenges in organic electronics (LiU), autonomous vehicles and robotics (Lund University (LU)), cyber security (LU, LiU), or game development (Blekinge Institute of Technology (BTH)), just to name a few from the ELLIIT universe.

Project Name	Funding agency	Total Amount	Duration
		(kSEK)	
National Research Infrastructure for Data Visu-	VR	80 000 (~8 000	2022-2026
alization – InfraVis (co-PI, node coordinator for		for LNU node)	
LNU)			
Visual Analytics for Enhancing Quality and Trust	WASP-DDLS Joint	2 500	2022-2024
in Genome-wide Expression Clustering and An-	Call		
notation (PI)			
Immersive Analytics for Urban Heat (co-PI)	Norrköping Fund	$\sim 2\ 000$	2022-2024

#### **External Funding Attracted**

#### Inter-University Cooperation within ELLIIT

Since I joint ELLIIT in 2021, I have been involved in a number of cooperation activities within ELLIIT such as proposal writing or building up research networks. One of the outcomes has been a granted research proposal, entitled *D4: Visual Analytics of Large and Complex Multilayer Technological Networks* within the ELLIIT Call D together with Dr Richard Pates (LU), cf. Sect. 6.5. Recently, I have submitted a proposal for a new ELLIIT Focus Period on *Visualization-Empowered Human-in-the-Loop Artificial Intelligence* to be held in 2025. The notification is still pending, but if accepted this initiative will surely foster further inter-university collaborations in the area of explainable AI and/or human-in-the-loop AI.

#### Inter-Disciplinary Cooperation

Information visualization and visual analytics are research fields that both use data from various sources and often solve domain-specific analytical problems. In this regard, interdisciplinary cooperation occurs regularly in our visualization research and in almost all running projects. In the recent years, we mainly collaborated with colleagues from the areas of systems biology (Prof Mathias Uhlén at Royal Institute of Technology and SciLifeLab), social sciences (Prof Giangiacomo Bravo at Linnaeus University), humanities (Prof Carita Paradis at Lund University and Prof Mikko Laitinen at Linnaeus University), natural language processing (Dr Maria Skeppstedt at Uppsala University as well as Prof Manfred Stede at Potsdam University), environmental change (Assoc Prof Tina Schmid Neset at Linköping University), and control systems (Dr Richard Pates at Lund University). To keep this list short, I only mentioned the leading cooperation partners and no others, such as Ph.D. students or other co-workers.

#### International Collaboration

I regularly collaborate and publish with researchers from various countries and universities. During the past years, I have worked and co-authored with a number of colleagues outside of Sweden which are briefly mentioned in the following. At the borderline of visualization and machine learning, I have worked with Prof Fernando V. Paulovich (Dalhousie University and TU Eindhoven), Prof Alexandru Telea (Utrecht University), Ass Prof Nina S. T. Hirata (University of São Paulo), and Prof Fabrice Rossi (Université Paris Dauphine). In visual text analytics, I have worked with Ass Prof Rafal Rzepka (Hookaido University and RIKEN Center for Advanced Intelligence Project) and Prof Manfred Stede (Potsdam University). In visual network analysis, I collaborated with Assoc Prof Margit Pohl (TU Vienna), Prof Falk Schreiber (University of Konstanz), Prof Kwan-Liu Ma (UC Davis), Prof Peter Eades (University of Sidney), Prof Stephen Kobourov (University of Arizona), and others. Again here, to keep this list short, I only mentioned the leading cooperation partners and no others, such as Ph.D. students or other co-workers. In addition, I have organized four (the most recent one on Visual Text Analytics, https://www.dagstuhl.de/22191) and attended more than 20 Dagstuhl Seminars and NII Shonan Meetings that all led to many international contacts.

#### Patent Applications, Open Source Software, and Contributions to Standards

No recent patent applications or contributions to standards. In the past five years, my group and myself made tools and source code available for the following published visualization approaches:

- FeatureEnVi, see https://leonard.lnu.se/git/ISOVIS/FeatureEnVi
- HardVis, see https://github.com/angeloschatzimparmpas/HardVis
- VisEvol, see https://leonard.lnu.se/git/ISOVIS/VisEvol
- t-viSNE, see https://leonard.lnu.se/git/ISOVIS/t-viSNE/
- Topics2Themes, see https://github.com/mariask2/topics2themes
- MVN-Reduce, see https://bitbucket.org/rmmartins/mvn-reduce/
- StanceXplore, see https://bitbucket.org/rmmartins/stancexplore/
- DoSVis, see https://sheldon.lnu.se/dosvis/

- PAL, see https://github.com/mariask2/PAL-A-tool-for-Pre-annotation-and-Active-Learning
- Several online interactive visual surveys, most of them are continiously maintained
  - Text Visualization Browser, see https://textvis.lnu.se/
  - SentimentVis Browser, see https://sentimentvis.lnu.se/
  - BioVis Explorer, see https://biovis.lnu.se/
  - TrustMLVis Browser, see https://trustmlvis.lnu.se/
  - VA+Embeddings Browser, see https://va-embeddings-browser.ivis.itn.liu.se/

More information on the respective tools and visualization approaches can be found when following the given URLs.

#### Exploitation and Cooperation with Industry and Institutes

Through under-/postgraduate thesis supervision/examination and my research projects, I regularly collaborate with companies, institutes, and the public sector. Here, I list the most recent ones:

- The WASP/DDLS-funded project *Visual Analytics for Enhancing Quality and Trust in Genome-wide Expression Clustering and Annotation* has been performed together with researchers from the Science for Life Laboratory (SciLifeLab), Stockholm.
- The project *Immersive Analytics for Urban Heat* has been granted funding from the Norrköping Fund and has been performed together with researchers from academia (LiU, LNU) as well as collaborators from SMHI and Norrköping Municipality.
- Together with the Institute for Language and Folklore we published a number of papers in the area of topic modelling and visualization.
- Through several student theses, we collaborated with Saab and iMatrics AB, among others.

#### Contributions to Undergraduate/Graduate Education

I always take care that newest research results have been used in my courses, being it as new knowledge/content in lectures or applied in the more practical labs. Of course, this new material is not restricted to my own scientific contributions but also covering results from the entire visualization and visual analytics research communities. Several of the textbooks that I co-edited or -authored have been used in courses at all levels not only in Sweden. For instance, the books *Human-Centered Visualization Environments* and *Multivariate Network Visualization*, published by Springer in 2007 and 2014, respectively, have widely been used in graduate courses over the past years. Our new book *Visual Analysis of Multilayer Networks* that I co-authored, published in 2021 by Morgan & Claypool, is more relevant for Ph.D.-level education. In 2021, I co-authored a chapter on visualization and image processing in the Swedish textbook *Medicinsk Informatik* which is the standard textbook in medical informatics education in Sweden. Occasionally, I have also published papers on my courses and didactic concepts in computer science education venues, such as the education paper track of the EuroGraphics conferences.

During my academic career, I have developed a large range of courses at all levels. Focusing on the past years, I would like to highlight the following educational contributions:

- In 2021, I developed the course *TNM048/TNM111 Information Visualization* (LiU/MIT) as course coordinator and examiner.
- In 2021, I developed single lectures on graph drawing and network visualization for the course *TNM098* Advanced Visual Data Analysis (LiU/MIT).
- In 2022, I developed single lectures on human visual perception for the course *TNM093 Practical Data Visualization and Virtual Reality* (LiU/MIT).
- In the past two years, I was external advisor (reference group member) for a new Master of Science program proposal at LiU called *Data-Driven Sustainable Development*.
- Since more than one year, I have been involved in the further development of the LiU/MIT study program *Master of Science in Media Technology and Engineering*.
- Our interactive online surveys (see Page 137) are worldwide used in master's level classes.

#### **Outreach Activities**

Spreading knowledge on visualization and visual data analysis outside the university is important for our entire research community as those efforts directly contribute to visualization literacy in other research areas but also the entire population. My work as LNU's node coordinator for the national infrastructure *InfraVis* (funded by VR) has greatly contributed to reach these goals. Moreover, I regularly give talks on perspectives and showcases of visualization for selected application/data domains. For instance in 2020, I gave a talk on the *Benefits and Perspectives of Information Visualization for the Humanities and Social Sciences* for the Danish Competency Development Program on Digital Literacy for Social Sciences and Humanities. In the recent years, my group members talked about their research in schools at events such as *ForskarFredag* and others. Besides minor activities on Twitter/X and LinkedIn to advertise our research and events we are involved in, some of our research presentations have been recorded and made available together with software demonstrations on several video channels:

- ISOVIS Vimeo channel on https://vimeo.com/channels/920169.
- iVis Vimeo channel on https://vimeo.com/channels/1710328.

#### Keynotes, Plenaries and Academic Service

In this section, I only list the most important plenary talks and academic services activities since I started as ELLIIT Recruited Faculty in 2021. For a complete list, I refer to my personal homepage (https://bit.ly/akerren-liu).

- Editorial Boards
  - Editorial Board Member of Computer Graphics Forum, Wiley, 2019-2022
  - Editorial Board Member of the new Book Series Language, Data Science and Digital Humanities, Bloomsbury Academic, since 2020
  - Editorial Board Member of the Information Visualization Journal, SAGE Publications, since 2012
- Organization
  - Program Committee Member of many conferences, such as IEEE VIS, EuroVis, Eurographics, VISSOFT, EuroVA, VDA, etc.
  - Most Influential Paper Award co-chair of the 11th IEEE Working Conference on Software Visualization, 2023
  - Member of the EuroVis Best Ph.D. Award Committee, 2022
  - Short paper co-chair of the 23rd EG/VGTC Conference on Visualization (EuroVis 2021), 2021
- Invited and Keynote Talks
  - Visualization Perspectives in Explainable and Trustworthy Machine Learning. PacificVis 2023 Visualization Meets AI Workshop (VisMeetsAI '23), 2023
  - BioVis Explorer: A Visual Guide for Biological Data Visualization Techniques. CNS Research Showcase, Indiana University Bloomington, 2022
  - Visualization Perspectives in Explainable AI. LNUC DISA Seminar, Linnaeus University, 2021
  - Visualization Perspectives in Explainable AI. 23rd International Conference on Control Systems and Computer Science, 2021
  - Visualization of Multidimensional Data: Possibilities, Pitfalls, and Practices. UEF Data-Driven Lunch Seminar, University of Eastern Finland, 2021
  - Showcases of Visualization Research for Data Analytics and Explainable AI. Annual ELLIIT Workshop, Linköping University, 2021

#### 7.2 Andrés Alayón Glazunov, Senior Associate Professor in Electrical Engineering

Andrés Alayón Glazunov is a senior associate professor of radio systems with the Department of Science and Technology, Linköping University (LiU), Norrköping Campus, Sweden, a guest associate professor at the Department of Electrical Engineering, University of Twente (UT), Enschede, the Netherlands and an affiliate associate professor with the Department of Electrical Engineering, Chalmers University of Technology, Gothenburg, Sweden. In addition, he is an ELLIIT senior associate professor supported by the Excellence Center at Linköping–Lund in Information Technology since April 2023.



Dr. Andrés Alayón Glazunov received his Ph.D. in Radio Systems from Lund University, Lund, Sweden, in 2009. Before 2006, he worked in the telecommunications industry in Sweden, starting in 1996 as a research engineer at Ericsson Research and later in 2001 as a senior specialist on antennas and propagations at Telia Research and TeliaSonera. After his Ph.D., he was on a temporary Marie Sklodowska - Curie fellowship at the University of Bedfordshire, UK, from 2009 to 2010. Then, he was a postdoc and, later, a research scientist at KTH, the Royal University of Technology, Sweden. From 2014 to 2018 he was a non-tenure track assistant professor at the Chalmers University of Technology, Sweden, where he received his docent degree qualification in antenna systems in 2017. Afterward, he held a tenured associate professor position

at the University of Twente, the Netherlands. At the end of 2022, he received and accepted the offer from Linköping University to join the Physics and Electronics (FE) group at the LiU, Norrköping Campus.

Dr. Alayón Glazunov has published over 170 peer-reviewed papers, articles, book chapters, and textbooks. His main research interests are designing and characterizing smart devices and environments for communications, sensing, and localization. More specifically, his research includes, but is not limited to, phased array antenna design, fundamental physical limitations of antennas in propagation channels, over-the-air (OTA) characterization of antenna systems and wireless devices, and the interactions between antennas and the radio propagation channel and related signal processing. His research has pioneered various OTA techniques applied to mobile and base stations as well as antennas on vehicles, where, among others, he has contributed to the first 3GPP standard on OTA testing and to the development of the random line-of-sight (Random-LOS) and the hybrid anechoic and reverberation chamber (HARC) OTA antenna characterization techniques. Also, he has pioneered work on the wireless performance of a building. His latest works together with doctoral students and collaborators are on proposing a figure of merit for the spatial weighting of radiated power of phased arrays [Ruiz et al., 2023] that was awarded the runner-up best student paper award, a fully metallic frequency selective surface (FSS) circular polarizer based on cost-effective chemical etching manufacturing technique [Yong et al., 2023], an overview of recent developments in gap-waveguide-based antennas and other components for mmWave and sub-THz applications [Yong et al., 2023] and miniaturization of a fully metallic bandpass frequency selective surface for mmWave applications [Yong Glazunov, 2023].

#### **Description of Research Group**

Dr. Alayón Glazunov is currently building his research group at the LiU. His research group at UT comprises six doctoral students working on various aspects of communications and sensing with applications to cellular, automotive, and satellite systems. The topics of research cover multiple aspects regarding the design of radomes to enhance the field-of-view and gain of radar systems at 77 GHz mounted on vehicles based on transformation optics theory and Luneburg lenses, among others; the design of compact, ultrawideband, wide scanning-angle, high gain, dual-polarized phased arrays for joint communications and sensing for automotive 77 GHz applications based on the gapwaveguide (GW) and the multi-layer waveguide (MLW) technologies and for satellite communications in the Ka-K band based on the combination of tightly coupled dipole array (TCDA) technique in combination with metamaterial substrate, the devising of OTA systems for radar and communications systems for 5G and beyond wireless systems for Random-LOS, rich multipath (RIMP) fading channels and a mixed thereof with focus on compact antenna test range (CATR) type plane wave generators,

#### Chapter 7. Recruited Faculty

reverberation chambers, anechoic chambers and HARCs, the optimization of irregular sparse antenna arrays for communications based on imperfect channel estimation, user fairness, interference footprints and other communication performance aspects, the wireless performance of buildings and the modelling of near- and far-field interactions between antennas and the propagation channel.

#### Plans for the Next Five Years

In the coming five years, I look forward to building, maintaining, and expanding my research group at LiU by acquiring several external research grants at the regional, national, and European levels. The targeted grant funding organizations are VINNOVA, VR, SSF, Horizon Europe MSCA, Eurekanetworks, and the ERC. I aim to initiate and consolidate my research group towards the research consortium within the ELLIIT environment. Research-wise, I aim to expand our activities in designing and characterizing intelligent devices and environments to focus on scenarios in 6G wireless systems covering satellite, automotive, and cellular systems, incorporating further communications, sensing, and localization applications. A special focus will be on extending it to the direct interaction between flying vehicles, on-the-ground vehicles, and the surrounding built environment. I'll look into incorporating machine learning and AI into the joint design and optimization of antennas and components for optimal multipurpose highly integrated antenna systems within intelligent confined environments, e.g., vehicles, buildings, and open environments, e.g., cities and rural areas. I will develop new over-the-air (OTA) characterization methods that efficiently test multipurpose devices.

#### **External Funding Attracted**

Project Name	Funding agency	Total Amount (kSEK)	Duration
Integrated Telematics for Next Generation 5G	H2020-MSCA-	9266	Oct. 2020 –
Vehicular Communications (5VC)	ITN-2020		Jan. 2025

The project was not acquired as part of ELLIIT, but I'm the main supervisor of 3 Ph.D. students while I have been a part of ELLIIT since April 2023.

#### Inter-University Cooperation within ELLIIT

Dr. Alayón Glazunov has contributed to several brainstorming meetings with the Halmstad University faculty members.

#### Inter-Disciplinary Cooperation

The nature of the research conducted by Dr. Alayón Glazunov is interdisciplinary.

#### International Collaboration

As a part of the 5VC consortium, collaboration is undergoing with the following universities: Universitat Politècnica de València (UPV), Spain, Technische Universitaet Ilmenau (TUI), Germany, Universitet Twente (UT), Netherlands, and industries: CasaSystems (CASA), Spain, Robert Bosch GMBCH (BOSCH), Volkswagen AG (VW), Germany, 5G Communications for Future Industry Verticals, S.L. (FIVECOMM), Spain, Daimler AG (DAIMLER), Germany, and Fraunhofer IIS (FRAUNHOFER).

#### Patent Applications, Open Source Software, and Contributions to Standards

Dr. Alayón Glazunov has previously contributed to the 3GPP and the ITU standards and is a holder of several national and international PA.

#### Exploitation and Cooperation with Industry and Institutes

The 5VC project is expected to contribute considerably to the Swedish industry in automotive radar systems and over-the-air (OTA) testing of wireless devices because research is done closely with Gapwaves AB, Bluetest AB, and Ranloss AB.

#### Contributions to Undergraduate/Graduate Education

Research results have been included in the training of early-stage researchers (ESRs), i.e., Ph.D. students working within the ITN-5VC consortium.

#### **Outreach Activities**

Minor activities on LinkedIn highlighting the success of 5VC and the individual achievements of my doctoral students.

#### Keynotes, Plenaries and Academic Service

This section lists my activities since my start in April 2023 or carried on continuously up to date.

- Editorial Boards
  - Editorial Board of IEEE Wireless Communications Letters.
  - Editorial Board of Frontiers in Communications and Networks and Frontiers in Antennas and Propagation.
- Organization
  - Chair of Session 4A2 on "Electromagnetic Interaction and Coupling" at AES2023, Torremolinos, Spain.
  - TCP member of the ISAP2023 conference in Kuala Lumpur, Malaysia.
  - Member of the Expert Board of Propagation WG of the European Association of Antennas and Propagation (EurAAP).
- Invited and Keynote Talks
  - Invited talk on "Intelligent Testing Environments for the Over-The-Air Characterization of Intelligent Wireless Devices" at the 9th International Conference on Antennas and Electromagnetic Systems Conference, AES2023, in Torremolinos, Spain.
  - Plenary talk on "Design and Characterization of Intelligent Devices and Environments for Wireless Communications" at the International Symposium on Antennas and Propagation Conference, ISAP2023 in Kuala Lumpur, Malaysia.

#### 7.3 Björn Landfeldt, Professor in Network Architecture and Services

Dr. Landfeldt is a professor at LU since 2012. Prior to that he was an associate professor at University of Sydney 2001-2012 and a research fellow at National ICT Australia. He was also a senior researcher at Ericsson Research (Stockholm) 2000-2001.



Dr. Landfeldt was awarded a Ph.D. in Telecommunications from the University of New South Wales (Australia) in 2000. He has served as editor, program- and general chair for many leading journals and conferences internationally and received the best paper award at ACM MobiWac 2008.

#### **Description of Research Group**

Our division does not have formal research groups anymore. From my previous research group my previous ELLIIT postdoc Emma Fitzgerald is now a lecturer and we continue our collaboration. Furthermore, I have two Ph.D. students, Antonio Franco and Ziyu Zhong.

#### Plans for the Next Five Years

I am now focusing on application offloading to edge cloud systems. Especially, I am targeting AR/VR applications as this class of application will greatly benefit from offloading but there are many unresolved issues before this can be made effectively. I will also study how mobility and variable wireless conditions impact the performance and propose new predictive methods for increasing the user experience. For example, offloading of VR applications could greatly benefit the form factor and battery life of VR headsets, but the offloaded application would have to be active in the edge cloud and placement would have to be predicted in order to keep latency low if the user has moved between sessions. Predictive user device input can be used as an alternative to predictive video coding in order to save on valuable edge resources, but it is not clear under what conditions this approach would be preferable as user experience can suffer. I plan to collaborate closely with the AR/VR lab at LTH to include user studies in the research to directly evaluate the effects and effectiveness of the proposed approaches.

#### **External Funding Attracted**

Project Name	Funding agency	TotalAmount(kSEK)	Duration
A5GARD	CELTIC-NEXT	50000 (8300 LU)	2020-2023
Н-ОРТО	CELTIC-NEXT	55000 (6000 LU)	2017-2020

#### Inter-University Cooperation within ELLIIT

I have a long collaboration with Prof. Nikolaos Pappas at LiU. We are currently working together with my Ph.D. student Antonio Franco to finish off his final work in modeling of Age of Information behaviour in networked systems. I have previously also worked with both Prof. Di Yuan and Prof. Vangelis Angelakis at LiU in the Marie Curie EU project MESH-WISE.

#### Inter-Disciplinary Cooperation

I am currently part of establishing a hub for AR/VR related research at Lund University. Apart from the close collaboration with the AR/VR lab at the interaction design department other members include the hematological stem cell research centre at the university hospital, the LunArc supercomputer centre at LU and the department

of Archeology and Ancient History. Our collaboration thus spans from application, via infrastructure to usability studies in a truly inter-disciplinary environment.

#### International Collaboration

Over the past few years I have worked together with researchers from Politécnico di Milano, University of Crete (MESH-WISE), West Pomeranian University, Adtran Gmbh, Nokia Belgium, British Telecom, Orange SA France and Max Linear Spain (H-OPTO and A5GARD). I am currently collaborating with Professor Mohsin Iftikhar from Charles Sturt University (Australia) on modeling of edge cluster load dynamics due to mobility for application offloading placement.

#### Patent Applications, Open Source Software, and Contributions to Standards

A highly customisable traffic generation tool for testing of wireless system behaviour was made public on GITHUB (https://github.com/smeets/jana)

#### Exploitation and Cooperation with Industry and Institutes

A notable exploitation took place in 2022 when I supervised two M.Sc. theses at Ericsson. The students developed an algorithm for efficient prediction of user mobility and location management in 5G networks. The work was patented by Ericsson and productified. One of the students was hired by Ericsson to contibue working with the productification. In the A5GARD project I worked closely with a Lund SME (Sensative AB) and the public health authority (Region Västerbotten). We implemented a testbed together at LTH in the 5G lab and created software for deploying smart services in old people's homes to enable the aging population to live at home longer. The smart services is now a new application area for Sensative and they are working with the region to roll out their services in municipalities in northern Sweden.

#### Contributions to Undergraduate/Graduate Education

I am the vice-chair of the teaching executive committee at LTH. As such I have a very central role in all policy making and all decisions taken regarding undergraduate and postgraduate education at LTH. We are responsible for all the teaching programs, the teaching budgets at the departments and ultimately the content of all the courses taught at LTH. We are also making desicions about new areas to cover with new programs or specialisations within existing programs and making sure that our teaching stays at the forefront of the respective fields.

#### **Outreach Activities**

I have given talks to high school students within the NMT scheme at LTH every year until 2022. These talks aim at attracting students into STEM education programs in Lund.

#### Keynotes, Plenaries and Academic Service

I have been the opponent or served in the grading committee of over 20 Ph.D. defences in the past 5 years. I have also been an external reviewer to Malmö University as they started up ME (Civilingenjör) programs in 2022. I was the general chair of IEEE CAMAD in 2017 and technical program committee member of ACM MSWIM 2017-2022.
# 7.4 Bo Bernhardsson, Professor in Automatic Control

Bo Bernhardsson received his Ph.D. in Automatic Control at Lund University in 1992. After a postdoc at IMA at Univ. of Minnesota, he returned to Lund where he received the degree of docent in 1998, and became professor in 1999. In 2000-2001 he was the Chairman of the Engineering Program Industrial Engineering and Management at LTH (during build up of the program), he was also Associate editor of IEEE Transactions of Automatic Control. During 2001-2010 he went on leave on absence, working at Ericsson with research, optimization of 2G manufacturing, debugging and optimization of the 3G WCDMA system and with the design of the 4G LTE system. He received the position of Expert in Mobile system Design and Optimization and was an inventor of 27 granted patents.



In 2010 he returned to Lund University and was a PI and board member of the Lund Center for Control of Complex Engineering Systems (LCCC). During 2015-2020 he was part of the WASP graduate school management team working with establishing its nationwide research school. He was the deputy head of the department of Automatic Control during 5 years, and since 2014 he is also a Member of the Royal Physiographic Society in Lund.

The most recognized of his research consists of early work on analysis and design of control systems involving communication networks with random time delays (1363 citations) and the work on event-based sampled control systems (1946 citations). He

has been the main supervisor for 10 Ph.D. students and cosupervisor for 16. His current research interests are in analysis of EEG signals, control of uncertain systems and radio-based positioning.

### **Description of Research Group**

My current research group consists of 3 Ph.D. students, working with the analysis of EEG signals and the design of brain-computer interfaces (BCIs), and a postdoc working on learning pharmacometric model structures from data. Together with Fredrik Tufvesson, I share supervision of 3 Ph.D. students: one at Automatic Control and two at EIT, working with machine learning techniques for the analysis of radio signals for positioning and activity recognition. Additionally, I am the co-supervisor of three Ph.D. students in Automatic Control and one in the Department of Mathematics.

# Plans for the Next Five Years

I will continue to work with BCI systems, radio communication systems, and uncertain control systems. However, a new research interest was initiated by the supervision of my Ph.D. student, Jacob Bergstedt. Jacob worked on modeling the human immune system in collaboration with Institut Pasteur in Paris. This led me into the challenges of modeling and analyzing biological data, particularly its application in precision medicine. It also established a close collaboration with co-supervisor Professor Magnus Fontes, who was then at Institut Pasteur and is now the general manager at Institut Roche in Paris.

In the next 5 years, I foresee an accelerated development of new machine learning techniques targeting biological data, especially in systems involving feedback mechanisms where causality needs to be modeled and understood. The close collaboration I have established with some researchers in the field will be invaluable, particularly for accessing data and research expertise. Major challenges arise from the fact that the data is multimodal and high-dimensional, and that only a limited number of controlled experiments can typically be performed on such systems.

In medical research, organoids are seen as a promising tool for understanding the human immune system due to their realism, control, and versatility. These miniaturized organ models offer a more controlled environment than in vivo studies, allowing for precise manipulation of variables. This is crucial for experiments designed to unravel the causality mechanisms within the immune system. Organoids enable the monitoring of the immune

response to different stimuli over time, generating time series data essential for understanding these mechanisms. This method holds great potential for advancing our knowledge of immune processes, disease progression, and the development of personalized therapies. This research connects naturally with modeling and control of uncertain feedback systems

### **External Funding Attracted**

Project Name	Funding agency	Total Amount	Duration
		(kSEK)	
Realtime Individualization of Brain Computer	KAW	2000	2020-2022
Interfaces (WASP)			
Optimizing the Next Generation Brain Com-	KAW	4000	2020
puter Interfaces using Cloud Computing			
(WASP)			
Learning Pharmacometric Model Structures	KAW	2000	2021-2024
from Data (WASP-DDLS)			
Joint Communication and Radar Sensing for	KAW	3200	2024-2028
Autonomous Systems (WASP)*			

In addition to the above listed projects I also have an industrial Ph.D. student financed directly by Ericsson (2021-2025) working on a project concerning realtime BCI systems.

### Inter-University Cooperation within ELLIIT

The ELLIIT project has played a pivotal role in enabling me to establish and sustain a close collaboration with researchers in Linköping. A prime example of the outcomes from this collaboration, particularly during the Covid pandemic, is the swift initiation of a joint research effort that led to a publication in Nature. This publication critically examined the epidemic models released by Imperial College in the UK and identified shortcomings in their analysis [Soltesz et al., "The Effect of Interventions on Covid-19," Nature, Dec 2020; 121 citations].". Many other examples also exist, concerning both research and education.

#### Inter-Disciplinary Cooperation

Much of my research work concern inter-disciplinary cooperation, and the ELLIIT project has been an important facilitator for such work. I would here like to mention the work with the control system (LLRF) for the European Spallation Source (ESS) involving interdisciplinary work with accelerator physics, control technology, and radio system design. The design challenges are similar as those I encountered working with the design of efficient radio systems for mobile communications, another area of inter-disciplinary cooperation that I have maintained active since I left Ericsson 13 years ago, through different research projects. My ELLIIT financing made it possible to (partly) support my Ph.D. student Jacob Bergstedt to work with modeling of the human immune system, which initiated my contacts with researchers in this field. Bergstedt's Ph.D. work resulted in the thesis "Statistical Modeling and Learning of the Environmental and Genetic Drivers of Variation in Human Immunity" with publications in highly renowned medical journals (Nature Immunology, Science Transl. Medicine). The cooperation established from this later led to the possilibity to arrange ELLIITs first focus period "Data-driven Modelling and Learning for Cancer Immunotherapy" in Lund, May 2022. I am now also part of the work group arranging DDLS-WASP collaboration, see https://www.scilifelab.se/data-driven/ddls-wasp-collaboration and I have received funding for a DDLS-WASP collaboration project in pharmacokinetic modeling. Also the research on BCI systems involve significant inter-disciplinary cooperation, exemplified by 10 M.Sc. thesis project during the last 5 years, supervised jointly by me and researchers at LiU and Eriksholm's Research Center.

### International Collaboration

I have a good international contact network in the fields of control and communication. I also have a good network in several application areas through my inter-disciplinary cooperation described above.

### Patent Applications, Open Source Software, and Contributions to Standards

The patent application WO2022128124A1 "Calibration of positions of EEG electrodes on a subject" was handed in Dec 2020. The US Patent 10,436,938, Control system for marine vibrators to reduce friction effects, was granted in Oct 2019.

### Exploitation and Cooperation with Industry and Institutes

During the last 5 years I have supervised 40 M.Sc. theses projects in collaboration with industry. An, incomplete, list of companies includes Axis, Carrier, Combine, Ericsson, Modelon, Iternio, Oticon/Eriksholm, Saab, Scania, Schneider, Sony, Oticon/Eriksholm. I also supervise two industrial Ph.D. students working at Ericsson. Both the M.Sc. and Ph.D. thesis projects are a good tool to facilitate a rapid transfer of research results and challenges in both directions. In 2019 I also held two commissioned education courses in Machine Learning for industry (together with Kalle Åström and administered by Lund University).

### Contributions to Undergraduate/Graduate Education

The following activities include contributions to education where recent research results have been incorporated into course syllabi:

- I have helped develop and teach (5 times) the Ph.D. course Autonomous Systems, given by the WASP Graduate School.
- I have helped to initiate, develop and lead the International Master Program in "Machine Learning, Systems and Control", which started in 2020. I share the responsibility as program leader with Prof. Mikael Nilsson.
- I have developed and am teaching the M.Sc. course "Modeling and Learning from Data". Starting as a course specially developed for the above mentioned master program, it is now offered to more engineering students at LTH, with over 100 students registering for the course each year.
- Especially targeting the participants of the ELLIIT 2022 focus period I developed and taught the 3-day course "Statistical Learning and Data Visualisation a data driven tour through the cancer immuno state space", see course modules (together with Magnus Fontes and Gerard Besson).

# **Outreach Activities**

During the Covid pandemic the above mentioned joint work on pandemic modeling was presented for the general public through newspaper articles (NyTeknik, DN debatt) and SR (Vetenskapsradion). The work was also awarded recognition by the Royal Swedish Academy of Engineering Sciences (IVA) by being on the "IVAs 100-lista 2021"). I also participated in production of an ELLIIT tech talk video, describing research on Navigation and Radio Channel Estimation (video in Swedish).

#### Keynotes, Plenaries and Academic Service

I helped organize the ELLIIT focus period in Lund, May 2022. I am regularly serving on the committe for Ph.D. dissertations, about 1-2 times per year. I was recently also external reviewer for an appointment as associate professor, and for appointment to the degree of docent, in the subject of Signal Processing at Uppsala University.

# 7.5 Daniel Jung, Associate Professor in Fault Diagnostics and Prognostics

Daniel Jung is Associate Professor at LiU at the Department of Electrical Engineering, Division of Vehicular Systems, since 2022 and prior to that he was an Assistant Professor since 2018. In 2017, Daniel was a Research Associate at the Center for Automotive Research, The Ohio State University, Columbus, Ohio. He received his Ph.D. at LiU in 2015. In 2013, during his Ph.D. studies he was a visiting scholar at Vanderbilt university, Nashville, Tennessee.



Daniel is an ELLIIT recruited faculty since 2022. His primary research focus is on fault diagnosis and prognostics of technical systems. His current research activities in fault diagnosis consider how to combine physical insights with machine learning to detect and identify abnormal system behavior when representative training data is limited. His latest work together with doctoral students and collaborators are on data-driven anomaly identification with limited training data [Jung et al., 2023], the impact of numerical solvers when training neural networks [Mohammadi et al., 2023], and security risk analysis of automotive applications using structural methods [Renganathan et al., 2023].

Daniel is also involved in research on electrification of transportation where is current research activities include planning of heavy-duty electric vehicles and optimization of charging infrastructure of public transportation. His latest work together with collaborators are on charging infrastructure for public transportation [Alfredsson et al., 2023] and analysis of tariffs and the impact on voltage stability in low-voltage grid with renewable energy and smart charging of electric vehicles [Jung et al., 2023].

# **Description of Research Group**

His research group is currently under construction and consists of two Ph.D. students. One student is working in data-driven fault diagnosis in collaboration with Scania AB and is planned to defend his Ph.D. in 2026. An industrial Ph.D. student is working with modeling and optimization for planning of electric trucks at Scania AB. He is working in a joint project together with an academic Ph.D. student at the Mathematical Department at LiU. The current research activities also includes Master's students in summer projects, project courses, and Master's thesis projects that have contributed to the development of fault diagnosis systems and algorithms for various applications.

# Plans for the Next Five Years

The plans to expand the research group is based on secured funding where the current focus is on expanding the research activities in data-driven fault diagnosis and method development for identification of abnormal behavior in technical systems when training data is limited. There are also activities and discussions with other research groups in other fields with the purpose of identifying new interesting research questions and interesting applications. Another goal is to attract international visitors and Ph.D. students to build up an inspiring research environment in fault diagnosis and prognostics research.

Project Name	Funding agency	r	Total Amount	Duration
			(KSEK)	
DELPHI Diagnos genom att nyttja fysikaliska	Vinnova/FFI		4755	2022 - 2024
insikter i neurala näverk				
Hybrid Methods For Fault Diagnosis and Prog-	Faculty fur	nd-	2700	2020 - 2025
nostics	ing/ZENITH			

# External Funding Attracted

### Inter-University Cooperation within ELLIIT

N/A

### Inter-Disciplinary Cooperation

There is ongoing collaborations with Elina Rönnberg at the Mathematical Department in a joint project together with Scania AB where two Ph.D. students are working. Daniel is also part of the management team in the new competence centre SEDDIT funded by Vinnova starting 2024. The cooperation in the project also include supervision and co-supervision of the two Ph.D. students.

Daniel has recently started discussions on joint investigations together with researchers at the Department of Biomedical Engineering, LiU, to evaluate methods previously developed for fault diagnosis of technical systems in system biology and medical applications.

### International Collaboration

Daniel has ongoing research collaboration with researchers at The Ohio State University related to mainly fault diagnosis and cybersecurity in automotive applications. This is a collaboration that has been going on since 2017 where Daniel is co-supervising a Ph.D. student.

### Patent Applications, Open Source Software, and Contributions to Standards

There are plans of publishing code related to ongoing research.

#### Exploitation and Cooperation with Industry and Institutes

Daniel's research activities have for a long time had strong connection with industry where research projects are in collaboration with industrial partners. Two ongoing projects are together with Scania AB, both in fault diagnosis and planning of electric trucks, and there are ongoing discussions on starting new research collaborations together with Volvo Cars, related to fault diagnosis. Daniel has also been involved in a research project on optimization of charging infrastructure for public transportation in collaboration with RISE and Östgötatrafiken that ended in 2023.

#### Contributions to Undergraduate/Graduate Education

Daniel is currently working on updating a course in fault diagnosis and supervision of technical systems at LiU where the plan is to including new content from recent and ongoing research.

# **Outreach Activities**

Daniel has been one of the main organizers of an information evening on Ph.D. studies for Master's students as a collaboration between the Divisions of Automatic Control and Vehicular Systems at LiU. The event has been organized two times and the purpose is to inspire more Swedish students to become Ph.D. candidates. The feedback from participants have been positive and the plan is to continue to organize this event in the future.

Daniel has also appeared in the LiU news ("Electrification of heavy transports requires new thinking") together with Elina Rönnberg presenting the joint research project "Condore" on electrification of heavy-duty vehicles in collaboration with Scania AB and Ragn-Sells which attracted attention from Swedish industry.

# Keynotes, Plenaries and Academic Service

To support the research field, Daniel is arranging a competition in fault diagnosis for the 12th IFAC (International Federation of Automatic Control) Symposium on Fault Detection, Supervision and Safety for Technical Processes (Safeprocess) 2024, link to competition details. Models and data are provided to help researchers develop and benchmark methods for data-driven fault diagnosis and address the challenges that industry is facing regarding incomplete data and identification of abnormal behavior.

# 7.6 Diana Moya Osorio, Associate Professor in Communication Systems

Diana Moya Osorio is currently Associate Professor at the Communication Systems Division, Department of Electrical Engineering, Linköping University, Sweden. Previously, she was Senior Research Fellow and Adjunct Professor at the Centre for Wireless Communications, University of Oulu, Finland.



She received her D.Sc. degree in electrical engineering with emphasis on telecommunications and telematics from the University of Campinas (UNICAMP), Campinas, Brazil, in 2015. From 2015 to 2022, she was an Assistant Professor with the Department of Electrical Engineering, Federal University of São Carlos, São Carlos, Brazil. She received the title of Docent in physical layer techniques for security from University of Oulu in 2021 and was awarded the competitive grant from Academy of Finland as postodoctoral fellow from 2020 to 2023. She is co-recipient of the Best Student Paper Award at 2021 Joint European Conference on Networks and Communications (EuCNC) & 6GSummit.

Diana Moya Osorio is an ELLIIT recruited faculty since October 2023. Her research is mainly focused on the modeling and analysis of wireless communication systems, signal processing for wireless communications, physical layer security solutions, and the design of resilient and trustworthy integrated sensing and communication (ISAC) systems in perceptive mobile networks. Recent works include security and privacy for 6G networks [Osorio, 2022], privacy assessment on the design of ISAC systems [da Silva, 2023], physical layer security in UAV-assisted networks [Cabezas, 2023], and exploitation of RIS for secrecy in mmWave MIMO networks [Egashira, 2022].

#### **Description of Research Group**

By the time of this report, I have been just one month with Linköping University, then I am starting to build my research group. Next year, it is planned to integrate a master and a Ph.D. student to work on privacy-preservation and resiliency of ISAC systems at the physical layer. The research group is expected to be extended with successful ongoing and future funding applications.

#### Plans for the Next Five Years

For the upcoming five years, it is planned to build and consolidate a research group focused on the design of trustworthy and resilient perceptive mobile networks, sensing-enabled security solutions, and the exploitation of dual-functional networks for applications beyond connectivity, for instance, in defense scenarios. It is also intended to look for cooperation with Industry from mobile networks and defense in Sweden, as well as collaborations within ELLIIT.

#### **External Funding Attracted**

Project Name	Funding agency	Total Amount	Duration
		(kSEK)	
FAITH: SaFeguarding mAchine-type commu-	AoF	~2960	2020-2024
nIcation neTworks at the pHysical layer (PI) *			
MUSE-COM <sup>2</sup> : AI-enabled MUltimodal SE-	AoF (CHIST-ERA)	~5700	2023-2026
mantic COMmunications and COMputing			
(PI)*			
Local 6G Connectivity: Controlled, Resilient,	NSF-AoF	$\sim 5700$	2024–2027
and Secure (6G-ConCoRSe) (Co-PI) *			

\*Note: With the termination of my position at University of Oulu, the grant from project FAITH was terminated and roles of PI and Co-PI of projects required to be transferred to other researchers at University of Oulu.

#### Inter-University Cooperation within ELLIIT

N/A

### Inter-Disciplinary Cooperation

I act as working group leader of Working Group 1 in "Trustworthy 6G" of the Cost Action 6G-PHYSEC, 2023-2027. Therein, I am coordinating the activities related to define trustworthiness of the 6G system. The group members include researchers working in different aspects of security from academic institutions in Europe and partners from Industry, such as Ericsson and Bosch.

#### International Collaboration

During the last five years, I have collaborate with several researchers within Europe, Brazil, and Ecuador. I maintain collaborations in topics related to Security for 6G with researchers at VTT Technical Research Centre, Finland; Zurich University of Applied Sciences (ZHAW), Switzerland; University College Dublin, Ireland. In security for hybrid RF/VLC systems with the Centre for Wireless Communications, University of Oulu, Finland. Modeling and evaluation of wireless systems with the State University of São Paulo, Brazil; the National Polytechnic School, Ecuador; and the University of "Las Americas", Ecuador. I have also collaborated and visited the 6Gmobile lab at the Czech Technical University in Prague, and I am planning to visit University of Málaga next spring. I have collaborated with several other researchers in Europe in the context of Cost Actions and organization of workshops.

# Patent Applications, Open Source Software, and Contributions to Standards

N/A

#### Exploitation and Cooperation with Industry and Institutes

I will be the examiner of a master thesis in collaboration with Ericsson next spring. Eventual collaborations for organization of workshops and Cost Action's activities have also been carried out.

#### Contributions to Undergraduate/Graduate Education

I developed and offered, together with other teacher, the course for graduate level (masters and Ph.D. students) "Intelligent Security", in Spring 2023, at the Faculty of Information Technology and Electrical Engineering,

University of Oulu, Finland. I was responsible for the preparation, lectures, and assessment of half of the course, which was focused on Physical Layer Security. The course was also offered at the Finnish Institute of Technology (FITech). Next year, I will be responsible to develop and teach the master-level course TSKS35, "Information and communications engineering", in Fall 2024.

# **Outreach Activities**

I usually participate as speaker at public events organized in form of webinars by main universities in Ecuador for disseminating the development of future wireless technologies and increasing the attractiveness of the field to students.

# Keynotes, Plenaries and Academic Service

- Associate Editor of IEEE Transactions on Information Forensics and Security, 2023–2027.
- Associate Editor of IEEE Wireless Communications Letters, 2023-2027.
- Working group leader at Cost Action 6G-PHYSEC, 2023–2027.
- Member of the IEEE Focus Group in Physical Layer Security.
- Technical program committee for IEEE ICC'24 SAC-13 ISAC Track (2024 IEEE International Conference on Communications (ICC): SAC Integrated Sensing and Communication Track).
- Technical program committee for WS19 IEEE ICC 2024 Second Workshop on Enabling Security, Trust, and Privacy in 6G Wireless Systems.
- Technical program committee for Globecom 2024 First Workshop on Enabling Security, Trust, and Privacy in 6G Wireless Systems.
- Organizer of the workshop "Key Technology Enablers for 6G: AI and Intelligent Metasurfaces" at MeditCom 2023.
- Invited speaker at the IEEE ITS Chapter, Bangalore Section, India, for the webinar "Physical layer security in 6G", 2023.
- Invited speaker to the Workshop on "E-health Security for Future 6G", IEEE ICC 2022.
- Publicity chair at the 2nd Workshop on "Network management for 6G communication systems (NET-MAN6G)", Globecom'21.
- Organizer of special session "UAV for Future Wireless Networks", ISWCS'19.

# 7.7 Farnaz Adib Yaghmaie, Assistant Professor in Automatic Control with focus on Reinforcement Learning

Farnaz Adib Yaghmaie is an Assistant professor in automatic control, Department of Electrical Engineering, Linköping University, Sweden.



She received her Ph.D. in Electronic and Electrical Engineering (EEE) from Nanyang Technological University (NTU) in Singapore in 2017. During 2015 and 2016, she was a visiting Ph.D. student at Centrale Supelec (now Universite Paris-Saclay). She joined Linköping University as a postdoctoral researcher in 2018. She is the recipient of the best thesis award from EEE-NTU among 160 Ph.D. students.

Farnaz Adib Yaghmaie is an ELLIIT recruited faculty since 2022 but has been on parental leave from May 2022-June 2023. She is also a teacher of WASP. Her primary research focus currently revolves around the investigation of theoretical aspects related to learning algorithms in control problems. Recent works in this area includes quanti-

fying the effect of noise [Adib Yaghmaie, 2022], designing safe reinforcement learning algorithms [Modares, 2023], controller design in presence of adversarial disturbances [Adib Yaghmaie, 2023], [Niknejad, 2023].

### **Description of Research Group**

At present, my research group comprises a single Ph.D. student who is scheduled to commence her studies in December 2023. The potential for additional Ph.D. student positions depends on the successful securing of funding. I maintain an active involvement in the research process, spanning from theoretical advancements to practical coding.

The research of my group is predominantly concentrated on two key domains. The first area focuses on the exploration of reinforcement learning within partially observable dynamical systems characterized by continuous state and action spaces, with the primary responsibility for this research direction resting with the incoming Ph.D. student. The second area of emphasis centers around the investigation of control in presence of adversarial disturbances and the development of robust learning algorithms. I personally spearhead this research direction.

### Plans for the Next Five Years

In the upcoming five years, I plan to expand my research group by receiving funding and hiring Ph.D. students and postdoc researchers. Currently, an ERC starting grant application has been submitted and two more research proposals for WASP and VR will be submitted. These proposals will center around the quantification of learning algorithm performance based on the system's specific characteristics, with the ultimate goal of enhancing performance as a result.

# **External Funding Attracted**

Project Name	Funding agency	Total Amount	Duration
		(kSEK)	
Reinforcement Learning for partially observ-	ZENIITH, Linköping	450 kSEK/year	2021-2026
able dynamical systems with continuous state	University		
and action spaces			

# Inter-University Cooperation within ELLIIT

I prepared a proposal for ELLIIT call D in collaboration with Pontus Giselsson at Lund university. The proposal did not get funded.

#### Inter-Disciplinary Cooperation

Together with Fredrik Heintz at IDA, Linköping University, and Johannes Andreas Stork, Örebro University, we developed a Ph.D. level course on Reinforcement learning for the WASP graduate school. The course was taught as a part of the WASP Ph.D. graduate program in the fall of 2022, with 31 Ph.D. students enrolled. This course was developed from scratch. I served as one of the three lecturers and was responsible for creating half of the course materials, including exercises and lectures. Additionally, I designed computer-based exercise sessions and a Python lab session for the course.

#### International Collaboration

I regularly initiate collaboration with other scientists inside and outside Sweden. During the last five years, I have collaborated with many researchers outside Sweden (Prof. Frank L Lewis at University of Texas at Arlington, USA, Prof. Michael Šebek, Czech Technical University, Czech Republic, Kristian Hengster- Movric, Czech Technical University, Czech Republic, USA) but focusing on the period affiliated with ELLIIT since 2022 and considering I was on parental leave for a year, I collaborated with Prof. Hamidreza Modares at Michigan State University, USA and I am currently collaborating on a research topic with Prof. Francesco Bullo, at University of California, Santa Barbara, USA.

### Patent Applications, Open Source Software, and Contributions to Standards

To make the research results in [Adib Yaghmaie, 2023] publicly available and reproducible, I have shared the source code in a public https://github.com/FarnazAdib/online\_tracking\_with\_adversarial\_disturbances.

#### Exploitation and Cooperation with Industry and Institutes

I acted as the examiner for the master thesis entitled "Labyrinth navigation using reinforcement learning with a high fidelity simulation environment", Combine, and the supervisor for the master thesis entitled "An Adaptive Strategy For Short Term Stock Trading Using Reinforcement Learning", Celerus Capital AB, in 2022. Together with Fredrik Heintz, at IDA, Linköping University and Johannes Andreas Stork, at Örebro University, we developed a Ph.D. level course on Reinforcement learning for WASP graduate school.

#### Contributions to Undergraduate/Graduate Education

Together with Fredrik Heintz at IDA, Linköping University, and Johannes Andreas Stork, at Örebro University, we developed a Ph.D. level course on Reinforcement learning for the WASP graduate school. This course was developed from scratch by us. This course contains new advancement in reinforcement learning and I have shared a part of my research results in [Adib Yaghmaie, 2022].

### **Outreach Activities**

In the pursuit of advancing research and knowledge in the field of reinforcement learning, I have taken the initiative to contribute to the research community by publicly sharing GitHub repositories.

- **Crash course in RL:** This repository serves as a valuable resource for researchers, practitioners, and enthusiasts interested in reinforcement learning with application in control, providing a curated collection of code implementations, tutorials, and educational materials. See https://github.com/FarnazAdib/Crash\_course\_on\_RL
- **Control theory blog:** To enhance general audience' understanding of control theory through practical applications, I am working on a repository summarizing important control concepts as blog posts along with on-fly coding.

See https://github.com/FarnazAdib/Control\_threory\_blog.

#### Keynotes, Plenaries and Academic Service

N/A

### 7.8 Fredrik Lindsten, Senior Associate Professor in Machine Learning

Fredrik Lindsten is Associate Professor of Machine Learning and Head of the Division of Statistics and Machine Learning, Department of Computer and Information Science, Linköping University, Sweden.



He received his M.Sc. degree in Applied Physics and Electrical Engineering in 2008 and a Ph.D. in Automatic Control in 2013, both from Linköping University. He was awarded the degree of Docent in Signal Processing from Uppsala University in 2018. In 2014 and 2015 he was a Postdoctoral Research Associate at the Department of Engineering, the University of Cambridge, UK. During spring 2012 he was a Visiting Student Researcher at the Statistical Artificial Intelligence Lab at the University of California, Berkeley, USA and during spring 2015 he was a Visiting Scholar at the Department of Statistics, the University of Oxford, UK.

He has received the Ingvar Carlsson Award by the Swedish Foundation for Strategic Research, and the Benzelius Award by the Royal Society of Sciences in Uppsala. He is a Faculty of WASP and an ELLIIT Recruited Faculty since 2020. His main research interests are in statistical machine learning and computational statistics. Recent work in this area includes linking Generative Flow Networks with Variational Inference [Zimmermann, 2023], calibration analysis for reliable uncertainty quantification (spotlight presentation at UAI; [Glaser, 2023], self-supervised representation learning for computer vision (notable paper at ICLR; [Govindarajan, 2023], combining Probabilistic Graphical Models with Graph Neural Networks [Oskarsson, 2022], and better understanding the effect of label noise on the training of classifiers [Olmin, 2022], to mention a few examples.

#### **Description of Research Group**

My research group currently consists of six Ph.D. students and three postdocs. The group is highly collaborative and most students/postdocs are involved in both internal and external collaborations. Our research topics span a wide range of applications and methods related to statistical machine learning. Most activities can, however, be categorized as dealing with either *uncertainty quantification* or *graph-based machine learning*, and often both. The former includes calibration analysis for probabilistic predictive models, probabilistic deep learning, approximate Bayesian inference, and probabilistic representation learning. The latter includes research on probabilistic graphical models and graph neural networks, with applications in materials science, weather forecasting, and biochemistry.

#### Plans for the Next Five Years

In the coming five years I plan to expand our research activities related to two application domains: machine learning for materials science, and machine learning for weather prediction and climate science. Despite the apparent differences between these areas, there is overlap in the underlying methodology related to graph-based machine learning, which gives rise to interesting possibilities for synergetic effects. In the area of materials science, a central goal is to develop efficient properties-to-structure generative models, i.e., models that can take a set of desired properties as input and produce structural and chemical information for plausible materials that possess these properties. In the area of machine learning for weather and climate, an important direction for future research is to build reliable uncertainty quantification into existing machine-learning-based predictive systems. This is of particular importance when using the models for predicting the risk of extreme weather or other rare events. In addition to ramping up our research activities in these two application areas, I foresee increased research related to unsupervised representation learning, specifically learning from uncurated data as well as going beyond the data modalities that are currently dominating this type of methods (text, images, audio).

Project Name	Funding agency	Total Amount	Duration
		(kSEK)	
Handling Uncertainty in Machine Learning	VR	4000	2021-2024
AI Powered Carbon Border Adjustments	Vinnova	$\sim 6800$	2021-2024
Probabilistic models and deep learning - bridg-	WASP Collabora-	$\sim 11000$	2019-2023
ing the gap	tion Project		
Attentive and Disentangled Representation	WASP Industrial	$\sim$ 1200 (aca-	2020-2025
Learning	Ph.D. project	demic part)	
Novel AI methods for experimentally con-	WASP-DDLS Post-	2500	2022-2024
strained protein structure prediction	doc Twinning		
Multidimensional Alignment and Integration	WASP NEST	20000	2022-2027
of the Physical and Virtual Worlds			

#### **External Funding Attracted**

#### Inter-University Cooperation within ELLIIT

I am currently involved in the organization of an ELLIIT Focus Period on *Machine Learning for Climate Science*, a joint effort by the partner Universities in Linköping and Lund. In addition to myself, the organizing committee consists of Prof Michael Felsberg (Linköping University), Prof Natascha Kljun (Lund University), and Assoc Prof Johan Lindström (Lund University). The focus period will take place in Linköping during fall 2024.

#### Inter-Disciplinary Cooperation

I am involved in several inter-disciplinary collaborations, focused on solving various applied problems using machine learning. I am collaborating with Tomas Landelius at the Swedish Meteorological and Hydrological Institute (SMHI) on using machine learning for weather forecasting. Together with Assoc Prof Rickard Armiento and Prof Johanna Rosén (both at Linköping University, Department of Physics, Chemistry and Biology) I work on two separate projects related to machine learning for materials science. I am also collaborating with Prof Sebastian Westenhoff at Uppsala University, Department of Chemistry on a project related to machine learning for biochemistry. I am currently hosting a visiting postdoc, Melisa Maidana Capitan (Department of Biomedical and Clinical Sciences, Linköping University), who is exploring possible way of using machine learning for problems in neuroscience. Finally, the Vinnova-funded project AI Powered Carbon Border Adjustments is truly interdisciplinary. It focuses on the development of an AI tool that can assist in carbon footprint calculations, for the purpose of enabling carbon border adjustment mechanisms. In addition to computer science researchers from my group, it involves project partners specializing on carbon footprint calculations (2050 Consulting), climate policies and political processes (Department of Thematic Studies, Linköping University) and industrial partners (Toyota Material Handling, Alfa Laval).

#### International Collaboration

I regularly interact and collaborate with researchers from other countries and universities. During the past five years I have co-authored papers with some 20 researchers outside of Sweden. To mention a few: David Blei (Columbia University), Jan-Willem van de Meent (University of Amsterdam), Arnaud Doucet (Oxford University and Google DeepMind), Arthur Gretton (University College London, UCL), Matti Vihola (University of Jyväskylä), James Hensman (Microsoft Research), and Lawrence Murray (Uber AI). In 2022 my former Ph.D. student David Widmann visited Prof Arthur Gretton at UCL for a couple of months, resulting in a joint publication (spotlight at UAI). In 2023, we are planning for an extended visit by my Ph.D. student Joel Oskarsson to Prof Marc Deisenroth, also at UCL. I have also hosted a Ph.D. student from the University of Amsterdam (Heiko Zimmermann, 2022) resulting in a joint publication, and an M.Sc. student from ENSAE Paris (Candice Baud, 2023).

# Patent Applications, Open Source Software, and Contributions to Standards

My former Ph.D. student David Widmann has developed a multi-language software package for evaluating the reliability (also known as *calibration*) of general probabilistic predictive models. The software is largely based on our research contributions in this area. The package is available at: https://github.com/devmotion/CalibrationAnalysis.jl

### Exploitation and Cooperation with Industry and Institutes

Through my research projects I collaborate with several companies and institutes:

- WASP Industrial Ph.D. student project with Qualcomm Technologies (Hariprasath Govindarajan)
- Per Sidén at Qualcomm Technologies is co-supervising one of my academic Ph.D. students (Joel Oskarsson)
- Trafikverket, Qualcomm Technologies and IKEA are industrial project partners in our WASP NEST project, Multidimensional Alignment and Integration of the Physical and Virtual Worlds.
- The Vinnova-funded project AI Powered Carbon Border Adjustments is led by 2050 Consulting, and additional industrial project partners are Toyota Material Handling and Alfa Laval.
- Informal collaboration with SMHI related to graph neural networks for numerical weather prediction.

# Contributions to Undergraduate/Graduate Education

I am one of the authors of the introductory text book *Machine Learning - A First Course for Engineers and Scientists* published by Cambridge University Press in 2022. The book is currently used as course literature for several B.Sc. and M.Sc. courses at Linköping University, Lund University, Upppsala University, Chalmers University of Technology, Stockholm University, and Newcastle University, Australia. During my academic career I have developed a range of courses at both B.Sc., M.Sc. and Ph.D. level. The courses developed in the last five years are:

- In 2019 I was responsible for modernising the time series course at the M.Sc. program in Statistics and Machine Learning at Linköping University, resulting in the new course *Time Series and Sequence Learning* which blends classical time series models with modern machine learning approaches.
- In 2019 I was responsible for developing a module on *Approximate Bayesian Inferencen* in the WASP Ph.D. course *Graphical Models, Bayesian Learning and Relational Statistical Learning*.
- In 2022 we developed a MOOC-like course on the Foundations of Machine Learning.
- I am currently leading the development of an M.Sc. level course on *Deep Learning*.

# **Outreach Activities**

I am responsible for the Linköping University adaptation of the course *Elements of AI: Part 2, Building AI*. The course targets a general audience with no background knowledge about the subject, with the purpose of educating the general public about the basics of AI and how it will influence our society.

# Keynotes, Plenaries and Academic Service

- Senior Associate Editor for ACM Transactions on Probabilistic Machine Learning (TOPML) since 2023
- Program Chair for ELLIIT Annual Workshop, 2022
- Area Chair for AISTATS 2023 & 2024
- Guest editor for special session on Sequential Monte Carlo Methods in Foundations of Data Science
- Keynote at the Workshop on Nonlinear System Identification Benchmarks, Eindhoven, The Netherlands, 2019

# 7.9 Henry Edison, Senior Lecturer in Software Engineering

Henry Edison is an ELLIIT-recruited faculty at Blekinge Institute of Technology (BTH). He joined as an associate senior lecturer in 2022 and was promoted to Senior Lecturer (Universitetslektor) in software engineering at the same university in 2023.



He received a Ph.D in computer science from Free University of Bozen-Bolzano (UNIBZ), Italy, in 2017 and an M.Sc in software engineering from BTH in 2010. Before joining BTH, he was an assistant professor of software engineering at Southern Denmark University (SDU), Denmark (2021–2022) and a Marie Curie Fellow within Lero – the Science Foundation Ireland Research Centre for Software at University of Galway, Ireland (2017–2021).

His main research interests include empirical software engineering, software innovation, lean, agility, and data-driven software engineering and analytics. In particular, my research investigates the use of contemporary development methods, i.e. agile/lean

and tools and technology, i.e. data analytics and artificial intelligence, to leverage the success of software product innovation in various contexts, such as small and emerging new startups and established and large organisations. He has published in leading journals and conferences in his field, including IEEE Transactions on Software Engineering, Journal of Systems and Software, Information and Software Technology, etc. His recent work in these areas includes internal startups [Tkalich, 2022], the use of NLP to improve agile estimation [Duszkiewicz, 2022], comparing methods for large-scale agile development [Edison, 2022], games for Scrum team collaboration [Hidayati, 2022]. temporality aspects of SLR [Wang, 2023].

# **Description of Research Group**

My research group consists of one Ph.D. student and me. The Ph.D. student recently joined and started his research in November 2023. The current research topics primarily focus on using recent AI technologies to support experimentation processes in new and emerging organisations.

# Plans for the Next Five Years

Within the next five years, I plan to continue expanding research in the following areas: (i)managing uncertainties in complex, dynamic, and unstructured environments and (ii) contemporary methods for large-scale development. In more detail, for direction (i), I will develop a data analytics strategy and control portfolio that could improve new software product development in complex, dynamic, and unstructured environments such as startups. In addition, I plan to expand my work by investigating the use of recent artificial intelligence (AI) to improve the experimentation process in a similar context. In turn, I expect improved development processes for radical software product innovation. In Nov 2023, a new Ph.D. student recently joined and started his research in this area. For direction (ii), I plan to examine how data analytics can help address more significant complexities and interdependencies of large-scale, organisation-wide development and how to organise and analyse activities and software produced in a way that manages all of the individual rhythms, processes and timing of a disparate set of developers and teams. This includes further investigating the various sources of process diversity, for example, by considering different levels of applications, e.g., individual, team, project, and portfolio levels, or how the process used by software teams evolves and changes over time.

### **External Funding Attracted**

Project Name	Funding agency	Total Amount	Duration
		(kSEK)	
'Let it Flow': Releasing Innovation in	Marie Skłodowska-Curie CO-	800	2018-2021
Software Development Flow	FUND Fellowship Programme		

### Inter-University Cooperation within ELLIIT

Since 2023, I have established my collaboration with Elizabeth Bjarnason (Lund University) on continuous experimentation in the context of small and emerging startups (see project A7). One publication was presented at the 14th International Conference on Software Business (ICSOB), 2023 [Edison, 2023]. We plan to continue working in the area in the near future.

### Inter-Disciplinary Cooperation

N/A

#### International Collaboration

I continue collaborating with researchers from various countries. The main ongoing collaborations are summarised in the following:

- Dr. Anita Hidayati, Jakarta State Polytechnic, Indonesia. In 2022, we applied for and received funding (SEK 30.000) for our research project "Serious Game for Collaboration of Software Engineering in Global Software Development Environment." The project was funded by the Ministry of Education, Culture, Research, and Technology, Republic of Indonesia. Some joint publications between the groups last year are part of the collaboration.
- Dr. Nurbojatmiko, Syarif Hidayatullah Islamic State University, Indonesia. In 2022, we applied for and received funding (SEK 70.000) for our research project, "The NFR and FR Integration Modelling Based on ISO/IEC 25023 using OWL 2 DL Ontology." The project was funded by the Ministry of Education, Culture, Research, and Technology, Republic of Indonesia.
- Dr. Xiaofeng Wang, an associate professor at Free University of Bozen-Bolzano, Italy. We have ongoing collaboration on using recent AI technologies, such as LLM or prompt engineering, to support software innovation and the temporality aspect of systematic literature review.

# Patent Applications, Open Source Software, and Contributions to Standards

N/A

# Exploitation and Cooperation with Industry and Institutes

In 2022, I collaborated with Morningtrain Aps, a software company in Odense, Denmark, on agile effort estimation. This work has led to two conference publications with co-authors from the industry - one paper will be presented in PROFES 2023 in Dornbirn, Austria. In 2023, I supervised one master's thesis at BTH in collaboration with industry. The thesis evaluates the use of low-code / no-code development methods to improve public services in the municipality. I have also initiated cooperation with four video game companies based in Karlshamn on experimentation in video game development.

# Contributions to Undergraduate/Graduate Education

N/A

### **Outreach Activities**

N/A

#### Keynotes, Plenaries and Academic Service

- Member of Research Grant Proposal Review Panel, National Research and Innovation Agency, Republic of Indonesia, since 2022
- Member of Research Grant Proposal Review Panel, SyMeCo a Marie Skłodowska-Curie Fellowship programme at Lero the Science Foundation Ireland Research Centre for Software, Ireland, 2023
- Poster Chair, 13th International Conference on Software Business, in Bolzano, Italy, 2022
- Keynote speaker at the 9th International Workshop of Large-Scale Agile Development, XP 2021. Title: "Exploring Method Jungle of Large-Scale Agile Development"
- PC Member:
  - International Conference on Software Business (ICSOB), since 2021
  - International Workshop on Software Intensive Business (IWSIB) since 2021
  - International Conference on Agile Software Development (XP), 2021 & 2023
  - International Symposium on Open Collaboration (OpenSym), 2019–2021
  - European Conference on Information Systems (ECIS), 2019 & 2021
  - 2nd International Workshop on Agile Transformation, Copenhagen, Denmark, 2020
  - International Conference on Advanced Computer Science and Information Systems, Indonesia, 2018–2021

# 7.10 Ingrid Hotz, Professor in Scientific Visualization

Ingrid Hotz is a professor in Scientific Visualization heading the respective group in the Division of Media and Information Technology (MIT) at the Department of Science and Technology, Linköping University, Sweden.



Ingrid Hotz received her M.S. degree in theoretical Physics from the Ludwig Maximilian University in Munich Germany and her Ph.D. degree from the Computer Science Department at the University of Kaiserslautern, Germany. During 2003–2006 she worked as a postdoctoral researcher at the Institute for Data Analysis and Visualization (IDAV) at the University of California. From 2006–2013 she was the leader of a research group at the Zuse Institute in Berlin Germany. From 2013-2015 she was the head of the scientific visualization group at the German Aerospace Center (DLR). Currently, she works as a Professor in Scientific Visualization at Linköping University in Sweden. She is an ELLIIT Recruited Faculty since 2015. Ingrid Hotz was awarded the Dr. Ram Kumar IISc Distinguished Visiting Chair Professor position at the Indian

Institute of Science for two years (August 2022-2024) (two-month stay per year).

Her research interests lie in the area of scientific visualization, with a focus on developing efficient, reliable, and scalable visual analysis environments tailored to large, complex data for exploratory data analysis and science communication. Applications range from basic research questions to effective solutions to visualization problems in scientific applications including flow analysis, engineering, physics, chemistry, and medicine. Her research builds on ideas and methods originating from different areas of computer sciences and mathematics, such as computer graphics, computer vision, dynamical systems, computational geometry, and combinatorial topology. Recent work includes topological data analysis for comparison of ensemble data and time series [Yan

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2022]. with applications e.g. in the hierarchical exploration of the evolution of cyclones [Nilsson 2022] or patient-specific brain activity Analysis in fMRI data. Data summarization and abstraction for the exploration of data ensembles of electronic density fields with applications in chemistry [Thygesen 2022] and physics [Thygesen 2023]. Multi-scale cycle characterization of spatially embedded graphs with application in granular materials [Rasheed 2023]. Interactive exploration of heterogeneous data from medicine and molecular dynamics simulations [Skånberg 2021].

#### **Description of Research Group**

The research group currently consists of six Ph.D. students, two postdocs, one principal research engineer, and two assistant professors. The group is highly interdisciplinary and collaborative, most students/postdocs are involved in some collaborations with other research groups. The current research topics are primarily focusing on topological data analysis, interactive volume rendering, data exploration, and in situ visualization, in diverse applications including climate research, molecular dynamics, electronic structures, mechanical engineering, medicine, and digital pathology. Besides research providing infrastructure and software development that ensures continuity in the research projects plays an important role in the group. These activities are mainly Inviwo an extensible, multi-purpose visualization framework, and VIA-MD, a software for the analysis of molecular dynamics simulation data, for more details see software contributions.

#### Plans for the Next Five Years

Overall, our focus will remain on developing methods for visual data analysis contributing to a better understanding of the data. Special emphasis is on combining automatic and explorative methods with the human in the loop. Our approach is to exploit methods from topological data analysis (TDA) which provide powerful concepts for hierarchical feature descriptors. Specifically, the development of reliable methods and algorithms able to deal with increasing data complexity will be in the foreground in the next years. In detail, this refers to (i) Efficient algorithms making optimal use of available resources such as storage space and computational time. We approach this problem by exploring the use of sparse representations for visualization purposes. (ii) Visualization concepts scalable with data complexity. It is often not enough to develop methods for individual data sets. Real-world applications typically examine many datasets simultaneously, e.g., when exploring large parameter spaces or the correlation of a large number of variables. Such settings require a well-thought-out design of exploratory methods. (iii) Integration of automatic and explorative analysis providing reliable and understandable analytics. As apparent from (i) and (ii), merging automatic analysis techniques with visual exploration is essential. Often the starting point will be the generation of compact data representation to be understandable by the human as well as by the machine. This keeps the analysis process transparent and allows the user to reject or modify automatic decisions in an exploratory environment. (v) Solid tools and software developments to ensure sustainable research will remain a focus of the group. From an application point of view, we plan to further extend the ongoing collaboration in the area of computational materials design (ranging from theoretical physics over chemistry to mechanical engineering), climate modeling, and bio-medical applications with focus on the visualization of 3d imaging data.

#### **External Funding Attracted**

Project Name	Funding agency	Amount per	Duration
		year (kSEK)	
Visual Data Analytics in e-Science Applications	Swedish e-Science re-	3 700	2015-2024
	search center (SeRC)		ongoing
Topological descriptors for tracking, comparison and	VR grant 2019-05487	850	2020-2024
visual exploration of complex scientific data			
Indo-Swedish joint network grant: Robust topologi-	VR grant 2018-07085	Total of 700	2020-2022
cal methods for analysis of dynamic large-scale data			Extended
for modern material design			until 2024
A topology-based approach to patterns in dynamic	WASP, academic phd	1 000	2021-2024
network data for decision support			
HUDI: Huge Complex Diagnostic Imaging Data: To-	WASP-DDLS	1 000	2023-2024
wards personalized models in the clinical workflow			
In-Situ Big Data Analysis for Flow and Climate Sim-	SSF BD15-0082	900	2017-2021
ulations			

#### Inter-University Cooperation within ELLIIT

Within ELLIIT there is an ongoing cooperation with Michael Doggett and Bo Bernhardsson from Lund University in relation to the ELLIIT project "Visual Feature Based Data Reduction – sparse representations for brain imaging data". Other short-term cooperations originate from the ELLIIT Visualization Infrastructure Support Access to Visualization Infrastructure, Software, and Competence. An example is the cooperation with the group of Gunnar Cedersund (Linköping University), in his digital twin project.

#### Inter-Disciplinary Cooperation

Visualization in nature is an interdisciplinary subject and thus most of our projects are either directly interdisciplinary or at least motivated by needs from other disciplines. The Swedish e-science Research Center (SeRC), one of our main funding sources supports interdisciplinary cooperation by bringing together IT research and scientists from application areas. Under this umbrella, we have interdisciplinary cooperation with Prof Tino Ebbers from the Center for Medical Image Science and Visualization (CMIV) at LiU in the area of analysis and rendering of imaging data. In context with computational material design, we have a long and intense collaboration with Prof Igor Abrikosov from the physics department LiU [Laniel 2023], Prof Patrick Norman [König 2018], and Prof Anna Delin. Another SeRC collaboration in varying intensity concerns the field of climate modeling with Prof Gnuilla Scenson from SU [Nilsson 2022], from the chemistry respective physics department at KTH. Further, there are collaborations with international groups in fluid mechanics (Luis Vega, professor in the Department of Mathematics at the University of the Basque Country, Spain) and mechanical Engineering (Prof. Markus Stommel [Hergel 2021] head of the Leibniz-Institut for Polymer Research, Dresden Germany).

#### International Collaboration

Our group has regular interactions with researchers from other countries. The main ongoing collaborations are summarized in the following • Vijay Natarajan, Professor in CS at Indian Institute of Sciences, Bangalore, India. We started a close collaboration on topological data analysis for material sciences initiated by a Joint Indo-Swedish VR grant (VR 2018-07085) in 2020. The collaboration resulted in several joint publications and research visits between the groups going far beyond the original grant. • Christoph Garth, Professor in CS at the University of Kaiserslautern, Germany. The collaboration focuses on topological tracking and comparison methods. Several joint publications and research visits between the groups in the last two years are part of the collaboration. • Bei Wang, Professor in CS University of Utah. Professor at the Scientific Computing and

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Imaging Institute at the University of Utah, USA. This collaboration was initiated in 2015 by joint work in the field of Tensor field analysis and has been ongoing since. • Other international collaborations with varying intensity include Prof Gerik Scheuerman from the University of Leipzig (DE), Daniel Baum from the Zuse Institute Berlin (DE), and some of the interdisciplinary projects mentioned in the previous paragraph.

### Patent Applications, Open Source Software, and Contributions to Standards

Open-source software for visual analysis as in the years before plays an important role in the group. Currently developed software are Inviwo – An open-source Visualization System with Usage Abstraction Levels, a software framework for rapid prototyping. It builds the basis for the development of novel visualization research and teaching in an increasing number of research groups in the world, with a growing number of application areas. Over the last years, we have been especially focusing on the integration of the open-source Topology Toolkit TTK in inviwo. The results have been presented during diverse tutorials at major visualization conferences. VIA-MD a software for the interactive analysis of molecular dynamics simulation data. The software VIA-MD has received good feedback from colleagues in the MD community who started using the software not only as research but also as a teaching tool. There have been a few high-impact publications within the application domain in which VIA-MD.

### Exploitation and Cooperation with Industry and Institutes

N/A

### Contributions to Undergraduate/Graduate Education

An ongoing contribution to undergraduate education is the annual courses giving an introduction to scientific visualization, information visualization, and computer graphics mainly targeting computer sciences and media information technology students. The visualization course for physics students in Linköping has been held for the fifth time. A Ph.D. level course on "Mathematical foundations in visualization" was offered at LiU during the fall of 2022 jointly taught by Talha Bin Masood and Ingrid Hotz. The primary purpose of this course was to strengthen the knowledge of theoretical and mathematical concepts often used in data analysis and visualization processes. Over the last 6 years, we offered three summer schools for Ph.D. students and other interested researchers with varying topics related to visualization. The summer schools have all been attended by about 20 international researchers.

- Introduction to visualization to people from application areas (2018).
- Visual Storytelling (2021)
- Topological data analysis in visualization (2023)
- During Corona, we also co-organized a spring school on biomedical visualization online with more than 150 participants (2021).

# **Outreach Activities**

Participation in the sixth episode of ELLIIT tech talks about Big data and network science

# Keynotes, Plenaries, and Academic Service

Recent Invited Talks/Keynotes

- Invited plenary talk Applied Topology in Bedlewo, Poland (2022)
- Keynote: IPF colloquium "Digitalization in plastics and elastomer technology", Leibniz-Institute for Polymer Research Dresden, Germany (2022)
- 3 invited talks at IISC Bangalore, India: Centre for Brain Research an Autonomous Centre of IISC, a talk

at the faculty hall of IISC, CSA Distinguished Lecture (2022/23). Guest lecture International Institute of Information Technology, Bangalore, India (2023)

• Invited talk Technical University Kaiserslautern (2023)

Recent Conferences and Workshops chairing and organization

- Co-Chair of the annual workshop on EG Workshop on Visual Computing for Biology and Medicine, 2023, Norrköping, Sweden.
- Organization of a SeRC summer school on topological data analysis, August 2023, Norrköping, Sweden.
- Conference Co-Chair of the Eurographics & Eurovis Conference, 2020, Norrköping Sweden.

Academic service

- Scientific Advisory Board of the Dioscuri Centre in Topological Data Analysis, Poland, supported by the MaxPlanck Society (since 2021).
- Editorial Board of EG Computer Graphics forum and Computers & Graphics.
- Member of Eurographics Executive Committee (since 2022)
- Member of the steering committee of the annual EG Symposium on Visual Computing for Biology and Medicine (since 2020)
- Coordinator of the SeRC Visualization Community, since 2015.
- Member of the SeRC Management group, since 2018.
- General Chair of the international workshop series for 'Topological Methods in Visualization (TopoinVis) from 2015–2022.
- Reviewing activities and PC member for multiple international journals and conferences; proposal reviewing for international funding agencies.

# 7.11 Johannes Fichte, Associate Professor in Theoretical Computer Science

Since March 2023, Johannes Fichte is Associate Professor in the Division of Artificial Intelligence and Integrated Computer Systems (AIICS), Linköping University, Sweden and ELLIIT Recruited Faculty.



From 2021 until 2023, he was a lecturer at the Research Unit on Artificial intelligence and Databases at TU Wien and Google Research Fellow during the Spring Semester 2021 in Residence under NIE at the Simons Institute for the Theory of Computing at UC Berkeley. From 2018 until 2021, he was a PostDoc at TU Dresden and before at TU Wien. Johannes received his Ph.D. from TU Wien in Computer Science in 2015 and has industry experience in data analytics, anonymization, and authenticity of data using asymmetric cryptography in health care.

#### **Description of Research Group**

Johannes Fichte is a member of the Theoretical Computer Science (TCS) Lab. His research concerns algorithms, computational complexity, and applications thereof such as

to logic and counting. Most exact problems in that realm are computationally hard and cannot be unconditionally solved efficiently unless the P versus NP problem is solved with a surprising outcome. Still, many decision problems in automated reasoning, artificial intelligence, biology, cognitive reasoning, and verification can be conveniently encoded into logic, making solving particularly interesting for modern information technology and communications.

Surprisingly, in industrial or application domains we can solve many instances quickly today. As a result, there is a huge gap between theoretical understanding and practical effectiveness. Most research activities are in the realm of theoretically understanding why various techniques perform well in practice and lifting techniques from decisions to more general paradigms, such as metrics or counting. This can be obtained by contributing to

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understanding underlying problem structures and introducing novel solving methods. In addition, his research interests include explainable, certifiable, and comprehensible algorithmic decisions as well as reproducibility and rigid methodology for practical algorithms.

# Plans for the Next Five Years

Within the next five years he plan to expand research in the following areas: (i) advancing exact model counting as a method for exact quantitative and probabilistic reasoning; (ii) facilitating faster problem solving by evaluating parameterized algorithmics with effects and limits on (massively) parallel hardware; and (iii) improving the theoretical understanding of hardness of counting problems. In more detail, for Direction (i), he will establish new concepts to certify correctness of results for various exact counting techniques. New proof systems for counting and frameworks for systematic comparisons thereof are envisioned. In turn, he expect improved procedures and scalability toward tackling mathematical conjectures that benefit from counting formulations. For Direction (ii), he will establish new algorithms, concepts, and limitations for parallel counting and consider the effect of abstractions and heuristics. To Direction (iii), He will improve on approaches to reproduce and replicate practically engineered algorithms, including standards for algorithmic evaluations. He believes that stronger practical and statistical evaluation tools are required to form a more solid basis for analyzing beyond plain worst-case complexity.

# **External Funding Attracted**

N/A

# Inter-University Cooperation within ELLIIT

N/A

# Inter-Disciplinary Cooperation

N/A

# International Collaboration

Johannes has collaborations with researchers from various countries and universities. During the past years he worked together with many researchers outside of Sweden. Among them Arne Meier (Leibniz University Hannover), André Schidler (TU Wien), Ciaran McCreesh (University of Glasgow), Daniel Le Berre (CRIL-CNRS Lens), Emanuelle Dietz (Airbus Hamburg), Friedrich Slivovsky (University of Liverpool), Kuldeep Meel (University of Toronto), Markus Hecher (Massachusetts Institute of Technology), Mario Alviano (University of Calabria), Norbert Manthey (Amazon Dresden), Olaf Beiersdorff (University of Jena), Robert Ganian (TU Wien), Sarah Alice Gaggl (TU Dresden), Sebastian Ordyniak (University of Leeds), Tobias Philipp (Secunet Dresden), Stefan Woltran (TU Wien), and Stefan Szeider (TU Wien).

# Patent Applications, Open Source Software, and Contributions to Standards

Contributions to various open source combinatorial solvers, for example, in model counting (gpuSAT and DPDB) and hypergraph parameters (FraSMT).

### Exploitation and Cooperation with Industry and Institutes

Informal collaboration with Emanuelle Dietz from Airbus Hamburg on logics for human reasoning and Tobias Philipp from Secunet AG Dresden on counting for verifying secure hardware.

### Contributions to Undergraduate/Graduate Education

Johannes Fichte has taught, developed, and advanced a range of courses at both B.Sc., M.Sc., and Ph.D. level over the last years at TU Wien and TU Dresden. He will take over the logic Course for Master students from 2024 at LiU and modernize the Curriculum in 2025. Johannes currently offers various thesis projects, including a practical component to attract students, together with Victor Lagerkvist in the research areas of the lab.

### **Outreach Activities**

Johannes co-authored a survey article The Silent (R)evolution of SAT that appeared in the Communications of the ACM in June 2023. The work appeared on various Media (YCombinator Hacker News, Twitter, LinkedIn) and has been supported by a short video teaser.

### Keynotes, Plenaries and Academic Service

- Organization Chair of the 31st International Joint Conference on Artificial Intelligence (IJCAI 2022) in Vienna;
- PC Member of the
  - AAAI Conference on Artificial Intelligence (AAAI) since 2018;
  - International Joint Conference on Artificial Intelligence (IJCAI) since 2019;
  - 26th International Conference on Theory and Applications of Satisfiability Testing (SAT 2023);
  - International Conference on Principles of Knowledge Representation and Reasoning (KR 2023);
  - European Conference on Logics in Artificial Intelligence (JELIA 2023);
  - European Conference on Artificial Intelligence (ECAI 2023);
- Co-Organizer of the annual Model Counting Competition since 2020; and
- SC Member of the annual Parameterized Algorithms and Computational Experiments Challenge (PACE) from 2020–2023.

# 7.12 Jonas Unger, Professor in Computer Graphics

Jonas Unger is, since 2019, professor in Computer Graphics at the Department of Science and Technology at Linköping University.



He obtained his Ph.D. in 2009 from Linköping University and became docent in 2015. He has spent about 2 years as a visiting researcher at the Institute for Creative Technologies at the University of Southern California, USA. Since 2009, he has built and is leading the computer graphics and image processing group consisting of around 20 senior researchers, Ph.D. students and research engineers.

Current research interests lie at the intersection of computational imaging, computer graphics, computer vision, medical image analysis, and in the combination of different

sensors, human perception, and machine learning to capture, model, analyze, and synthesize visual aspects of the world.

Unger has been the main supervisor for 7 Ph.D. students and co-supervisor for 1, and is currently supervising 6 as main supervisor and 3 as co-supervisor. He is and has been leading several larger research initiatives including the Wallenberg Autonomous Systems and Software Program (WASP) cluster Interaction and Communication

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with Sensor-Rich Autonomous Agents, the visualization research in the MedTech4Health Advanced Imaging and Data Arena (AIDA), the Visual Sweden Platform for Augmented Intelligence, and the WASP NEST Multdimensional Alignment and Integration of Physical and Virtual Worlds. Prof. Unger has received awards for his research, recently including the Swedbank Research Stipend (2018), Best Poster Award VCBM (2023), and Chester Carlsson research award from the Royal Academy of Engineering Sciences in Sweden (2023).

#### **Description of Research Group**

The research group currently consists of 5 senior researchers, 9 Ph.D. students, 4 research engineers, and 2 post-doctoral researchers. The vision of the group is to research and develop new theory and technology for computational imaging by fusing computer graphics, vision and sensors with human perception and machine learning to capture, digitize and reason about aspects of the world that have not been possible before. With a strong foundation in the theoretically oriented research, the group is also active within a number of industrial and academic collaborations directed towards development of state-of-the-art applications ranging from 3D-reconstruction of scenes, photo-realistic image synthesis and digitization of optical material properties to computer vision for heart surgery, perceptual display algorithms and software for autonomous systems such as self driving cars and robot navigation.

#### Plans for the Next Five Years

Over the upcoming 5 years, we will within ELLIIT continue our work on sparse models, dictionary learning and compressed sensing for imaging applications. In our previous work within ELLIIT, we have developed learning based techniques that enables us to train basis representations under sparsity constraints. We use a dictionary learning approach where we train/optimize a dictionary of basis functions such that patches extracted from visual signals (images, video, light fields, light field video) can be represented by sparse coefficient vectors while the reconstruction error is minimized. We have utilized the sparse modeling framework for both compression and compressed sensing for imaging applications with very promising results. Over the next five years we will focus primarily on efficient sampling and signal reconstruction. An example of this is to accelerate computer graphics rendering, which is a very costly computational problem. Using our sparse basis representations, we can reconstruct high quality images without any noticeable degradation from less than 10% of the original pixel samples. This leads to a reduction in computation time and energy consumption of around 90%. Another example relevant within ELLIIT is that we will continue our work in diffusion-weighted magnetic resonance imaging (dMRI). We believe that our methods have strong potential to support significant technological leaps in visualization and analysis of brain data. We also see strong connections between sparse models and the latent representations obtained in deep neural networks, and will investigate, e.g., how sparse models can be used in the context of generative machine learning models.

Project Name	Funding agency	Total Amount	Duration
		(kSEK)	
Multi-dimensional alignment and integration	WASP	20.000	2022 - 2026
Predictive Rendering in Manufacturing and	EU-ITN	6.400	2021 - 2025
Engineering			
Sparse modelling and compressive imaging	Wallenberg Launch-	4.500	2021 - 2023
	pad		
Pos-doc research grant	Knut & Alice Wal-	4.000	2019 - 2023
	lenberg Foundation		
Sparse representation of high dimensional sig-	WASP	4.000	2019 - 2023
nals			

#### **External Funding Attracted**

### Inter-University Cooperation within ELLIIT

Ongoing collaborations within ELLIIT include cooperation with Prof. Ingrid Hotz from Linköping University, and Michael Doggett and Prof. Bo Bernhardsson from Lund University. The collaboration is carried out within the ELLIIT project "Visual Feature Based Data Reduction – sparse representations for brain imaging data", and has concretely resulted in novel modelling techniques where sparse modelling and dictionary learning is used to build models ad algorithms for high dimensional data from diffusion-weighted magnetic resonance imaging (dMRI).

# Inter-Disciplinary Cooperation

Within the scope of ELLIIT, we have collaborated with mathematicians Prof. George Baravdish, Thomas Johansson, and Lucas Maly at Linköping University to investigate how Neural Ordinary Differential Equations (NODEs) can be used to build deep neural networks, and their relation to standard deep neural networks. In this collaboration we jointly supervised an ELLIIT affiliated Ph.D. student, Rym Jaroudi, who graduated during the Spring of 2023. Through joint projects with Prof. Amy Loutfi at Örebro University, and Prof. Michael Felsberg, we are collaborating on topics at the intersection of human-system interaction, computer vision, and computer graphics. We are also a core partner in WASP WARA Media and Language. In this context we collaborate with Johanna Björklund from Umeå University to build a physical lab environment combining visualization, computer graphics and machine learning in the form of the rapidly emerging large language models (LLMs).

### International Collaboration

Relevant to ELLIIT we have ongoing international projects with Prof. Rafal Mantiuk at the University of Cambridge (UK) in which we research and develop novel methods for high dynamic range (HDR) imaging, and with Ass. Prof. Jeppe Revall Frisvad at Denmark Technical University (DTU) with whom we investigate methods for photo-realistic appearance capture of objects and materials using machine learning methods.

# Patent Applications, Open Source Software, and Contributions to Standards

#### Patents:

- 1. Jonas Unger, Ehsan Miandji, Per Larsson, A method, computer program, computer program product and system for representing visual information, US 2022067431, 2021-06-11
- 2. Jonas Unger, Ehsan Miandji, Per Larsson, A method, computer program, computer program product and system for representing visual information, CN 113454975, 2021-06-11
- 3. Magnus Wrenninge, Jonas Unger, Method for image analysis, US10235601B11, 2019-03-19.
- 4. Jonas Unger, Gabriel Eilertsen and Rafal Mantiuk, System and method for realtime tone-mapping, WO2017035661A1, 2016-09-02.

**Open source initiatives:** Unger and his team are strong believers in reproducible research. Hence, it is a key goal to publish the data and the software that was produced in generating the new results. Most of our code and data are available through: https://computergraphics.on.liu.se/.

Examples that we would like to highlight include:

- 1. Synscapes A photorealistic data est for street scene parsing, https://synscapes.on.liu.se/.
- 2. LiU HDRv repository a repository with examples and data sets for imaging research.
- 3. LUMA HDRv A compression framework and compression codecs for high dynamic range (HDR) video.

#### Exploitation and Cooperation with Industry and Institutes

In addition to the academic work, Unger has co-founded and supported a number of startup companies including:

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- 1. IrysTec Inc. (Canada) developing perceptual display algorithms for automotive applications and mobile devices. Acquired by Faurecia (FR) in 2020.
- 2. 7DLabs Inc. (US) developing software systems for autonomous vehicles. Acquired by Aurora Innovation (US) in 2019.
- 3. Sparsit AB developing sparse modeling and compressed sensing technology for imaging and other applications. Sparsit was supported through Wallenberg Launchpad and is now moving forward as a startup-company.

We are and have been active in a number of collaborations with industrial partners, both directly within joint research/development projects, but also through joint M.Sc thesis projects. Current and previous collaborations include: IKEA Marketing and Communications (SE), Swedish History Museums, Livrustkammaren (The Royal Armoury) (SE), SpheronVR AG (DE), SICK-IVP (SE), GoHDR (UK), Philips (NE), MPC (UK), Sony Picture Imageworks (US), Swedish Meteorological and Hydrological Institute (SMHI) (SE), Swedish Aviation Authorities (SE), IRYSTEC (Canada), SECTRA (SE), Skåne University Hospital (SE), Zenuity (SE), Qualcom (USA), Tandemlaunch (Canada), List3D (USA), Veoneer (SE), Arriver (SE), and Aurora Innovation Inc. (USA) to name a few.

#### Contributions to Undergraduate/Graduate Education

Contributions from our research are continuously incorporated into undergraduate and graduate education. We are involved in undergraduate courses in computer programming, computer graphics, image processing, and machine learning, mainly targeting students from computer sciences and media technology. We are also organizing graduate courses for our Ph.D. students. Over the last years, we have given Ph.D. courses in sparse modeling, generative machine learning, and advanced topics in computer graphics.

#### **Outreach Activities**

Through our industrial collaborations and work within the Visualization Center C in Norrköping, we participate in different types of outreach activities. We participate in public events to promote our research and are invited to give presentations. Some invited presentations include: the Royal Academy of Engineering Sciences (October 2023), SEB workshop (2023), IKEA (2022), Saab (2021), Vehicle ICT Arena Vinnova (October 2018), WASP-NTU meeting (October 2017), Head of Swedish heart surgery clinics yearly meeting (May 2017), ABB (April 2017), and Zenuity (April 2017) to name a few.

#### Keynotes, Plenaries and Academic Service

I was general chair for Eurographics Annual Conference 2020, general chair for the Scandinavian Conference on Image Analysis (SCIA) 2019, co-chair of the Swedish Symposium on Image Analysis / Swedish Symposium on Deep Learning (SSBA/SSDL) 2023, co-chair of the European Conference on Computer Vision (ECCV) workshop BxDF4CV 2017, and Papers chair of ACM Symposium on Virtual Reality Software and Technology (VRST) 2017. Program committee member and reviewer for different tracks at venues such as ACM SIGGRAPH, Eurographics, ACM Transactions on Graphics, IEEE Transactions on Visualization and Graphics, and Computer Graphics Forum. I'm regularly faculty opponent and committee member at licentiate and Ph.D. defences. Recent invited plenary/keynote presentations at conferences include: WASP Winter Conference 2022, WARA Media & Language (2021), London Imaging Meeting (LIM) 2021, WASP4All 2020, Computational Light Fields Imaging workshop (CLIM) 2019, International Conference on Computer Vision (ICCV) workshop 2017.

# 7.13 Jürgen Börstler, Professor of Software Engineering

Jürgen Börstler is a professor of software engineering at Blekinge Institute of Technology (BTH), Sweden, since 2010.



He received a Ph.D. in computer science from Aachen University of Technology (RWTH), Germany, in 1994 and an M.Sc. in computer science with economics as a secondary subject from Saarland University, Saarbrücken, Germany, in 1987. Before joining BTH, he was a professor of computer science at Umeå University, Sweden. Jürgen Börstler is an ELLIIT recruited faculty since 2010 and a member of the ELLIIT program board since 2012. His main research interests are software quality and research methods in empirical software engineering. Recent work in these areas includes work in defect prediction [Laiq, 2023] and [Bennin, 2022], an international study on software developers' perception of code quality [Börstler, 2023a], work on acceptance behav-

ior theories in software engineering [Börstler, 2023b] and on double-counting in tertiary studies [Börstler, 2023c].

In 2006, his Ph.D. student Magnus Ericsson received the Brian Mar Award at INCOSE for the best student paper (with Jürgen Börstler as one of three co-authors). In 2019, he received an ACM Distinguished Paper Award at ICGSE (together with a BTH colleague and two people from the industry). In 2022, his Ph.D. student Muhammad Laiq received a Best Poster Presentation award at PROFES (with Jürgen Börstler as one of four co-authors). In 2023, his Ph.D. student Umar Iftikhar received a Technical Research Best Paper Award at Software Quality Days (with Jürgen Börstler as one of four co-authors).

### **Description of Research Group**

My research group overlaps to a large degree with another group at my department that also works within ELLIIT; see project B7 in Section 4.8. The group collaborates closely and regularly with Professor Kai Petersen at the University of Applied Sciences Flensburg, Germany. Together, we are 4 senior researchers and four Ph.D. students. Within this group, we work closely together with several industry partners, e.g., Ericsson. The research on research methods in empirical software engineering and acceptance behavior theories is mainly between senior researchers. By means of shared supervision of three Ph.D. students, we are carrying out collaborative research on the analysis of code quality and code review comments. The fourth Ph.D. student has recently started researching the design and teaching of team project courses in software engineering education. Recently, a second ELLIIT faculty joined the department (Henry Edison, see Section 7.9), adding another senior and another Ph.D. student to the group.

#### Plans for the Next Five Years

I am planning to retire by the end of 2025. Until then, I will continue my work on acceptance behavior theories and how they can be used in empirical studies of software process improvement. Furthermore, we will advance our work in code analysis in collaboration with industry. In particular, we plan to integrate our current prototypes with the ways-of-working at further case companies.

#### **External Funding Attracted**

N/A

#### Inter-University Cooperation within ELLIIT

I have close collaboration with Lund University. I was a co-PI in Emma Söderberg's ELLIIT-project on code reviews; see project A8 in Section 3.9. Furthermore, my group works closely with Emelie Engström on analyzing

#### **Chapter 7. Recruited Faculty**

bug reports and empirical methods in software engineering. In our work on the analysis of bug reports, Emelie is a (formal and actual) co-supervisor of a Ph.D. student. Emma, Emelie, and I have co-authored several publications in the last few years; see, e.g., [Söderberg, 2022], [Laiq, 2023] and [Laiq, 2022].

#### Inter-Disciplinary Cooperation

For our work on acceptance behavior theories in software engineering [Börstler, 2023b], we have worked with a colleague from industrial economics with a psychology background. This work has already led to further studies on (technology) acceptance (in revision). With colleagues from technology/science education (nationally and internationally), I have researched students', teachers', and developers' perceptions of code quality. This work has led to a recent spin-off publication [Börstler, 2023a]. Furthermore, we also work together with the School of Business at Örebro University, specifically on statistical analyses (Panagiota Chatzipetrou, see [Nurdiani, 2019]).

#### International Collaboration

I regularly collaborate with Kai Petersen from the University of Applied Sciences Flensburg, Germany (e.g., [Börstler, 2023c]). Recently, I have worked with Ebo Bennin (Wageningen University and Research, The Netherlands) on using data resampling techniques to analyze bug reports [Bennin, 2022]. As outlined above, I have also worked with researchers from Germany, the Netherlands, the USA, and Finland on developers' perceptions of code quality [Börstler, 2023a].

### Patent Applications, Open Source Software, and Contributions to Standards

• Open data: All data, the study design, and the coding guide for our study on developers' perceptions of code quality are available on Zenodo (https://zenodo.org/records/8233989).

#### Exploitation and Cooperation with Industry and Institutes

I have (co-)supervised and examined numerous master theses in collaboration with industry. I still collaborate with my former industrial Ph.D. student (Mohsin Irshad, Qvantel, now Ericsson), who graduated in 2021 on refactoring [Irshad, 2022] and software testing [Minhas, 2023]. Together with two colleagues, I have worked with Ericsson on effort estimation and the on-boarding of software developers. This work has led to several publications with co-authors from industry, e.g., [Britto, 2020].

# Contributions to Undergraduate/Graduate Education

- I completely redesigned BTH's thesis course for master of science of engineering ("civilingenjör") students, which is mandatory for all 7 "civilingenjör"-programs at BTH. I have coordinated and taught this course until 2022.
- Together with a colleague, I developed a new introductory course for BTH's "civilingenjör"-programs. The course was developed "from scratch" and is mandatory in 2 programs. Initially, I was the course responsible and a teacher. This course reuses material from my research on object-oriented software design.
- I have started recording lectures on research methods and academic writing. The first two lectures have already been used in 3 local courses.
- I am currently serving as supervisor in BTH's mentoring program to improve the scholarship of teaching and learning of university lecturers ("adjunkt") and help them advance their academic careers (promotion to first lecturer or senior lecturer).
- I'm regularly contributing with a lecture on systematic reviews to BTH's mandatory university-wide Ph.D. course "Information Retrieval for Ph.D. students".

#### **Outreach Activities**

- I contributed to the ELLIIT tech talk series with a talk on software quality ("Building large software systems faster, cheaper and better?"). My Ph.D.student Vi Tran held another ELLIIT tech talk on software testing ("Software Testing Who watches the watchers?"). We both participated in a follow-up discussion about the next-generation software technology; see ELLIIT tech talk 10: Next-generation software technology 2.
- I contributed to the ELLIIT Impact story Dialogue improves software development.

#### Keynotes, Plenaries and Academic Service

- 2014–2019, I served as a Head of Department for the Department of Software Engineering at BTH.
- Since 2012, I am a member of ELLIIT's program board.
- Since 2019, I am the chairman of BTH's appointment board ("rekryteringskommitté").
- I am a member of the editorial board of informatica didactica (a peer-reviewed electronic journal in Computer Science Education).
- I have served on the PC for CSEE&T 2020 and 2023 and EASE 2021–2023.
- Our paper "Understanding the order of agile practice introduction: Comparing agile maturity models and practitioners' experience" [Nurdiani, 2019] was invited for presentation at the "JSS Happy Hour" (JSS=Journal of Systems and Software). The JSS Happy Hour events were organized to compensate for the canceled International Conference on Software Engineering (the major conference in our area). The paper was selected for its high download statistics, topic, and overall quality.

# 7.14 Michael Lentmaier, Associate Professor in Communications

Michael Lentmaier is an Associate Professor at the Department of Electrical and Information Technology, Lund University.



He received his Dipl.-Ing. degree in Electrical Engineering from Ulm University, Germany, in 1998 and his Ph.D. degree and Docent degree in Telecommunication Theory from Lund University in 2003 and 2018, respectively. In 2003 and 2004 he was a Postdoctoral Research Associate at University of Note Dame, Indiana, and at Ulm University. From 2005 to 2007 he was with the Institute of Communications and Navigation of the German Aerospace Center (DLR) in Oberpfaffenhofen, where he worked on signal processing techniques in satellite navigation receivers. From 2008 to 2012 he was a Senior Researcher and Lecturer at the Vodafone Chair Mobile Communications Systems at TU Dresden, where he was heading the Algorithms and

Coding research group. In 2013 he joined Lund University as an ELLIIT Recruited Faculty. His main research interests are in information theory, with focus on modern coding theory, graph-based iterative algorithms and the impact of spatial coupling on their performance. Applications include reliable communication [Zhu, 2023], localization, security/privacy [Yang, 2022] and group testing [Mashauri, 2023]. He received the best presentation award for his paper titled "Dynamic Multipath Estimation by Sequential Monte Carlo Methods" at ION GNSS (2007) [Lentmaier, 2007], the IEEE Wireless Communications Letters Exemplary Reviewer Award (2012), and the IEEE Communications Society & Information Theory Society Joint Paper Award (2012) for his paper "Iterative Decoding Threshold Analysis for LDPC Convolutional Codes" [Lentmaier, 2010].

#### **Description of Research Group**

As a member of the Communications Engineering division, I am currently the main supervisor of two Ph.D. students, Mgeni Makambi Mashauri and Neharika Valecha, who started in 2019 and 2020, respectively. Another student, Muhammad Umar Farooq, graduated November 2022 and is now working at Ericsson in Lund. I hope

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that I can secure some funding through WASP and VR to hire one or two new Ph.D. students by the end of 2024. Our current research spans from i) the design and analysis of error correcting codes and advanced iterative receivers for reliable communications over ii) sparse graph codes for efficient large scale group testing to iii) highly accurate positioning based on mmWave massive MIMO systems.

### Plans for the Next Five Years

In the upcoming years, I plan to continue my research on reliable communications, considering error correcting codes and their interaction with other receiver components. Our previous research has shown that spatially coupled graphical models not only can substantially improve the performance of message passing receivers, but also make them benefit from universality and become robust against changing channel conditions. In particular, one aim is to investigate the interaction between channel coding and antenna diversity in massive MIMO systems, which both aim at improving reliability but have rarely been considered together. Reliable communication is also the topic of a planned cooperation with Ericsson, where the objective is to contribute to improved channel coding schemes to be included in the upcoming 6G and next-generation Wi-Fi standards.

Another direction is to take advantage of sparse graph codes in applications beyond communications. For example, we recently managed to substantially improve the performance of existing quantitative group testing schemes based on hard-decision message passing decoding. In this context, many questions are still open: what are the fundamental limits that can be achieved with such schemes, how much can soft-input (priors) improve the performance, and how can one exploit correlations in a dynamic group testing scenario? As another example, in a recently started student project, supervised together with Onur Günlü from Linköping University, error correcting codes are used to achieve information theoretic security. We hope that this will result in an ongoing collaboration between our groups in this direction. As a third example, I see large potentials in applying the concept of redundancy and coding to machine learning. This could result in improved performance, robustness against adversarial attacks, or soft information about the output reliability.

Project Name	Funding agency	Total Amount	Duration
		(kSEK)	
Enhancing Iterative Receivers with Spatial	Swedish Research	3884	2018-2021
Coupling (PI)	Council (VR)		
MINTS: Millimeter-wave Networking and	European Union	1700	2019–2023
Sensing for Beyond 5G (co-PI)	(H2020)		

# **External Funding Attracted**

#### Inter-University Cooperation within ELLIIT

In 2023 we started a cooperation with ELLIIT faculty member Onur Günlü from Linköping University in form of a master student project on information theory and security. We expect that this project will result in a publication and hopefully lead to some ongoing cooperation.

#### Inter-Disciplinary Cooperation

Coding theory has always fascinated me in the sense that one can go all the way from information-theoretic analysis of fundamental limits over abstract algebra and combinatorial designs to efficient implementations in software and hardware, and find challenging open problems in each domain. For example, I have on one hand worked with Prof. Roxana Smarandache from the Department of Mathematics at University of Notre Dame on algebraic code design. On the other hand, I have collaborated with Prof. Norbert Wehn from TU Kaiserslautern, together with some colleagues from our circuit design group, on the VLSI design of a class of codes. I have also worked with the cryptography group on applying message passing decoding algorithms to efficiently solve equation systems containing non-linear terms and so demonstrating weaknesses of some existing systems.

# International Collaboration

I have a long history of collaboration on several facets of codes on graphs and spatial coupling with Prof. Daniel J. Costello, Jr. at University of Notre Dame, IN, USA, where I worked as a post-doctoral researcher in 2003/2004. Furthermore, I have active international collaborations with New Mexico State University, USA, Xidian University, China, Technical University Of Kaiserslautern, Germany, Technical University of Munich (TUM), Germany, the German Aerospace Center (DLR), and Duke University. Ph.D. student Mgeni Makambi Mashauri is co-supervised by Alexandre Graell i Amat from Chalmers University.

# Patent Applications, Open Source Software, and Contributions to Standards

- Bengt Lindoff, Wei Zhou, Michael Lentmaier, Sergei Semenov, Wenquan Hu, "Combined belief propgation (BP) and ordered statistics decoding (OSD) for concatenated codes", Number WO2020151835A1, published July 30, 2020.
- Wei Zhou, Michael Lentmaier, Sergei Semenov, Wenquan Hu, Bengt Lindoff, "Simplified check node processing for LDPC decoding", Number WO2020052754A1, published March 19, 2020.

### Exploitation and Cooperation with Industry and Institutes

- With Leif Wilhelmsson and Saeedeh Moloudi (ELLIIT graduate in 2018) at Ericsson Research we investigated multi-layer transmission for efficient transmission over unknown channels in a master project. Results have been published as a conference paper at VTC-Spring 2021.
- With Leif Wilhelmsson as a co-applicant, I have applied for a 2023 SSF Strategic Mobility Grant to work part time at Ericsson over two years. The decisions will be announced in December.
- I am also acting as degree project supervisor at our department, with several master projects per year carried out in industry.

#### Contributions to Undergraduate/Graduate Education

- I serve as director of the Master's Program in Wireless Communications at LU since July 2013.
- In the undergraduate course on Information Theory I am including material related to my recent research in modern coding theory. Group testing based on sparse graph codes is given as an application example.

# **Outreach Activities**

I am preparing a popular science lecture for high school students entitled "Measuring information: on data compression, error correction and more" to be given during the NMT days at Lund University in March 2024.

#### Keynotes, Plenaries and Academic Service

- Invited speaker at Workshop on Application-Driven Coding Theory, Simons Institute for the Theory of Computing at UC Berkeley, March 2024
- Keynote, IEEE Globecom Workshop on Channel Coding Beyond 5G, Brazil, 2022
- Keynote, Intern. Symp. on Turbo Codes and Iterative Information Processing, Hong Kong, 2018
- Invited speaker at Intern. Zürich Seminar on Information and Communication, Switzerland, 2018
- IEEE Sweden Vehicular Technology, Communications, and Information Theory Societies (VT/COM/IT) joint chapter: board member 2013–2017, vice-chair 2018–2020, chapter chair since 2021
- Associate editor, IEEE Transactions on Information Theory, 2017–2000
- Program chair, ELLIIT Annual Workshop, 2021
- TPC chair, IEEE Information Theory Workshop, Visby, Sweden, 2019
- Technical program committee member
  - IEEE International Symp. on Information Theory (ISIT): 2018, 2020, 2021, 2022, 2023, 2024

- 27th International Workshop on Smart Antennas (WSA): 2024
- Intern. Symp. on Turbo Codes and Iterative Information Processing (ISTC): 2018, 2021,2023
- IEEE Global Communications Conference Workshops (Globecom): 2022, 2023
- Intern. ITG Conference on Systems, Communications and Coding (SCC): 2019, 2023
- IEEE Intern. Symp. Personal, Indoor and Mobile Radio Communications (PIMRC): 2023
- IEEE Information Theory Workshop (ITW): 2018, 2020, 2022

# 7.15 Onur Günlü, Assistant Professor of Information-Theoretic Privacy and Security

Onur Günlü received the B.Sc. degree (Highest Distinction) in Electrical and Electronics Engineering from Bilkent University, Turkey in 2011; M.Sc. (Highest Distinction) and Dr.-Ing. (Ph.D. equivalent) degrees in Communications Engineering both from the Technical University of Munich (TUM), Germany in October 2013 and November 2018, respectively.



He was a Working Student in the Communication Systems division of Intel Mobile Communications (IMC), now Apple Inc., in Munich, Germany during November 2012 - March 2013. As a Visiting Researcher, among more than ten research stays at top universities and companies, he was at TU Eindhoven, Netherlands during February 2018 - March 2018 to visit Prof. Frans M. J. Willems. He was a Visiting Research Group Leader at Georgia Institute of Technology, Atlanta, USA during February 2022 - March 2022 to visit Prof. Matthieu Bloch. Onur has been a Visiting Professor at TU Dresden, Germany during January 2023 - March 2023 to visit Prof. Rafael F. Schaefer. He was a Research Associate and Dozent between June 2019 - September 2020 and

was a Research Group Leader and Dozent between October 2020 - March 2021 at TU Berlin, and he held the same academic titles at Chair of Communications Engineering and Security at University of Siegen, Germany from April 2021 until September 2022.

Onur has been working as an ELLIIT Assistant Professor at Linköping University (LiU), Sweden in the Information Coding Division (ICG) since October 2022. Onur has been a Brain City Berlin Ambassador since June 2020, received the VDE Information Technology Society (ITG) 2021 Johann-Philipp-Reis Award, been selected by the IEEE Communications Society as 2021 Exemplary Reviewer of the IEEE Transactions on Communications (TCOM), and received the 2023 ZENITH Research and Career Development Award.

#### **Description of Research Group**

The Information Theory and Security (ITS) research group, within the LiU Information Coding Division (ICG), consists of a postdoctoral student and a Ph.D. student who will join in January 2024 both of whom are based in LiU ICG. A Ph.D. student at the Technical University of Dresden in Germany who is co-supervised by Onur Günlü also belongs to the research group. Multiple Master and Bachelor students join the group for project works and theses, and one of them is expected to join the group within 2024.

#### Plans for the Next Five Years

I will continue my research on information-theoretic privacy and security by analyzing promising future communication and computation applications to develop provably secure and practical methods. Moreover, as a newcomer to Sweden, I will continue establishing contacts with the industrial partners.

### **External Funding Attracted**

Project Name	Funding agency	Total Amount	Duration
		(kSEK)	
Towards a Multi-Layer Security Vision for	Chalmers Transport	500	09/23 - 08/24
Transportation Systems in the 6G Era	Area of Advance		
	(AoAT)		
Quality of Security Service Guarantees for In-	ZENITH Research and	3000	01/23 - 12/27
telligent Internet-of-Things Devices	Leadership Career Or-		
	ganization		
Cutting-edge Research for 6G Communication	German Federal Min-	8 356	06/22 - 05/25
Networks with a Focus on Human-Machine	istry of Education and		
Collaboration	Research (BMBF)		
Physical Layer Security for TeraHertz-MIMO	German Federal Min-	3 651	10/20 - 09/23
Communications	istry of Education and		
	Research (BMBF)		

#### Inter-University Cooperation within ELLIIT

I am currently supervising one Master student together with ELLIIT faculty member Michael Lentmeier from Lund University and we expect this supervision to result in a publication.

### Inter-Disciplinary Cooperation

N/A

# International Collaboration

Numerous international collaborations take place, including researchers from TU Munich, TU Berlin, TU Dresden, M.I.T., Princeton University, Georgia Institute of Technology, New Jersey Institute of Technology, Fraunhofer Heinrich-Hertz Institut Berlin, Ohio State University, Nanyang Technological University, etc.

#### Patent Applications, Open Source Software, and Contributions to Standards

- Onur Günlü and Rafael F. Schaefer, "Method and System for Decorrelating Input Signals from a Physical Identifier", granted on June 10, 2020 by the European Patent Office with the Patent Application No: 20164810.2 and Patent No: EP3886358.
- Onur Günlü, Rick Fritschek, and Rafael F. Schaefer, "Methods and Systems for Data Transfer via a Communication Channel", filed on August 31, 2022 to the Luxembourg Intellectual Property Office with the Patent Application No: 502737.
- Onur Günlü and Rafael F. Schaefer, "Method and System for Increasing Privacy of User Data Within a Dataset and Computer Program Product", filed on February 23, 2022 to the European Patent Office with the Patent Application No: 10695204.
- Onur Günlü, Joerg Kliewer, Rafael F. Schaefer, and Vladimir Sidorenko, "Method and System for Identification via Channels and Computer Program Product", filed on June 09, 2021 to the European Patent Office with the Patent Application No: 21178612.4.

# Exploitation and Cooperation with Industry and Institutes

I have carried out joint research projects with the Fraunhofer Heinrich-Hertz Institut Berlin in Germany and I am currently carrying out such a joint project with Sectra Communications in Linköping.

#### Contributions to Undergraduate/Graduate Education

I have incorporated my recent research results on physical unclonable functions (PUFs) into the Cryptology course that I took over, which resulted in an arrangement of a Master thesis on this topic that will take place next semester.

### **Outreach Activities**

I have been a Brain City Berlin Ambassador and have written popular science articles and held popular science talks within this initiative. Furthermore, I have been a member of the IEEE Information Theory Society - Student and Outreach Subcommittee and organized numerous events, including the "Meet the Shannon Lecturer" events during which I interviewed and/or led the discussions with the Shannon Award recipients.

#### Keynotes, Plenaries and Academic Service

- Frans M.J. Willems, Tanya Ignatenko, Lieneke Kusters, and O. Günlü, "An Information-Theoretical Approach Toward SRAM-PUF Authentication," Keynote Speech in IEEE Workshop on Information Forensics and Security, Delft, The Netherlands, December 2019.
- ITG International Workshop on Smart Antennas (WSA) 2024 Exhibition Chair, Dresden Germany, March 2024 (jointly with Rafael F. Schaefer, Gerhard P. Fettweis, Peter Rost, Norman Franchi, Martin Mittelbach, Rico Radeke, Thomas Uhle, and Daniel Seifert).
- IEEE Global Communications Conference (GLOBECOM) 2023 Main Symposium Technical Program Co-Chair for the Communication and Information System Security Symposium (CISS), Kuala Lumpur, Malaysia, December 2023 (jointly with James Xiaojiang Du and Safa Otoum).
- ITG International Workshop on Smart Antennas (WSA) 2021 Special Session Organizer on Security and Privacy for Future Wireless Communication Systems, Eurecom, French Riviera, France, November 2021 (jointly with Samir M. Perlaza and Rafael F. Schaefer).
- IEEE/EURASIP International Symposium on Wireless Communication Systems (ISWCS) 2021 Special Session Organizer on Physical Layer Security, Berlin, Germany, September 2021 (jointly with Rafael F. Schaefer).
- IEEE International Workshop Organizer on Privacy and Security for Information Systems (WPS) 2020, Avignon, France, July 2020 (jointly with Rafael F. Schaefer, Matthieu Bloch, and H. Vincent Poor).
- Munich Workshop Organizer on Physical Unclonable Functions (MPUF) 2017, Munich, Germany, November 2017 (jointly with Michael Pehl, Tasnad Kernetzky, Georg Sigl, and Gerhard Kramer).
- IEEE Communications Society (ComSoc) Transactions on Communications (TCOM) Associate Editor for Communication Theory and Systems I (2023 2026).
- Entropy Journal Special Issue on Information Theoretic Methods for Future Communication Systems (2021 2022) (jointly with Rafael F. Schaefer, Holger Boche, and H. Vincent Poor) Associate Editor
- EURASIP Journal on Wireless Communications and Networking (2021-Present) Associate Editor
- Entropy Journal (2020 Present) Topic Advisory Panel Member
- Computers Journal (2020-Present) Reviewer Board Member
- Information Journal (2020-2021) Reviewer Board Member

# 7.16 Richard Pates, Associate Professor in Automatic Control

Richard Pates is an Associate Professor in Automatic Control at Lund University since 2020. Prior to that he has held positions as an Adjunct Lecturer at both Lund University, and the University of Cambridge, UK, as well as postdoc positions at both universities.



He received the Ph.D. and M.Eng degrees in from the University of Cambridge in 2014 and 2009 respectively. He has been an ELLIIT Recruited Faculty since 2020. His research interests include scalable control system design, with a focus on electric power system applications. His recent work in this area includes fundamental contributions on the scalable control of electrical networks [Pates, 2022]. Applications to electric power systems have been considered in [Jiang, 2020] and [Lindberg, 2022], district heating networks in [Agner, 2023], and connections to optimization methods in [Chaffey, 2023].

# **Description of Research Group**

My research group currently consists of 5 Ph.D. students (2 as main supervisor, and 3 as co-supervisor), and operates within the Department of Automatic Control at Lund University. We conduct research on the sustainable and safe operation of large-scale systems, with a special focus on scalable control for electric power systems, district heating networks, transportation networks, and autonomous vehicles.

# Plans for the Next Five Years

Over the next five years my group will primarily expand its research efforts to consider optimal control in the large-scale setting. Optimal control is of fundamental importance since it quantifies the best possible (in some suitably defined sense) operation of dynamical systems. This makes it an idea tool to provide fundamental engineering insights into important large-scale engineering challenges, such as the transition of electric power systems from conventional to renewable generation. There will be a particular focus on:

- 1. Exploiting network structure in the design of optimal control laws. The dynamical models of many large-scale systems obey conservation laws. These can be used to give fundamental insights into the scalable design, and scalability proprieties, of optimal control laws.
- 2. Exploiting sparse factorisations in the implementations of optimal control laws. This has the potential to greatly broaden the applicability of optimal control techniques into domains where the optimal control laws are not inherently sparse (which is the norm). This is the primary focus of the recently started ELLIIT project D10: Optimal Estimation and Control at Scale.

Both fundamental research lines will be supported by applications involving industrial partners in electric power systems, autonomous vehicles, and beyond.

# **External Funding Attracted**

N/A

# Inter-University Cooperation within ELLIIT

I am currently PI on the ELLIIT project D10: Optimal Estimation and Control at Scale, and co-PI on the ELLIIT project D4: Visual Analytics of Large and Complex Multilayer Technological Networks. Both projects have recently hired Ph.D. students, who are jointly supervised between Lund University and Linköping University, by Professor Anders Hansson and Professor Andreas Kerren respectively. This involves regular in person, and digital meetings to discuss and plan research directions. In addition I am currently acting as program chair for

the next ELLIIT Annual Workshop, which will be held in Lund on March 7-8, 2024.

#### Inter-Disciplinary Cooperation

There is a heavy emphasis on power system applications in the research conducted by my group. This has lead to much cooperation with the power systems group at Lund University (more specifically with Professor Olof Samuelsson's research group), and companies based in this area, including DNV-GL, E.On and emulate.energy. In the last five years I have also been involved with a sideline of research focused on applications of control techniques for healthcare (with NHS England), the design of optimisation algorithms (with Associate Professor Pontus Giselsson, Lund University), and the analysis of control system software (with Professor Martina Maggio, University of Saarland).

### International Collaboration

My research regularly involves a strong element of international collaboration. In the past five years I have coauthored papers with 18 internationally based collaborators, including Professors Fernando Pagnini (Universidad ORT Uruguay), Enrique Mallada (Johns Hopkins, USA) and Kaoru Yamamoto (Kyushu University, Japan).

# Patent Applications, Open Source Software, and Contributions to Standards

A recent collaboration on the analysis of weakly-hard constraints for real time control system applications resulted in the release of an open source software package https://github.com/NilsVreman/WeaklyHard.jl.

### Exploitation and Cooperation with Industry and Institutes

I have fostered industrial collaborations with emulate.energy, E.On, DNV-GL, Sony and Perstorp through the joint supervision of 10 masters thesis projects. These have covered a range of application areas including electric power systems, software for mobile devices, and the analysis of supply chains.

#### Contributions to Undergraduate/Graduate Education

I recently took a post as an associate editor for Control Systems Magazine, with the job of curating a Lecture Notes section for the magazine (the first article will appear in February 2024). I also run a YouTube channel https://www.youtube.com/richard\_pates, with a focus on control system education. The channel has more than 4,000 subscribers worldwide, and the videos are used by a lecturers at a number of internationally based universities, including ETH (Switzerland), Tel Aviv University (Israel) and The University of Sao Paulo (Brazil). In the past five years I have also been responsible for developing a range of undergraduate, masters and graduate level courses, covering a wide range of topics in control theory and electric power system analysis.

#### **Outreach Activities**

I run a research blog https://richardpates.com that explains my research activities to a general audience. These articles are often supported by videos, some of which have been highlighted in international competitions such as The Summer of Math Exposition.

#### Keynotes, Plenaries and Academic Service

- Associate Editor for Control Systems Magazine (since 2022).
- Program chair for the ELLIIT Annual Workshop 2024.
- Member of the CSS Technical Committee on Power Generation.
- Member of the steering group for the LTH Profile Area: The Energy Transition.

# 7.17 Soheil Samii, Senior Associate Professor in Cyber-Physical Systems

Soheil Samii is a Senior Associate Professor at the Department of Computer and Information Science at Linköping University, starting full-time in 2023.



He received his Ph.D. degree in 2011 from Linköping University, Sweden. He has 12 years of research and development experience from industry, including at Saab, General Motors, and Motional. He was a major contributor to the IEEE 802.1 TSN standards, now in use in the industrial automation and automotive sectors, and he received the IEEE 802.1 Working Group Chair Award for outstanding contributions to IEEE Std 802.1Qcr-2020.

#### **Description of Research Group**

I have started building my research group, thanks to funding by ELLIIT, SSF, and CUGS. My research group currently consists of two Ph.D. students whom I co-supervise, and two incoming Ph.D. students with me as the main supervisor. In addition, I supervise and examine several master thesis students in areas close to my research activities. The research carried out by myself and my group includes design optimization of switched Ethernet networks with Time-Sensitive Networking (TSN) technology, particularly focusing on real-time and safety-critical applications. In addition, we are addressing problems related to optimization of real-time and safety-critical applications where the computing and communication platform expands from the traditional embedded system to comprise edge and cloud computing, as well as wireless and cellular data communication. We are considering both design-time analysis and optimization, as well as runtime decision making and adaptation. The application area is generally real-time and control, with special emphasis on applicability and relevance to industry roadmaps. One major focus area is automotive systems, particularly advanced driver assistance systems and driving automation. I consistently apply my industry experience and leverage my large professional network to ensure that our research problems are both scientifically challenging and of high significance to future application in industry and society.

#### Plans for the Next Five Years

In the next few years, my research will focus on design and optimization of real-time and safety-critical applications on cyber-physical systems with Ethernet TSN, edge/cloud computing, and cellular communication such as 5G and beyond. In the area of Ethernet for real-time applications, TSN offers several technologies such as preemption, traffic shaping, and redundancy, leaving a large, unexplored research area in design optimization. My plan is to cover this research area, initially, with one Ph.D. student. I will continuously assess opportunities for technology insertion into the IEEE 802.1 standards, leveraging my past experience as voting member and my professional network. One of my top priorities will be to continue to expand my research group to consider design and optimization of cyber-physical systems with edge/cloud computing and 5G communication, which require the development of new performance and quality-of-service models, and their full integration into the overall design and optimization process for cyber-physical systems. One Ph.D. student will work in this research area and I plan to seek funding opportunities for a postdoc to amplify our research in this area and diversify the group's expertise and knowledge. All research activities will be done in cooperation with industry. Finally, I plan to identify an industrial Ph.D. student candidate from the automotive industry to carry out research on zonal system architectures, which are of very high interest to the automotive industry but pose very challenging research problems from deployment and design optimization perspectives. To support the outlined growth, I will seek external funding opportunities from VR, WASP, and SSF.
#### **External Funding Attracted**

Project Name	Funding agency	Total Amount (kSEK)	Duration
Adaptive Software for the Heterogenous Edge-	SSF	30.000	2022–2027
Cloud-Continuum			

#### Inter-University Cooperation within ELLIIT

I have a long-lasting collaboration with the Department of Automatic Control at Lund University. In project B6, we are currently collaborating on control–scheduling co-design for real-time control applications with sensor, controller, and actuator communication closed over 5G networks, with configured-grant scheduling. We have integrated a jitter–performance assessment toolchain, developed by Lund University, with a 5G network scheduling algorithm, developed by Linköping University. A joint paper will be submitted to a conference in early 2024. This collaboration will continue to be one of the cornerstones of my future research.

#### Inter-Disciplinary Cooperation

The aforementioned collaboration within ELLIIT is interdisciplinary (control theory and computer science).

#### International Collaboration

N/A

# Patent Applications, Open Source Software, and Contributions to Standards

N/A

# Exploitation and Cooperation with Industry and Institutes

I have supervised and examined 5 master theses (6 students) in 2023. The theses cover various aspects in 5G RAN, security, and machine learning for embedded applications. All theses have been sponsored by and carried out at companies in the Linköping area. In my master level course "System Design and Methodology" (spring semester every year), I invited a guest lecturer from Ericsson. This will continue in 2024 and beyond. I also remain in close contact with the automotive industry, specifically TechTeal who are based in Gothenburg and work closely with Swedish and German automotive companies, to identify new research and collaboration opportunities. There will be a guest lecture in my Ph.D. course "Real-Time and Dependable Ethernet Communication with IEEE TSN Standards" in 2024. I have also recently started a research cooperation with Scania.

#### Contributions to Undergraduate/Graduate Education

My research on Ethernet TSN, as well as other key results by other researchers in the community, have been incorporated into the Ph.D. course "Real-Time and Dependable Ethernet Communication with IEEE TSN Standards," which I have developed and will teach for the third time in 2024. I have also added selected, basic results into the master level course "System Design and Methodology" (spring semester of 2024).

#### **Outreach Activities**

Appeared in June 2023 edition of "Framtidens forskning" which is part of the "Dagens Industri" newspaper in Sweden, covering the area of offloading of computations to edge and cloud compute resources for future automotive cyber-physical systems.

#### Keynotes, Plenaries and Academic Service

Guest Editor of special issue of ACM Transactions on Cyber-Physical Systems. Served on two Ph.D. examination committees.

# 7.18 Susanna F. de Rezende, Assistant Professor in Theoretical Computer Science

Susanna F. de Rezende is an Assistant Professor of theoretical computer science at the Department of Computer Science at Lund University, Sweden, since December 2021.



Prior to that she was a postdoc at the Institute of Mathematics of the Czech Academy of Sciences in Prague, Czech Republic with a grant from the Knut and Alice Wallenberg Foundation, and a Simons-Berkeley Research Fellow at the Simons Institute at UC Berkeley, USA. She received her Ph.D. degree from KTH Royal Institute of Technology in 2019 and a M.Sc. from the University of São Paulo, Brazil, in 2014.

She was featured as one of the "rising stars" women in theoretical computer science at the 52nd Annual ACM Symposium on Theory of Computing (STOC) 2020, and received a Prize for Excellent Doctoral Dissertation 2018/2019 awarded by Stockholm Mathematics Centre.

#### **Description of Research Group**

I have started building my research group at Lund University, thanks to funding from ELLIIT, the Swedish Research Council (VR) and the Wallenberg AI, Autonomous Systems and Software Program (WASP). I currently have one Ph.D. student and two other Ph.D. students will be starting soon. I have also had internship students visiting for 3-6 month periods, and postdocs or Ph.D. students visiting for 1-4 weeks. My group collaborates closely with Jakob Nordström's group, which is based at both Lund University and the University of Copenhagen, and I co-supervise the five students in his group. Both our groups benefit from regular interactions and from being part of the vibrant research environment in theoretical computer science located in the Öresund region, where the IT University of Copenhagen, the Technical University of Denmark (DTU), and the University of Copenhagen all have very strong groups. Moreover, I have started collaborating with Elina Rönnberg from Linköping University through an ELLIIT funded joint Ph.D. position (project D4).

#### Plans for the Next Five Years

My plan for the next five years is to build a strong research group in complexity theory at Lund University and make progress towards some of the central goals of computational complexity theory: establishing limits on the minimum computational resources needed for concrete computational tasks. Two lines of research we will pursue in the upcoming years concern connections between proof and circuit complexity, and the hardness of searching for proofs of optimality. My group will soon consist of three Ph.D. students, and the plan is that with additional funding we will be able to expand by hiring more Ph.D. students and some postdoctoral researchers. I will leverage our collaborations with international researchers, including those in the Öresund region, to strengthen our group and attract top candidates for our positions. I will also continue to invite guest researchers for visits and to host research internships.

#### **External Funding Attracted**

Project Name	Funding agency	Total Amount	Duration
		(kSEK)	
The Complexity of Proving (Hard) Theorems	KAW	$\sim 4000$	2019–2023
(PI)			
Efficient Proofs and Computations: a Unifying	VR	4000	2022–2025
Approach (PI)			
Efficient Proofs and Computations: a Unifying	WASP	$\sim 4000$	2022-2026
Approach (PI)			

#### Inter-University Cooperation within ELLIIT

I am co-PI in the ELLIIT-funded project "Discrete Optimisation for Automatic Decision-Making in Large-Scale Complex Systems" with Elina Rönnberg at Linköping University (see project D4).

#### Inter-Disciplinary Cooperation

The above-mentioned project, with Elina Rönnberg from the Mathematical Department at Linköping University, is of inter-disciplinary nature. Our goal is to strengthen the research in the intersection between mathematical programming and computer science for discrete optimisation problems.

#### International Collaboration

I am fortunate to have a wide network of international collaborators with whom I have, or have had, joint research projects. In the past few years these have included: Kilian Risse (EPFL), Mika Göös (EPFL), Dmitry Sokolov (EPFL), Aaron Potechin (University of Chicago), Marc Vinyals (University of Auckland), Robert Robere (McGill University), Antonina Kolokolova (Memorial University of Newfoundland), Bruno Cavalar (University of Warwick), Or Meir (University of Haifa), Pavel Pudlák (Institute of Mathematics of the Czech Academy of Science), Erfan Khaniki (Institute of Mathematics of the Czech Academy of Science and Charles University), Massimo Lauria (Sapienza University), Albert Atserias (Universitat Politècnica de Catalunya), Ilario Bonacina (Universitat Politècnica de Catalunya), Srikanth Srinivasan (University of Copenhagen and IIT Bombay), and Toniann Pitassi (Columbia).

# Patent Applications, Open Source Software, and Contributions to Standards

N/A

# Exploitation and Cooperation with Industry and Institutes

N/A

# Contributions to Undergraduate/Graduate Education

N/A

# **Outreach Activities**

I was invited to speak at the closing ceremony of the European Girls' Olympiad in Informatics (EGOI) 2023.

# Keynotes, Plenaries and Academic Service

Academic service activities:

- Member of the Board of Trustees for Computational Complexity Foundation Inc. (CCF), 2023-2026.
- Member of the editorial board for the Mathematical Logic Quarterly Journal, 2023-2025.
- Program committee member for the 38th Computational Complexity Conference (CCC) 2023.
- Program committee member for the 55th Annual ACM Symposium on Theory of Computing (STOC) 2023.
- Co-organizer of Proof Complexity Beyond Propositional Logic Special Session at the 2023 North American Annual Meeting of the Association for Symbolic Logic (ASL), March 2023.
- Program committee member for Federated Logic Conference (FLoC) proof complexity workshop 2022.
- Co-organizer of the Proof Complexity Workshop at the 62nd IEEE Symposium on Foundations of Computer Science (FOCS '21), February 2022.
- Guest editor for Special Issue of Theory of Computing Systems on selected papers from the 16th International Computer Science Symposium in Russia (CSR '21).

Invited talks:

- In April 2023, I was invited to present my research on average-case complexity for maximum clique problem at the *Satisfiability: Theory, Practice, and Beyond Program* at the Simons Institute for the Theory of Computing, UC Berkeley, USA.
- In January 2023, I was invited to give two survey talks, on automatability and connections between proof and circuit complexity, at the *Meta-complexity Boot-Camp* at the Simons Institute for the Theory of Computing, UC Berkeley, USA.
- In October 2022, I was invited to to give a survey talk on automatability at the *Theory and Practice of SAT* and *Combinatorial Solving Seminar* at Dagstuhl, Germany.
- In July 2022, I was invited to give a survey talk on automatability at the *Mathematical Approaches to Lower Bounds workshop* at the International Centre for Mathematical Sciences (ICMS), Edinburgh, UK.
- In June 2022, I was invited to give a survey talk on connections between proof and circuit complexity at the *Logic Colloquium* in Reykjavik, Iceland.
- In June 2022, I was invited to give a survey talk on connections between proof and circuit complexity at the *Satisfiability: Theory, Practice, and Beyond Reunion* at the Simons Institute for the Theory of Computing, UC Berkeley, USA.

# 7.19 Tom Ziemke, Professor in Cognitive Systems



Tom Ziemke has been professor of cognitive systems at LiU since 2016. Prior to that, he was professor of cognitive science at the University of Skövde.

He received his Ph.D. in computer science from the University of Sheffield in 2000. In 2021 he received the ISAL (*International Society for Artificial Life*) Award for *Outstanding Publication of the Decade* together with Tom Froese.

# **Description of Research Group**

Ziemke leads the *Cognition & Interaction Lab* (COIN), a group of 20+ researchers working on different aspects of human-machine interaction, in particular human-robot interaction, human-vehicles interaction, and human factors. COIN closely collaborates with several neighboring research institutes, including VTI (*Swedish National Road and Transport Research Institute*), KMC, (*Center for Disaster Medicine and Traumatology*), FOI (*Swedish*)

#### **Chapter 7. Recruited Faculty**

Defense Research Agency), and RISE SICS East (part of the RISE Research Institutes of Sweden).

#### Plans for the Next Five Years

My current main research focus is my new project "Social cognition in human-robot interaction" funded by Vetenskapsrådet (Swedish Research Council) 2023-2026, which investigates the cognitive and social mechanisms underlying people's interpretation and anticipation of a range of interactive robotic systems, from automated vehicles, over animal-like robots, to humanoid robots. I also participate in a second VR project (PI: Mattias Arvola) that investigates the design of social robots intended to stimulate school kids' interest in book reading. In addition to these ongoing projects, I intend to further extend my collaboration with VTI on people's interaction with (partly) automated vehicles. The overall research agenda is to better understand the cognitive mechanisms underlying (quasi-) social interactions with different types of robotic systems. I also plan to collaborate with researchers in social neuroscience to investigate the brain and bodily mechanisms underlying such interactions. The long-term goal is to make robotic technologies and AI more understandable for people.

#### **External Funding Attracted**

Project Name	Funding agency	Total Amount	Duration
		(kSEK)	
DREAM - Development of robot-enhanced	European Commission,	77.000 (in total)	April 2014 -
therapy for children with autism spectrum dis-	FP7		March 2019
orders			
SmartWork – Smart age-friendly living and	European Commission,	apx. 3.000	January 2019
working environment	Horizon 2020		- March 2022
Social cognition in human-robot interaction	Vetenskapsrådet (Swedish	2.800	2023 - 2026
	Research Council)		
How hot is the Bookbot? Designing for emo-	Vetenskapsrådet (Swedish	3.900	2023 - 2026
tion and motivation in reading with a social	Research Council)		
robot in school			

#### Inter-University Cooperation within ELLIIT

Within ELLIIT I have submitted collaborative grant proposals together with researchers at Lund University (Aliaksei Laureshyn) and Halmstad University (Eren Erdal Aksoy), but so far without success. Previously (until 2019) I also collaborated with researchers at Halmstad University as part of a distributed research environment grant on *"Action and Intention Recognition in Human Interaction with Autonomous Systems"*, which I coordinated.

#### Inter-Disciplinary Cooperation

My research is highly interdisciplinary. My own research group integrates researchers from computer science, cognitive science, psychology, and human factors research. In addition, I currently actively collaborate with researchers in, for example, design, robotics, neuroscience, traffic psychology, education, and gender studies.

#### International Collaboration

I have a broad network of international contacts, with whom I regularly collaborate and publish (not least as a result of about 10 European projects in the last 15 years; cf. examples above).

#### Patent Applications, Open Source Software, and Contributions to Standards

As a result of the European DREAM project, which I coordinated 2014-2019, we published an open source software package and online dataset, *"The DREAM Dataset: Behavioural data from robot enhanced therapies for children with autism spectrum disorder"*. This was listed among the "Top 3 Downloads" in the Swedish National Data Service's Annual Report 2021

#### Exploitation and Cooperation with Industry and Institutes

I currently collaborate with both VTI and RISE. This includes the supervision of Ph.D. students Christian Jernberg (VTI) and Oscar Bjurling (RISE). The latter also involves collaboration with Saab Aeronautics (co-supervisor Jens Alfredsson). I also collaborate with VTI (co-PIs Jan Andersson and Anna Anund) in ELLIIT project A22 (*Human interaction with autonomous minibuses*). Collaborations with several international companies in the European projects DREAM (SoftBank Robotics Europe, now: Aldebaran Robotics) and SmartWork (e.g., Roessingh Research & Development).

#### Contributions to Undergraduate/Graduate Education

Based on the research in my group, I regularly teach Ph.D. courses on topics like "AI & Robot Ethics" (2024) and "Critical Perspectives on AI" (2023). In 2024 I will also teach a new Ph.D. course on "AI Fundamentals & Limitations" as part of the WASP-HS graduate school. My co-workers and I also regularly supervise cognitive science and computer science student projects at master, bachelor and second-year level directly related to our research on human-robot, human-vehicle and human-AI interaction.

#### **Outreach Activities**

I regularly give popular-science presentations on the public perception of AI and limitations of AI (e.g., as part of LiU's popular-science week in 2022, and the *Swedish Air Force Museum*'s theme day on *"Tomorrow's Technology"* in 2023.

I currently collaborate with a number of schools in Norrköping as part of a VR project (cf. above) on social robots intended to stimulate children's interest in book reading (PI: Mattias Arvola). We also collaborate with several municipalities and eldercare centers in Östergötland in our research social robots in eldercare (Ph.D. student Sofia Thunberg). During the DREAM project we collaborated with a number of autism treatment centers in Romania.

#### Keynotes, Plenaries and Academic Service

My most recent keynote was given at AGI-23, the 16th Annual Conference on Artificial General Intelligence in Stockholm in June 2023.

Guest-edited a special issue on "*Explainable Robot Behavior*" for the journal *ACM Transactions on Human-Robot Interaction*, together with Maartje de Graaf (Utrecht University), Bertram Malle (Brown University) and Anca Dragan (UC Berkeley), which was published in July 2021.

Program co-chair for CogSIMA 2022, the *IEEE Conference on Cognitive and Computational Aspects of Situation Management*, held in Sorrento, Italy, in June 2022.

Currently organizing a workshop on "Cars as Social Agents", to be held in Gothenburg in December 2023.

Program co-chair for the conference CogSIMA 2024, the *IEEE Conference on Cognitive and Computational Aspects of Situation Management*, to be held in Montreal, Canada, in May 2024.

# 7.20 Viktor Larsson, Assistant Professor in Mathematics



Viktor Larsson is an assistant professor at the divsion for Computer Vision and Machine Learning in the Centre for Mathematical Sciences, Lund University. He became an ELLIIT recruited faculty in 2022.

Prior to this, during 2018 - 2022, he was a PostDoc and senior researcher in the Institute for Visual Computing at ETH Zurich, Switzerland. He received his Ph.D. degree in Mathematics from Lund University in 2018. He has received best paper awards from ICPR (2016), ACCV (2018) and ICCV (2021).

#### **Description of Research Group**

My research is about visual localization and mapping, with a focus on solving the robust estimation problems that appear in 3D computer vision (e.g. Structure-from-Motion [Larsson, 2020], localization and positioning [Sarlin, 2021], SLAM and dense geometry estimation [Zhu, 2022]). Currently, the main challenges are related to dealing with scene repetitions or ambiguous structures, low-texture regions or weakly connected viewing graphs. Unfortunately, these are common in man-made environments, especially indoors. In my research group we are looking at different approaches for tackling these problems. For example, building richer map representations that more easily can integrate structural priors [Liu, 2023], or developing new learning-based robust estimation methods that can detect and discard incorrect or ambiguous correspondences [Cavalli, 2023]. Part of our research is exploring how to best combine deep learning with traditional geometry-based pipelines, aiming to replace hand-crafted heuristics and assumptions with more data-driven alternatives. My research group currently consists of myself and two Ph.D. students, and I am planning to hire one more Ph.D. student early 2024. I am also currently co-supervising two Ph.D. students at the Institute for Visual Computing at ETH Zurich.

#### Plans for the Next Five Years

In the next five years I plan to further grow and establish my research group in 3D geometric computer vision. For this I plan to acquire additional funding to hire one or two new Ph.D. students that will work on large-scale global Structure-from-Motion and mapping methods. The global (non-sequential) paradigm for map building is attractive due to being extremely scaleable compared to the current state-of-the-art reconstruction methods which perform incremental reconstruction, i.e. sequentially registering images to the reconstruction. However, the global approaches currently have comparably lower accuracy and robustness. In the next five years, in addition to my currently ongoing research directions, I plan to better understand and rectify these shortcomings.

#### **External Funding Attracted**

Project Name	Funding agency	Total Amount (kSEK)	Duration
Beyond 3D Points in Sparse Visual Mapping	VR	4000	2024-2027

#### Inter-University Cooperation within ELLIIT

Together with Michael Felsberg (LiU) and Mårten Wadenbäck (LiU), I submitted (and got accepted) a proposal for ELLIIT Call D (title: *Revisiting Data Associations in Large-Scale Mapping*, 5 MSEK). There is also ongoing collaboration with LiU as part of project B.10.

#### Inter-Disciplinary Cooperation

N/A

# International Collaboration

I have many international collaborators which I publish with regularly. In the last couple of years this has included Marc Pollefeys (ETH Zurich), Daniel Barath (ETH Zurich), Torsten Sattler (CIIRC, Prague), Tomas Pajdla (CTU Prague), Zuzana Kukelova (CTU Prague), Ondrej Chum (CTU Prague), Benjamin Kimia (Brown University), Martin Oswald (University of Amsterdam), Timothy Duff (University of Washington), Johannes Schönberger (Microsoft), Pablo Speciale (Microsoft), Janne Heikkilä (University of Oulu), Andreas Geiger (University of Tübingen), Vincent Lepetit (ENPC ParisTech), Konrad Schindler (ETH Zurich), Zhaopeng Cui (Zhejiang University), Hideo Saito (Keio University) and Shohei Mori (TU Graz).

#### Patent Applications, Open Source Software, and Contributions to Standards

I currently develop and maintain the open-source library PoseLib for camera calibration and estimation. The library contains reference implementations for the current state-of-the-art for minimal camera estimators and is aimed at making them available not only for researchers but also practitioners working on applications.

#### Exploitation and Cooperation with Industry and Institutes

I have a long ongoing collaboration with the Microsoft Mixed Reality and AI Lab in Zurich which has resulting multiple joint publications. In the scope of the collaboration we look at mapping and localization in the context of augmented reality devices, as well as considering the potential privacy concerns. I have also supervised multiple master thesis at companies such as Sony, Axis Communications, Volvo Cars, Mainblades and Microsoft.

#### Contributions to Undergraduate/Graduate Education

I am organizing the Ph.D. course *Advanced Topics in Computer Vision* which is given in the fall semester of 2023. The course is aimed at giving a broad overview of the current research while giving the students the opportunity to dig deeper into particular topics.

#### **Outreach Activities**

In November 2022, I gave talk titled *Mapping and Localization for AR* in the RI.SE organized seminar series *Learning Machines*.

#### Keynotes, Plenaries and Academic Service

- Area Chair for the International Conference on 3D Vision (3DV) 2022, Prague, Czechia.
- Area Chair for the European Conference on Computer Vision 2024, Milano, Italy.
- Organized tutorial *Benchmarking Localization and Mapping for Augmented Reality* at the *European Conference in Computer Vision* (ECCV) 2022, Tel Aviv, Israel.
- Organized tutorial *Camera Geometry Problems in Computer Vision* at the *IEEE International Conference* on *Computer Vision* (ICCV) in 2023, Paris, France.
- Started work as Local Chair for *European Conference on Computer Vision* 2026 which we are organizing in Malmö.
- Invited plenary talk at SIAM Conference on Applied Algebraic Geometry (SIAM AG23) 2023.
- Ph.D. committee member for the Ph.D. defenses of Marcel Geppert (ETH Zurich), Remi Pautrat (ETH Zurich), and discussion leader for the midway seminar of Kunal Chelani (Chalmers).
- Member of the European Laboratory for Learning and Intelligent Systems (ELLIS)

# 7.21 Xuesong Cai, Assistant Professor in Communications Engineering

Xuesong Cai is an Assistant Professor of Communications Engineering at the Department of Electrical and Information



He received his B.S. degree and the Ph.D. degree (with distinction) from Tongji University, Shanghai, China, in 2013 and 2018, respectively. In 2015, he conducted a three-month internship with Huawei Technologies, Shanghai, China. He was also a Visiting Scholar with Universidad Politécnica de Madrid, Madrid, Spain in 2016. From 2018-2022, he conducted several postdoctoral stays at Aalborg University and Nokia Bell Labs, Denmark, and Lund University, Sweden. He is currently an Assistant Professor, a Marie Skłodowska-Curie Fellow, and EL-LIIT Recruited Faculty at Lund University, closely cooperating with Ericsson and Sony.

Dr. Cai was a recipient of the China National Scholarship (the highest honor for Ph.D. Candidates) in 2016, the Outstanding Doctorate Graduate awarded by the Shanghai Municipal Education Commission in 2018, the Marie Skłodowska-Curie Actions (MSCA) "Seal of Excellence" in 2019, the EU MSCA Fellowship (ranking top 1.2%, overall success rate 14%) and the Starting Grant (success rate 12%) funded by the Swedish Research Council in 2022. He was also selected by the "ZTE Blue Sword-Future Leaders Plan" in 2018 and the "Huawei Genius Youth Program" in 2021. He is a Senior Member of the IEEE and an Associate Editor of *IEEE Transactions on Vehicular Technology, IET Communications*, and *Wireless Communications and Mobile Computing*. His research interests include radio channel characterization [Cai, 2023], high-resolution parameter estimation [Cai, 2019], over-the-air testing [Cai, 2021], resource optimization [Cai, 2023], and radio-based localization [Tian, 2023] for 5G/B5G wireless systems.

#### **Description of Research Group**

He closely collaborates with Prof. Fredrik Tufvesson in the same Department. The group consists of nine Ph.D. students and three postdocs. He is co-supervising four Ph.D. students, and will become the main supervisor of one student if his docent application is successful. The group is highly collaborative and most students/postdocs are involved in both internal and external collaborations. The research spans a wide range from theory to practice within the area of radio propagation and the interplay between radio channels and the rest of the communication system. The activities can be mainly categorized as dealing with *channel characterization* and *radio-based applications*, and often both. The former includes channel sounding, high-resolution channel parameter estimation and channel modeling. The latter includes machine-learning-based positioning and sensing and multipath-assisted positioning and sensing using messaging passing algorithms.

#### Plans for the Next Five Years

Funded by the projects secured, he is working on THz channel characterization based on physical-model-based methodology, specifically 1) developing a novel real-time THz channel sounder that can capture dynamic channel characteristics in a comprehensive manner; 2) developing a novel, generic and low-complexity high-resolution-parameter-estimation (HRPE) algorithm that is applicable for the THz channels; and 3) establishing comprehensive and realistic THz channel models that are applicable for 6G, i.e., not only for conventional communications but also for more broader communication purposes including positioning and sensing, especially in the challenging non-line-of-sight (NLoS) scenarios. For future plans, he will extend his research by exploiting machine-learning-based methodology. He will develop novel deep-learning-based HRPE algorithms, aiming to directly output accurate initialization, estimation, and tracking results of multipath components from measurement data. He will also propose deep generative modeling frameworks, and in the frameworks establish trajectory-embedded THz channel models that are naturally spatially consistent. Moreover, taking advantage of

the comprehensive understanding of THz channels and the massive realistic measurement data, he will work on the fundamentals of radio-based positioning and sensing at THz bands, in the form of multipath-assisted radio-based positioning algorithms and fundamental performance limitations. He has (in November 2023) applied to the European Research Council (ERC) for a Starting Grant with a budget of 2.5 MEUR. A successful ERC grant will allow him to establish a large research team with postdocs and Ph.D. students. Moreover, he plans to apply for the Wallenberg Academy Fellow (next call deadline in spring 2025) for follow-up research, such as establishing a real-time THz testbed and further advancing the investigations on radio-based sensing and positioning at THz bands.

# **External Funding Attracted**

Project Name	Funding agency	Total Amount	Duration
		(kSEK)	
Breaking the barriers of terahertz communica-	The Swedish Research	4,000	2023.01-
tions: understanding wave propagation for 6G	Council		2026.12
Lower THz rAdio propagation channeL sound-	Horizon Europe Frame-	2,539	2022.07-
ing, parameter Estimation and modeliNg To-	work Programme, Marie		2024.06
wards 6G and beyond	Skłodowska-Curie Post-		
	doc Fellow		
Research on Propagation Channels for Tera-	The Crafoord Foundation	1,000	2023-2025
hertz Communication, Positioning and Sens-			
ing Towards 6G			
Fast and Intelligent Modeling for Lower THz	The Royal Physiographic	257	2022-2023
Radio Channels	Society of Lund		
Next Generation Communication and Com-	Vinnova	36 000	2024–2028
putational Infrastructures and Technologies			
(NextG2Com)			

# Inter-University Cooperation within ELLIIT

He supervised a master's student at Lund University who recently joined the group of Erik G. Larsson at Linköping University as a Ph.D. student. Our groups are collaborating on the EU project 6GTandem: A Dual-frequency Distributed MIMO Approach for Future 6G Applications.

#### Inter-Disciplinary Cooperation

N/A

# International Collaboration

He is active in interacting and collaborating with researchers from other institutes and universities. Main collaborators include: Tongji University, CN (Prof. X. Yin and Ass. Prof. J. R. Piñeiro), Peking University, CN (Prof. X. Cheng), Beijing Jiaotong University, CN (Prof. A. Bo), Electronics and Telecommunications Research Institute, KR (J. Lee), Tokyo Institute of Technology, JP (Prof. J. Takada), Technical University of Madrid, ES (Prof. A. P. Yuste and Prof. C. Briso), Aalborg University, DK (Assoc. Prof. W. Fan, Assoc. Prof. T. Pedersen, Prof. G. Pedersen, and Prof. P. E. Mogensen), Technical University of Vienna, AT (Prof. M. Rupp, Assoc. Prof. S. Schwarz), University of Twente, NL (Ass. Prof. Y. Miao), and KU Leuven, Belgium (Prof. L. V. d. Perre).

# Patent Applications, Open Source Software, and Contributions to Standards

N/A

#### Exploitation and Cooperation with Industry and Institutes

He has been performing agreement-based technical cooperation with Ericsson AB, Sweden since February 2022. The main topics include mmWave and THz channel characterization and new applications such as massive MIMO based localization. He is also closely collaborating with Sony on reconfigurable intelligent surface (RIS)-assisted communications towards a doctoral thesis. He has successfully supervised one master's thesis project with Ericsson and one with Sony, respectively, and have two ongoing master's thesis projects with Ericsson.

#### Contributions to Undergraduate/Graduate Education

The latest knowledge of mmWave and THz channels has been integrated into the advanced courses "EITN75 Wireless System Design Principles" and "EITN85 Wireless Communication Channels".

#### **Outreach Activities**

- 1. "Wireless Communications: Past, Present, and Future", South Sweden Science and Technology Forum, May 13, 2023, Lund, Sweden.
- 2. "Wireless Communications meet THz", NMT days for high school students and teachers in South Sweden, March 13-17, 2023, Lund University, Lund, Sweden

#### Keynotes, Plenaries and Academic Service

#### Assignments as editor of journals

- 1. Associate Editor, IEEE Transactions on Vehicular Technology (IF 6.24), 2023-present
- 2. Associate Editor, IET Communications (IF 1.35), 2023-present
- 3. Academic Editor, Wireless Communications and Mobile Computing (IF 2.15), 2021-present

#### Organizing and chairing conference sessions

- 1. COST-INTERACT propagation measurement and modeling for 6G and beyond, EuCAP 2024.
- 2. Recent advances in integrated communication and sensing in 6G, IEEE CAMA 2023.
- 3. Practical evaluation of key scientific problems, strategies, and technologies for integrated communication and sensing in 6G, IEEE SPAWC 2023.
- 4. Measurement-based radio channel and related applications, IEEE CAMA 2022.
- 5. UAV communications for 5G and beyond, ICWMC 2021.

#### Assignments in academic organizations

- 1. Member for Delegates Assembly, European Association of Communication and Networking (EURACON), 2023-2025.
- 2. Management Committee Substitute Member, COST Action: CA20120 Intelligence-Enabling Radio Communications for Seamless Inclusive Interactions (INTERACT), 2023.
- 3. Vice Chair of "IEEE Denmark Joint Chapter Vehicular Technology Society, Aerospace and Electronic Systems Society, Information Theory and Communications Society", 2020-2021.

# 7.22 Yiannis Karayiannidis, Associate Professor in Automatic Control with focus on Robotics



Yiannis Karayiannidis is an Associate Professor (ELLIIT Recruited Faculty) with the Department of Automatic Control, Faculty of Engineering, Lund University since 2022. He received a diploma in electrical and computer engineering and a Ph.D. degree in electrical engineering from Aristotle University of Thessaloniki, Thessaloniki, Greece, in 2004 and 2009, respectively. He was previously affiliated with KTH, Royal Institute of Technology, from 2011 to 2020, and Chalmers University of Technology, from 2015 to 2022.

He received his Docent in 2017 at Chalmers University of Technology. He is a WASP-

affiliated faculty member and, currently, a supervisor of two WASP funded Phd students. His research interests include robot control and manipulation, robot navigation, haptic perception, physical human-robot interaction, adaptive control and nonlinear control systems

#### **Description of Research Group**

The core of my research group comprises four Ph.D. students: three are based at Chalmers University of Technology, and one at Lund University, where I have been positioned since August 2022. Two of the Ph.D. students at Chalmers are expected to graduate in January and April 2024, respectively. Additionally, a new Ph.D. student will join my team at Lund in January 2024. The research activities of these students cover a broad spectrum of my research interests. M. Guberina, funded by ELLIIT, and S. Fregnan, funded by WASP and starting in January 2024, will focus on the topics outlined in my research plans. Gabriel Arslan Waltersson explores friction modeling for grasping and in-hand haptic perception. Rita Laezza's thesis revolves around Robot Learning for Deformable Object Manipulation. A. Dahlin works on Reactive Motion Planning and Control under Constraints using Dynamical Systems. This diverse team significantly contributes to advancing various aspects of my research agenda. In Lund, I am co-director of the RobotLab LTH and I have close collaboration with Dr. Björn Oloffson (Associate Professor) and I am co-supervisor of two Phd students.

#### Plans for the Next Five Years

In my next research phase, my goal is to integrate three key robotic functionalities – grasping, navigation, and manipulation – traditionally associated with distinct hardware components: robotic hand, mobile platform, and robotic arm, respectively. This integration seeks to develop cohesive systems capable of performing more complex tasks in larger workspaces, a significant advancement as compared to confined environments suited for static manipulators performing simple pick-and-place tasks. For the next five years, I will focus on the design of whole-body compliance to enable advanced loco-manipulation abilities such as robot writing on a big white board, and tackle the separate yet crucial challenge of hand-arm coordination, essential for intricate manipulation tasks such as dynamic in-hand regrasping with simple grippers. I will rely on nonlinear control methods and haptic perception, focussing on adaptive techniques capable of responding to uncertainties and dynamic environmental changes. To address the limitations of current model-based approaches in these areas, I will incorporate learning-based strategies, contributing to the evolving field of robot learning. Moreover, the integration of these functionalities necessitates the development of modular software architectures, along with their precise and timely coordination.

#### **External Funding Attracted**

Project Name	Funding agency	Total Amount	Duration
		(kSEK)	
Haptic Perception for In-Hand Object Track-	WASP	4,200	2021 - 2026
ing			
Whole-body Interactive Mobile Manipulation	WASP	4,200	2024 - 2028
DAta-driven foundations for Robust de-	WASP	5,000	2019 - 2023
formable object MAnipulation (DARMA)			
DARMA bridge	WASP	500	2021

#### Inter-University Cooperation within ELLIIT

I am co-PI of the LTH Robotics Lab Infrastructure (Section 9.1) an endeavour initiated by the main PI Prof. Volker Kruger (Computer Science, LU)

#### Inter-Disciplinary Cooperation

Robotics is a field that not only encompasses multiple disciplines, but also fosters collaborations across different areas. For example, I have participated in the "Remote controlled concrete pump truck hose robot" project at the Center of Construction Robotics. Additionally, I have collaborated as a co-author of an article (currently under review) with members of the Bionics research group at Chalmers, contributing to the refinement of bionic limb control using reinforcement learning.

#### International Collaboration

I have coauthored a survey paper on "Robot Manipulation in Contact" with V. Kyrki (Aalto University, Finland) and M. Suomalainen (VTT Technical Research Centre of Finland). [Suomalainen et. al, 2022]. During 2022-2023, I hosted 4 international Phd students M. Sileo (University of Basilicata, Italy), M. Shetab-Bushehri (Institut Pascal, University of Clermont Auvergne, France), Ignacio Cuiral-Zueco (University of Zaragoza, Spain), Andrea Monguzzi (Polytechnic University of Milan, Italy.) The outcome of these collaborations was a journal publication [I. Cuiral-Zueco et. al, 2023], a conference paper, an article in preparation, and one under review.

# Patent Applications, Open Source Software, and Contributions to Standards

- US Patent Application. Publication number: 20210001486. Filed: Jul 1, 2019. Publication Date: Jan 7, 2021. Inventors: Amr Salem, Yiannis Karayiannidis. Application Number: 16/458,424.
- Controlling YuMi through ROS driver, Rita Laezza and Gabriel Arslan WalterssonGithub-yumi
- OpenAI Gym compatible RL environments for deformable linear object manipulation, Rita Laezza Github-ReForm

#### Exploitation and Cooperation with Industry and Institutes

Since August 2022, I have supervised master's theses in collaboration with industrial partners. Notable examples include projects using machine learning and probabilistic prediction techniques with Bosch AB to forecast events and predict movements of electric bicycles, and with Axis to track objects across multiple movable cameras.

# Contributions to Undergraduate/Graduate Education

As the course responsible and lecturer for "Nonlinear Control and Servo Systems" (master level course, LTH) in 2022 and 2023, I have integrated key aspects of my research into the curriculum. This includes developing

examples related to robot control, friction modeling and identification for object manipulation, which are central to my research. These topics have been effectively utilized in my lectures to enrich the learning experience.

#### **Outreach Activities**

I have delivered introductory presentations to school students visiting during the Robotic Week at LTH, hosted by RobotLab LTH November 2022 and 2023. Additionally, I was involved in planning some of the demonstrations that were presented to the students throughout their visits.

#### Keynotes, Plenaries and Academic Service

- Associate Editor for Robotics and Automation Letters (2018 2024).
- Associate Editor for International Conference on Robotics and Automation (2023 2024).
- Associate Editor for International Conference on Intelligent Robots and systems (2020 2023).
- Associate Editor for European Control Conference (2018 2024).
- Invited talk "Manipulation of Deformable (Linear) Objects: From simulation to real world experiments," 3rd workshop on Robotic Manipulation of Deformable objects: challenges in perception, planning and control for soft interaction (ROMADO-SI) at IROS22.
- Invited Talk "Adaptability in collaborative robotics tasks" in Sino-EU Conference on Intelligent Robots and Automation, June 2021.
- Session chair for the session "Compliance and Impedance Control 2," IROS22.
- Organizer of the workshop Bridging the Gap between Data-driven and Analytical Physics-based Grasping and Manipulation II, at ICRA21.
- Organizer of the workshop Representing and Manipulating Deformable Objects, at ICRA21.
- Session chair for sessions Control of Manipulation II, Learning-based Control I, Learning- Based Manipulation VI, ICRA21.

# 7.23 Yonghao Xu, Assistant Professor in Machine Learning for Remote Sensing

Yonghao Xu is an Assistant Professor in Machine Learning for Remote Sensing at the Department of Electrical Engineering, Linköping University, Sweden.



He received his B.S. and Ph.D. degrees in photogrammetry and remote sensing from Wuhan University, Wuhan, China, in 2016 and 2021, respectively. From 2021 to 2023, he was a Postdoctoral Researcher with the Institute of Advanced Research in Artificial Intelligence (IARAI), Austria. He has been an ELLIIT Recruited Faculty since 2023. He was a recipient of the First Place award in the IEEE Geoscience and Remote Sensing Society (GRSS) Data Fusion Contest in 2018. Since 2022, he has been working as the co-lead of the Benchmarking Working Group in the IEEE GRSS Image Analysis and Data Fusion Technical Committee.

His research interests include remote sensing, computer vision, and machine learning.

Recent work includes text to remote sensing image synthesis [Xu, 2023], weakly supervised semantic segmentation of remote sensing data [Xu, 2022a], universal adversarial examples in remote sensing [Xu, 2022b], and natural hazard monitoring with satellite data [Ghorbanzadeh, 2022].

# **Description of Research Group**

My research group is currently under construction and will recruit 2 Ph.D. students in the upcoming year. The primary focus of this group will be on the intersection of remote sensing technology and climate science. It will center on innovative machine learning methods and big data solutions designed to extract extensive geographical

#### Chapter 7. Recruited Faculty

insights from the vast volume of Earth observation data. It is anticipated that the research accomplishments of the group will find widespread applicability in addressing major global issues, notably including the challenges posed by escalating urbanization, the pursuit of the United Nations' Sustainable Development Goals, and the ever-evolving dynamics of climate change.

#### Plans for the Next Five Years

In the next five years, my research will focus on climate monitoring using remote sensing techniques. Currently, climate changes are posing an increasingly serious threat to the Earth system and human society. One of the most promising strategies to manage the climate crisis involves the utilization of artificial intelligence and remote sensing techniques. Nevertheless, current research mainly concentrates on individual remote sensing data sources for climate monitoring, which struggles to meet the demands of intelligent analysis and accurate prediction of climate events, such as extreme weather and natural disasters. Consequently, fusing multimodal remote sensing data to achieve a more comprehensive Earth observation has not only emerged as an international scientific frontier but has also become a major requirement for governments to address the escalating climate challenges. Thus, I plan to foster a more sustainable and intelligent approach to address the global climate emergency using multimodal remote sensing data and cutting-edge AI techniques.

#### **External Funding Attracted**

Project Name	Funding agency	Total Amount	Duration
		(kSEK)	
Community driven approach to 3D hyperspectral AI	Vinnova	1,995	2023 - 2026
for universal biodiversity classification			
Multimodal remote sensing for climate monitoring	Zenith	3,000	2024 - 2028

# Inter-University Cooperation within ELLIIT

N/A

# Inter-Disciplinary Cooperation

I am involved in two inter-disciplinary collaborations that focus on solving various applied problems using machine learning and remote sensing techniques. Together with Michael Felsberg (Professor at Linköping University) and Levi Farrand (CEO and founder of Deep Forestry), I work on three-dimensional hyperspectral artificial intelligence for universal biodiversity classification. This project is funded by Vinnova, and aims to explore and implement methods for developing a standardized hardware solution that integrates hyperspectral and LiDAR sensors into an autonomous drone platform, enabling the generation of three-dimensional hyperspectral data for biodiversity monitoring. I am also collaborating with Leif Haglund (Strategic Advisor at Maxar and adjunct Professor at Linköping University) on a project related to remote sensing for climate monitoring. This project is funded by Zenith, which represents an interdisciplinary research initiative aimed at bridging the knowledge gap between AI and the utilization of multimodal remote sensing data to foster the sustainable development of the planet.

#### International Collaboration

I am currently serving as the co-lead of the Benchmarking Working Group in the IEEE GRSS Image Analysis and Data Fusion Technical Committee, where I collaborate with researchers from other countries in many academic activities. For example, together with Ronny Hänsch (German Aerospace Center), I have been developing and maintaining the Earth Observation Database, which is a well-known interactive online platform for cataloging

different types of datasets leveraging remote sensing imagery.

During the past five years, I have co-authored papers with more than 10 researchers outside of Sweden. To mention a few: Pedram Ghamisi (Helmholtz-Zentrum Dresden-Rossendorf), Sepp Hochreiter (Johannes Kepler University Linz), Peter M Atkinson (Lancaster University), Dacheng Tao (University of Sydney), and Liangpei Zhang (Wuhan University).

#### Patent Applications, Open Source Software, and Contributions to Standards

Together with colleagues in the IEEE GRSS Image Analysis and Data Fusion Technical Committee, I have been developing and maintaining the Earth Observation Database. This database is available at: https://eod-grss-ieee.com/. Another open-source software related to this project is Txt2Img-MHN, which is available at: https://github.com/YonghaoXu/Txt2Img-MHN.

#### Exploitation and Cooperation with Industry and Institutes

Through my research projects, I collaborate with several companies:

- Vinnova project on "Community driven approach to 3D hyperspectral AI for universal biodiversity classification" with Deep Forestry (Levi Farrand).
- Zenith project on "Multimodal remote sensing for climate monitoring" with Maxar (Leif Haglund and Amanda Berg) and Deep Forestry (Levi Farrand).

#### Contributions to Undergraduate/Graduate Education

I have developed one M.Sc.-level course on *Artificial Intelligence for Remote Sensing*, which was given at Humboldt University of Berlin in the Summer of 2023. I am currently participating in the development of an M.Sc.-level course on *Deep Learning* at Linköping University, led by Fredrik Lindsten.

#### **Outreach Activities**

N/A

#### Keynotes, Plenaries and Academic Service

- Co-lead of the WG-BEN in *IEEE GRSS Image Analysis and Data Fusion Technical Committee* since 2022.
- Organizing Committee Member of the IJCAI 2022 Landslide4Sense Competition.
- Technical Committee Member of the CVPR 2022 Workshop on EARTHVISION.
- Program Committee Member of the IJCAI 2022 Workshop on Complex Data Challenges in Earth Observation.
- Program Committee Member of the CIKM 2021 Workshop on Complex Data Challenges in Earth Observation.
- Guest Editor of Special Issue on "Adversarial Attacks and Defenses for Remote Sensing Data", *Remote Sensing*, 2022 2023.
- Guest Editor of Special Issue on "Remote Sensing for Ecosystem Studies", *Frontiers in Remote Sensing*, 2022 2023.

#### 7.24 Zheng Chen, Associate Professor in Communication Systems

Zheng Chen is an Associate Professor with the Department of Electrical Engineering at Linköping University.



She received her M.Sc. degree in 2013 and Ph.D. degree in 2016, both from Centrale-Supélec, Université Paris-Saclay, France. She has been an ELLIIT Recruited Faculty since 2021 and obtained her Docent degree in Communication Systems from Linköping University in 2023. She has conducted research on various topics in wireless communication systems, including wireless edge caching [Chen, 2017], age of information [Chen, 2021], and massive MIMO [Chen, 2019].

Her current research focuses on distributed information processing and machine learning over wireless networks. Some of her recent works in this area include asynchronous wireless federated learning [Hu, 2023], over-the-air computation [Chen, 2023], and

communication-efficient decentralized learning [Herrera, 2023]. She is the recipient of the 2020 IEEE Communications Society Young Author Best Paper Award [Chen, 2017], and a senior member of the IEEE.

#### **Description of Research Group**

My research group consists of four Ph.D. students, with me as the main supervisor. I am also co-supervising four more students and have joint work with all of them. The research activities of my group can be classified into three main directions: 1) resource allocation for federated edge learning; 2) Over-the-Air (OtA) computation for distributed learning and estimation; and 3) communication-efficient decentralized optimization and learning. The specific topics span data compression, resource allocation, signal processing, medium access control, privacy, and security aspects of distributed intelligence over wireless networks. Broadly speaking, our research group aims to identify new topics and interesting problems within the intersection of communication theory, distributed algorithms, and machine learning.

#### Plans for the Next Five Years

My plan for the next five years can be listed in three parts:

- **Research**: The goal is to continue our current research activities and establish ourselves as one of the leading groups in wireless edge intelligence. One main component of our research will be communication-efficient methods for distributed systems, including distributed estimation, inference, control, optimization, and learning. From an architectural perspective, we plan to explore server-based, fully decentralized, and hierarchical designs. From a signal processing perspective, we will investigate digital, analog (with OtA computation), and hybrid communication designs. Different combinations of these two design aspects lead to different system models and research questions. Some additional side tracks (for my own research interests) include information dissemination in large random networks and neural point processes.
- **Funding**: I plan to actively apply for research projects and grants from Swedish and European funding agencies, including ERC, VR, Vinnova, and Wallenberg foundations.
- **International visibility**: I plan to increase the international visibility of my research group by organizing academic events (summer schools, conferences and workshops), giving talks and seminars at high-visibility platforms, and expanding my collaboration network.

#### **External Funding Attracted**

Project Name	Funding agency	Total Amount	Duration
		(kSEK)	
Next-generation communication design for	Swedish Research	4,000	2023-2027
distributed intelligence over wireless networks	Council (VR)		
Decentralized machine learning over large-	WASP	5,000	2023-2028
scale wireless device-to-device networks			
Wireless network design for decentralized ma-	Zenith	1,560	2021-now
chine learning			
Turning the air into an AI computer (as co-PI)	KAW	5,000	2023-2028

#### Inter-University Cooperation within ELLIIT

I was among the organizers of the 2022 IEEE SPS – EURASIP summer school on "**Defining 6G: Theory, Applications, and Enabling Technologies**". Several researchers within ELLIIT have been involved in this event, either as the organizers or invited speakers, such as Erik G. Larsson (LiU), Fredrik Tufvesson (Lund), and Nikolaos Pappas (LiU).

#### Inter-Disciplinary Cooperation

N/A

#### International Collaboration

Within the last five years, I have co-authored papers with several researchers outside Sweden, including Harpreet S. Dhillon (Virginia Tech, USA), Markus Leinonen (University of Oulu, Finland), Praful Mankar (IIIT Hyderabad, India). Through the organization of a workshop and a summer school, I have also established connection with Osvaldo Simeone (King's College London, UK), Vincent H. Poor (Princeton University, USA), Petar Popovski (Aalborg University, Denmark) and Matti Latva-Aho (University of Oulu, Finland). Currently I am in close discussions with Michel Kieffer (Paris-Saclay University, France) and Themistoklis Charalambous (University of Cyprus) for research collaboration.

#### Patent Applications, Open Source Software, and Contributions to Standards

N/A

#### Exploitation and Cooperation with Industry and Institutes

Ericsson Research in Linköping is the industrial partner of my Zenith project on "*Wireless network design for decentralized machine learning*". We have been collaborating through joint patent applications (pending) and scientific publications (ongoing).

# Contributions to Undergraduate/Graduate Education

I am in the process of developing a Master-level course titled "Distributed Information Processing and Machine Learning". This course aims at providing basic knowledge on consensus averaging algorithms over fixed and time-varying networks, and how they can be applied in dencentralized training of machine learning models across networked agents. This course aligns closely with my own research, providing a practical example of how various concepts in optimization, control, and communications are integrated in emerging engineering problems.

#### **Outreach Activities**

I have recorded an invited lecture "When complex networks meet decentralized machine learning", as part of the ELLIIT Tech Talk series.

#### Keynotes, Plenaries and Academic Service

#### **Editorial Service**

• Associate Editor of IEEE Transactions on Green Communications and Networking, since 2022.

#### **Event Organization**

- Co-chair of special session on "Decentralized learning with resource-constrained communication", at IEEE ICASSP, 2024.
- Co-chair of workshop on "Wireless Communications for Distributed Intelligence", at IEEE GLOBECOM, 2021-2023.
- Co-chair of special session on "Fast, Secure and Reliable Over-the-Air Aggregation", at IEEE Asilomar Conference on Signals, Systems, and Computers, 2023.
- Technical program chair of 2022 IEEE SPS EURASIP summer school on "Defining 6G: Theory, Applications, and Enabling Technologies".
- Program co-chair of ELLIIT Annual Workshop 2022.

#### **Invited Talks**

- Uppsala University, "Accelerating decentralized learning over wireless networks with broadcast-based communication", November 2023.
- INRIA (Sophia Antipolis) and EURECOM, France, "Distributed learning over wireless networks: A communications perspective", June 2023.
- Digital Futures Fly High seminar, "Distributed intelligence over wireless networks", December, 2021.
- ELLIIT digital seminar, "When complex networks meet decentralized machine learning", October 2021.
- IEEE Young Professionals (YP) under the IEEE Kharagpur Section, "Leveraging the heterogeneity and randomness of mobile data traffic", 2020.

# 7.25 Previous ELLIIT Recruited Faculty

The table below lists ELLIIT recruited faculty who have left the environment or are no longer supported.

Title	University	Name
Professor in Cognitive Systems	LiU	Alexander Kleiner
Associate Professor in Communication Systems	LiU	Emil Björnson
Associate Professor in Visualization and Evaluation	LiU	Camilla Forsell
Associate Professor in Electronics	LiU	Mario Garrido
Professor in Interactive Visualization	LiU	Timo Ropinski
Associate Professor in Embedded System Design	LU	Jörn Janneck
Associate Professor in Computer Vision	LU	Cristian Sminchisescu
Associate Professor in Communication Systems	LU	Harsh Tataria
Associate Senior Lecturer in Applied Electromagnetics	HH	Maria de Lauretis
Professor in Computer Science	HH	Mohammad Reza Mousavi
Professor in Computer Science	HH	Walid Taha



# **Support Activities**

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10	ELLIIT Workshop	213
11	Gender Program	215
12	ELLIIT Tech Talks	219
13	Industrial Advisory Board and Industry rum	Fo-



# 8. Research Infrastructure

The ELLIIT management has identified infrastructure as critical for several of the research activities within ELLIIT. To get a broad view for strategic discussions, the SG and PG invited researchers from the ELLIIT environment to suggest infrastructure support initiatives. Ten applications were received in spring 2021 and eight infrastructure projects were funded for five years (2022-2026). In total, the funding allocated to these initiatives (2023 figures) is 9500 kSEK per year. This funding mainly covers salary costs for research engineers and to a lesser extent equipment costs.

# 8.1 Robotics Lab Infrastructure

PI: Volker Krueger (LU) Co-PIs: Yiannis Karayiannidis (LU)

This research infrastructure initiative provides the opportunity of experimental research on planning, control, and perception for cases where there is significant force interaction between a mobile platform and a manipulator or load on an autonomous ground vehicle.



The joint vision of LU and LiU is the development of software for autonomous robotic systems (ARS) that are able to perform a predefined task through goal-directed sensing, thinking, learning and acting. This includes the ability to: use a variety of sensory data such as vision, force and torque from sensors across the entire robot, use machine learning and AI-based reasoning for reliable interpretation of the sensory data and autonomous decision making for controlling safely, with suitable forces, its actuators.

A key focus of LU is to maintain and support the software for enabling the ARS. LU and LiU collaborate with the same robot platform to allow easy replication of results for indoor environ-

ments. In addition, LU has available a Boston Dynamics SPOT robot with LiDAR and arm for experimentation in outdoor environments as well.

This initiative facilitates the exchange of hardware and software knowledge and code between ELLIIT sites, also making the resources available for research to the complete ELLIIT environment.

#### 8.2 LISA – Large Intelligent Surface Testbed with Remote Access

#### PI: Ove Edfors(LU)

Co-PIs: Fredrik Tufvesson (LU) and Liang Liu (LU)

At LU, the Large Intelligent Surface (LIS) testbed provides means to explore extreme use of the spatial dimension in wireless applications. As part of a large ELLIIT infrastructure investment, LIS became LISA (LISA – Large Intelligent Surface testbed with remote Access), a platform that can be accessed remotely and used by all ELLIIT researchers.

LISA provides a remote-access interface to the Large Intelligent Surface (LIS) testbed at LU. The LIS testbed provides means to explore extreme use of the spatial dimension in wireless applications along the lines of Massive MIMO, but with a much higher antenna count and thereby a much higher spatial resolution. The testbed operates in the sub-6 GHz frequency range and provides software-defined high-performance digital co-processing of signals to and from each antenna element, making it possible to perform measurements as well as real-time test of algorithms for, e.g., communication, over-the-air sensing, and localization. Ground-truth measurement systems are used to calibrate spatial measurements and experimental platforms are remotely controllable. Exploiting the spatial dimension can give large gains in spectral efficiency, localization precision, and link reliability, while substantially reducing the transmitted energy. This makes LIS technology a prime candidate for future wireless systems, including 6G and beyond.



#### 8.3 6G Wireless, Sub-THz Radar, and Research Beyond

PI: Lars Ohlsson Fhager (HH)

Co-PIs: Henrik Sjöland (LU), Daniel Sjöberg (LU) and Buon Kiong Lau (LU)



The platform for 6G, Sub-THz Radar, and Beyond is useful for laboratory validation of hardware research in wideband millimeter wave (mmW) and sub-THz technology. It enables probed and free-space characterization of emerging hardware for 6G wireless, quantum computing, and sub-THz radar.

This platform provides a route toward next-generation efficient sub-THz hardware, providing high-end modular equipment that can be used beyond the low-end mmW range for laboratory validation of circuit, antenna, device, and materials innovations.

# 8.4 Autonomous Systems Laboratory

PI: Erik Frisk (LiU) Co-PI: Björn Olofsson (LU and LiU)



This research infrastructure, jointly hosted at LiU and LU, provides the opportunity of experimental research on planning, control, and perception for cases where there is significant force interaction between a mobile platform and a manipulator or load on an autonomous ground vehicle.

The overall objective is the development of research platforms that features: 1) the use of a variety of sensory data such as vision, force, and torque from sensors across the entire robot; 2) force-aware planning and control for safety and efficient sensing; and 3) the use of machine learning and AI-based reasoning for reliable interpretation of sensory data and autonomous decision making for autonomous systems.

The research platform at LiU mirrors a combined autonomous ground vehicle and robot-arm setup already available at LU. In addition, sensors for perception and small-scale autonomous vehicles for collaborative scenarios are included. This initiative thus facilitates the exchange of hardware and software knowledge and code between ELLIIT sites, also making the resources available for research to the complete ELLIIT environment. The platform is integrated with the ELLIIT infrastructure Visionen 2.0.

#### 8.5 5G Connectivity and Edge Computing Lab

#### PI: Maria Kihl (LU)

Co-PIs: Fredrik Tufvesson (LU), William Tärneberg (LU) and Haorui Peng (LU)

The 5G lab at Lund University is a research platform that enables applied research on time-sensitive and mission-critical applications over 5G. The infrastructure lays the foundation for a competitive advantage going into 6G core and application research.

In collaboration with Ericsson AB, this research infrastructure is a deployment with a stand-alone 5G cell including an Open5GS-based core and Ericsson Baseband 6630, operating on NR band n3. Also, there is a Kubernetes-based edge-cloud break-out with real-time support. Further, there are several industrial UEs, which can be used to connect devices to the 5G network. The tight integration of the 5G core and cloud compute resources provides a best-case performance scenario and will allow researchers to investigate cross-layer solutions that span applications, edge, core, and wireless infrastructures. The infrastructure is in particular suitable for research on control over the cloud and Industry 4.0. With the infrastructure, time-sensitive applications



controlled over 5G or other edge computing systems can be deployed and validated in a real 5G network. The infrastructure lays the foundation for a competitive advantage going into 6G core and application research.

#### 8.6 AlOps: A Scalable Research Platform for Artificial Intelligence

#### PI: Fredrik Heintz (LiU) Co-PI: Fredrik Lindsten (LiU)

Based on many years of experience working in several different AI/ML frameworks, the research group of Fredrik Heintz has developed a light-weight DevOps platform for AI and machine learning. The platform builds upon custom-made tools mainly developed from open-source software. It supports containerization, detailed version control on multiple levels, and thereby reproducibility.



The platform greatly simplifies and speeds up research by allowing faster and better experimentation, especially when the methods transition from local development to execution on largescale computing infrastructure. It works equally well for AI/ML and robotics research including highly complex full AI-robotics stacks. For robotic research the DevOps platform includes version-controlled development environment, build environment, and run-time environment inside docker/singularity containers. The entire robot stack, as well as virtual world simulators and virtual sensors (e.g., camera, LIDAR, IMU) run inside containers that can be readily deployed on any real/virtual machine.



# Example AI-Robotics Stack and Simulation Environment

The platform can provide support to many groups within ELLIIT. It supports a wide range of use cases from simpler ML applications using data sets, to interactive reinforcement learning applications and complex robotic systems involving many different components. A research engineer is available to support researchers and provide software support, as well as accelerate and broaden the scope of machine learning by allowing large and complex experiments to run on the platform.

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# 8.7 Visualization Support and Consulting – Infrastructure, Software, and Competence

PI: Ingrid Hotz (LiU) Co-PI: Martin Falk (LiU)

This platform provides access to visualization infrastructure, software, and competence. It offers visualization consultancy as well as software development. Its main goals are to provide ELLIIT researchers with access to the state-of-the-art software and hardware infrastructure available at the Visualization Center C and the connected research units at LiU and to assist ELLIIT researchers in developing applications in software packages such as Inviwo.

Visualization for efficient data analysis and science communication plays an increasing role in many scientific applications, including ELLIIT projects. However, effective use of visual data analysis requires access to infrastructure, overview over state-ofthe-art software, hardware, and competent human support. The development and application of novel data analysis and advanced visualization methods for a large variety of applications is the focus of the scientific visualization group at the division of media and information technology at LiU in Norrköping. Since 2012, an open-source software and platform for interactive visualization, Inviwo, has been developed, mainly driven by research needs. Inviwo is now used by researchers not only at Linköping University, but also at other universities in Europe.



# 8.8 Visionen 2.0

PI: Daniel Axehill (LiU) Co-PI: Michael Felsberg (LiU)

The Visionen arena at LiU is a large modern research arena with an indoor positioning system and projectors directed towards the floor and one wall. The facility is by its combination of size and technical capabilities in terms of combined positioning and projection, a nation-unique research and demonstration arena for autonomous systems such as drones and ground robots. Furthermore, it invites for advanced motion capture and interaction with AI systems through, for example, body gestures.



The arena offers an obstacle-free volume of size  $12 \times 12 \times 8$ , meters which invites for agile experiments both on the floor as well as in the air. Positioning of objects inside the area is performed using a Qualisys marker-based optical motion-capture system, that offers a very high accuracy in the estimated pose of tracked objects made available to systems in the arena in real time. Virtual visual worlds can be built up in the area by projecting on the floor and one wall. As an example, roads where miniature autonomous vehicles move can be projected and data from these physical systems can be augmented in real time at the position of the physical robot. This brings both an impressive presentation as well as good possibilities for understanding the algorithms used

in the physical systems. Currently, the arena is upgraded in terms of motion capture system performance as well as in terms of the immersive experience offered by the projection system.



The ELLIIT Focus Period program is an ambitious guest and exchange program for international top-level scholars. The focus periods are organized twice a year at one of the four ELLIIT universities and aim to create optimal circumstances for innovating research and new collaborations. Researchers from participating universities are invited to work with other internationally established scientists on a dedicated cross-disciplinary research topic. During the 5-week focus period, the organizing university hosts visiting scholars in addition to the regular ELLIIT recruited faculty, postdocs and Ph.D. students. During each period, several seminars and a three-day high-level symposium are organized, tailored to stimulate cross-fertilization and new ideas. Since the autumn of 2021, the program has invited, once a year, proposals by potential organizers willing to host future focus periods.

# Data-Driven Modelling and Learning for Cancer Immunotherapy

The first edition of the Focus Periods program (April– May, 2022, in Lund) gathered young international scholars, ELLIIT researchers and top international academics active in domains such as systems biology, cancer treatment, machine learning and dynamical systems. These researchers worked together on jointly defined research topics.

In addition to seminars and joint research challenges using unique data sets, a larger symposium with invited top-level scientists provided knowledge exchange and networking opportunities.

The aim of the focus period was to forge new, longlasting, collaborations based on life science research



that use and drive the development of novel machine learning techniques.

More details are available here.

# Hybrid AI - Where Data-Driven and Model-Based Methods Meet

Following the same format, during October–November 2022, young international scholars, ELLIIT researchers and other well-established international academics gathered in Linköping to study techniques and methods for Hybrid AI. The focus was on two particular areas: a) Optimization for Learning and Learning for Optimization; and b) Statistical-Relational approaches to Planning, Control and Decision-making.



In connection with this focus period, there will be a topical collection hosted by the Springer journal *Operations Research Forum*. Specific topics for this edition are optimization for learning, learning for optimization, and statistical-relational approaches to planning, control and decision-making. The main purpose of the topical collection is to encourage publications from interdisciplinary work initiated during the focus period, but other contributions addressing hybrid AI within the intersection between machine learning, optimization and automatic control are also welcome.

More details are available here.

# **Network Dynamics and Control**

A central task in Network Science is to understand how to extrapolate emerging collective dynamical behaviors out of a large number of interacting elementary entities. An even more challenging task is to move from a passive observation of the behavior of a network to an active way of controlling its dynamics. Both tasks require a system-level thinking, and can have profound repercussions across the many different domains of science in which networks are of relevance, such as biology, ecology, social sciences, economical sciences, and engineering.



The aim of this focus period was to stimulate the interaction between scientists working on network dynamics and control from different perspectives, and to favour cross-talk by promoting awareness of what is available "next door".

The focus period took place in Linköping during September–October 2023. Several young international scholars interested in these research challenges participated and interacted with leading scientists and ELLIIT researchers. During the third week there was a 3-day symposium, with several invited top-level researchers.

More details are available here.

# 6G – Forming a Better Future



Research related to 6th Generation Wireless Systems (6G) comprises a wide range of topics. This focus period took a broad perspective on the possibilities and limitations of available technology and what services and applications can be provided by a future 6G system. Topics spanned from communication theory and fundamental limits to practical implementations and novel services and applications.

The goal was to close the gaps between different research disciplines, increase synergy effects, and, together, identify the most critical inter- and intra-disciplinary research challenges for 6G. What are the technical issues that we have to address from that perspective? What are the possible solutions, from a technical perspective? How should 6G be designed to contribute, in the best way, to solving global challenges?

The focus period was held in Lund during October– November 2023. Several international scholars interested in these research challenges joined to interact with leading scientists as well as ELLIIT researchers. The third week featured a 3-day symposium, with several invited top-level researchers.

More details are available here.

# Security and Fault Tolerance of Cyber-Physical Systems

This focus period will run in Lund in April–May, 2024. The goal will be to plant the seed for a radical rethinking of the way cyber-physical systems are constructed, questioning their fundamental principles, striving for constructions that are secure, safe, controllable, and dependable from the beginning.

More details are available here

#### Machine Learning for Climate Science

This focus period will bring together researchers who share an interest in machine learning for climate science in general, and machine-learning-augmented modeling and analysis of climate and weather systems in particular. The period will run in Linköping during September–October, 2024.

More details are available here

#### Plans for 2025

During 2025, two focus periods are planned: Robot Learning (at LU), and Visualization-Empowered Human-in-the-Loop Artificial Intelligence (at LiU).



Once a year, the ELLIIT community meets at one of the four participating universities for scientific discussions and networking. The event is open to everyone involved in ELLIIT, as well as invited guests. The program typically features invited keynote speakers, presentations by ELLIIT recruited faculty, poster sessions, and mini-workshops with the purpose of stimulating discussions about future directions and collaborations. In total, since the start of ELLIIT in 2010, we have organized 13 workshops.

Recent ELLIIT workshops include:

- ELLIIT workshop 2022 (October 19-20, Linköping)
- ELLIIT workshop 2021 (October 26-27, Lund)
- ELLIIT workshop 2020, digital due to the pandemic
- ELLIIT workshop 2019 (October 15-16, Karlskrona)

Details on these workshops, including workshop programs, are available on the workshop section of the ELLIIT webpage.

#### Highlights from the ELLIIT Workshops 2021 and 2022

Since 2020, ELLIIT has grown with many new recruited faculty, new postdoc and Ph.D. projects, infrastructure initiatives, and the Gender Program.

The two past ELLIIT annual workshops took place at Lund University (2021) and Linköping University (2022), and research leaders presented their projects and results. At both occasions, around 200 participants from the participating universities (LiU, LU, BTH and HH), industrial partners and invited guests met for scientific discussions and networking.

Both annual workshops were two days long, and comprised a broad mix of talks, mini-workshops, poster sessions, keynote addresses, social activities for networking, and – most importantly – scientific discussions. The workshop ended with mini-workshops where ELLIIT researchers could discuss lessons learned from completed projects.



Project presentations at the ELLIIT Annual Workshop 2021.



Industry talks at the ELLIIT Annual Workshop 2021 (left) and 2022 (right).



Poster session at the ELLIIT Annual Workshop 2022.

# 11. Gender Program

In recent years, greater focus has been placed on the integration of gender aspects into all levels of decision making and into the visibility profile of ELLIIT. Specifically, this involves the use of role models to motivate young researchers of underrepresented gender both in research and in education, at all levels, from the undergraduate to the graduate level. It also implies review, auditing, and refinement of decision processes, at all levels of ELLIIT, in order to enforce and follow up the awareness of gender-related issues among everyone involved.

At Lund University there is a special ELLIIT support initiative for young researchers of underrepresented gender, with the aim of bridging the funding gap directly after the Ph.D. Researchers supported in the past include:

- 2013-2014, Hui Li, now Professor in antenna technology at Dalian University of Technology, China
- 2015-2016, Martina Maggio, now Professor in automatic control at Lund University
- 2017-2018, Emelie Engström, now Associate Professor in computer science at Lund University
- 2019-2020, Carina Geldhauser, now Associate Professor in applied mathematics at Lund University
- 2021-2022, Elena Pagnin, now Assistant Professor in security at Chalmers University of Technology, Sweden
- 2023-2024, Ida Arvidsson, currently postdoc in mathematics at Lund University

During 2019, ELLIIT introduced the ELLIIT Gender Call, a special initiative that supports gender equality activities such as career development, mentorship, and outreach. The total budget allocated was 450 kSEK per year. This effort was continued in 2021 and 2022 under the name ELLIIT Gender program. To further strengthen this, ELLIIT's steering group decided to establish a group with representatives from each partner. This group decides, in consultation with the PG, which activities to focus on and allocate funds to projects implemented by the respective universities.

Some examples of projects that have been partly or fully financed by the Gender Program are given below.

#### **11.1** Building a Community at LU

PIs: Sandra Pott (LU), Sara Maad Sasane (LU) and Carina Geldhauser (LU)

This project deals with the empowerment of the women mathematicians working and studying at LU. Many activities as Women's career events, Career fika and Mentoring female students have been initiated to inspire and empower female students and staff members to succeed in their careers.

To inform our female students about the many opportunities with a degree in mathematics or engineering mathematics, and to give them the opportunity to ask their questions in a protected environment, we launched a series of career talks, which we complemented by a women's career fika.

Motivation and a positive environment are crucial to prevent the drop-out of underrepresented groups. In 2021 LTH Mathematics launched a mentoring program aimed at providing support and guidance to junior female staff. The program paired experienced female staff members with junior female colleagues, providing them with the opportunity to receive mentorship and guidance as they progress in their careers. The mentoring program was well received by all participants. We also had side-events for this. For example, we supported our female students in their application for fellowship programs.

#### 11.2 Women and Mathemathics

PIs: Sara Maad Sasane (LU) and Carina Geldhauser (LU)

The goal of this project was to connect women mathematicians working in Sweden. There was a network, in the 1980s/1990s, called "kvinnor och matematik". We aimed at the revival of the old network, and make it a meeting place for all women mathematicians in Sweden. We started to reach out to all women mathematicians with a Ph.D. degree at other Swedish universities. We are proud to report that our network has reached the majority of women mathematicians at Swedish universities. Furthermore, we created a LinkedIn Group, to better connect staff, students and Alumnae. A steering committee has been formed to achieve a more sustainable action within the group. To connect back to the older generations, who were active in the old network, we formed a senior advisory. Gerd Brandell, Barbro Grevholm and Lars-Erik Persson are part of this group.

In 2022 LU organized a Louise Petrén Day celebrating Louise Petrén, the first woman to obtain a Ph.D. in mathematics in Sweden. The event was repeated 2023 and will be a yearly event consisting of a Louise Petrén lecture and other invited speakers. It is open to everybody including undergraduate students. In 2023 the Louise Petrén lecture was given by Prof. Nina Gantert, Technical University of Munich, who works in the area of probability theory and is an exceptional mathematician, an amazing supervisor, mentor and role model.

#### 11.3 AI Lund Diversity in AI Program

#### PI: Sonja Aits (LU)

The focus has been to inspires current and future students by outreach activities by female LU researchers. For example female LU researchers have given public lectures and made available teaching material for the general public. A "diversity in AI at LU" website has also been developed.

#### 11.4 Attitudes Toward Female Ph.D. Supervisors

#### PI: Katerina Vrotsou (LiU)

Women are still widely underrepresented in senior academic positions. This is especially true in STEM (Science, Technology, Engineering and Mathematics). Despite the large body of research conducted to try to explain this gap and active initiatives taken to reduce it, the differences persist. With this as motivation, this project set out to explore the attitudes and expectations directed towards female academics in their roles as supervisors of Ph.D. students.

The project "Attitudes towards female Ph.D. supervisors" was inspired by a report for the pedagogic course in Research Supervision which explored the attitudes of Ph.D. students towards their female supervisors through a small-scale interview study and a literature review. This small study gave rise to initial insights into common experiences that female academics have. The report is available here.

A larger exploration of the topic was, therefore, pursued that was directed to all female academic staff working with STEM at LiU. An anonymous survey was composed exploring the experiences of female supervisors w.r.t.
### Chapter 11. Gender Program

discrimination, challenging of their supervisor capacity, as well as differences in attitudes and expectations toward them. Respondents were encouraged to leave their contact information if they were willing to participate in a follow-up interview. The survey so far has collected responses from 31 female main/co-supervisors and 4 follow up interviews were conducted. The results and insights from it are being summarized in an article.

### 11.5 Training and Networking for Female Researchers

PIs: Nauman bin Ali (BTH) and Jürgen Börstler (BTH)

The aim of this project is to offer female Ph.D. students and early career researchers training on career planning and leadership. The training has been conducted by an independent organization specializing in academics' personal and professional development. In 2019, this opportunity was availed by two Ph.D. students and two associate professors at BTH. The training and network activities have so far contributed to a successful funding application and a promotion to associate professor. In 2023, training for three female Ph.D. students from two departments at BTH was funded by ELLIIT.

## 11.6 Workshop for Early-Career Women Researchers

PIs: Nauman bin Ali (BTH) and Marlena Nowaczyk (HH)

In 2023, BTH and HH organized a half-day workshop at BTH, Karlskrona, for early-career female researchers from "young" Swedish universities.

The workshop brought together senior and early career researchers from BTH and HH to discuss practical concerns for early career researchers at "young" Swedish universities. It aimed at raising awareness of career paths and key performance indicators of academia, learning about funding possibilities and opportunities, and networking.

The workshop had a plenary session (open to everyone who signed up) with two talks by leading academics at BTH. It followed a moderated discussion on challenges and opportunities for early career researchers.

### 11.7 Inspirational Evenings for Female Students

### PI: Svante Gunnarsson (LiU)

The aim of the project was to arrange inspiration events for female students. The first inspiration evening for female students was held in collaboration with the student associations Yvette, Emma and Donna in February 2020. The participants listened to very good presentations from three female LiU alumni who now work at Scania, Saab and ABB, respectively. About 35 students participated, and the lectures aroused a lot of questions and discussions, and the event was much appreciated. Similar events were carried out in February 2021 (remotely due to the COVID-19 pandemic) and March 2022.

### 11.8 Activities Aimed at High School Students

### Visits at BTH and HH

PIs: Nauman bin Ali (BTH) and Marlena Nowaczyk (HH)

In December 2023, BTH and Ericsson Karlskrona organized a Girls Technology Day. Over 120 girls from different schools participated in several hands-on activities during this event. The event is aimed to raise awareness and curiosity about a career in technology. We also had some ELLIIT branded giveaways with a URL to ELLIIT webpage. In December 2023 there was a technical day at HH for young girls from schools in Kungsbacka.



ELLIIT workshop for early career researchers 2023 at BTH, Karlskrona.

# Programming with Satellite Data

### PI: Görel Hedin (LU)

This activity focused on Inspirational Python programming exercises for high school students. By using real open data such as satellite images and other environmental data, we wanted to give the students scientific and societal aha moments, as well as spike their interest in programming. The exercises are collected at a website that can be used freely in schools and at science centers. The project was a collaboration between researchers in Computer Science and in Ecosystem Sciences, and with educators at the Vattenhallen Science Center, all at Lund University. In addition, the project had collaboration with the Swedish National Space Agency (Rymdstyrelsen), the European Integrated Carbon Observation System (ICOS), and the Swedish Science Centers organization (SSC). In the project we had a mix of female and male participants at all levels: researchers, educators, and university students.

### RoboCup@Home and LiU@HomeWreckers

### PI: Tom Ziemke (LiU)

The Ph.D. student Sofia Thunberg was the leader of LiU's student robot competition team. The aim of the project was to support Sofia in the process of preparing and participating in a robot competition event in Bordeaux during 2020. Efforts were devoted to the preparation phase for the competition, however, due to the COVID-19 outbreak, the 2020 competition was canceled.



ELLIIT has recorded an ambitious seminar series on digital transformation and societal challenges from an ICT (Information and Communications Technology) perspective. The four ELLIIT sites participated and the topics are based on visions from 2030 Technology Foresight.

During the fall of 2022 and the spring of 2023, a new theme was released on YouTube every two weeks. Each topic comprises presentations by two ELLIIT researchers on the topic of the theme, with interviews of the two researchers, and a summary discussion with an invited external guest. All in all, the series spans 18 hours of popular science presentations and discussions with a target audience of high school students and technically interested people and engineers in all fields. The twelve themes are as follows:



- 1. Industry 4.0
- 2. AI, large-scale algorithms, ML, deep learning, and XAI
- 3. Intelligent assistants and tools
- 4. Mobile processing architectures and devices
- 5. Next-generation software technology part 1
- 6. Big data and network science
- 7. Design for security, privacy and trust part 1
- 8. Design for security, privacy and trust part 2
- 9. Autonomous vehicles and robots
- 10. Next-generation software technology part 2
- 11. Digital business models and legal aspects
- 12. Communications and networks beyond 5G

Detailed contents of the themes can be found here.





# 13. Industrial Advisory Board and Industry Forum

# Industrial Advisory Board

The Industrial Advisory Board consists of representatives from six industry partners with high relevance for the ELLIIT environment. The board has the following roles:

- 1. Coordinate contacts between companies and ELLIIT, help facilitate technology transfer of results from ELLIIT to industry, and identify industrial challenges to ELLIIT.
- 2. Disseminate information about ELLIIT to the company management at large and, in relevant cases, to the individuals in the organization who work specifically with university contacts.
- 3. Advise the ELLIIT management on how ELLIIT can expand existing cooperation with Swedish industry and create new such collaborations.
- 4. Help facilitate new joint university-industry ventures, for example funded by national agencies such as VINNOVA and the Knowledge Foundation, and by the European commission.
- 5. Provide advice to ELLIIT management, for example, when making specific strategic decisions.
- 6. Actively participate in the ELLIIT workshops and stimulate workshop participation from industry.
- 7. Act as host for delegations from ELLIIT at technology visits.
- 8. Promote and facilitate mobility between industry and academia.

Current members of the Industrial Advisory Board are:

- Magnus Frodigh (Ericsson)
- Björn Ekelund (Ericsson)
- Nicklas Johansson (Ericsson)
- Petter Bedoire (Saab)
- Stefan Andersson (Saab)
- Shiva Sander-Tavallaey (ABB)
- Fredrik Hertzberg (Axis Communications)
- Azra Habibovic (Scania)
- Oskar Nilsson (Schneider Electric)

## The Industrial Advisory Board Day in June 2022

During the industrial advisory board's day at LiU on 2 June, about 20 people from the business and academic sectors attended. The discussions included what businesses need and how ELLIIT can maximize the benefit to industry and society in terms of what can be achieved in the research field.



# **Industry Forum**

To continue to develop ELLIIT's cooperation with industry, we are currently forming an industry forum. While the ELLIIT Industrial Advisory Board has a more formalized role, the industry forum is an informal association, open to everyone in the Swedish business community who is interested in ELLIIT's activities. Initially, the focus of the industry forum will be on companies in geographic proximity of Linköping/Norrköping, Lund, Karlskrona, and Halmstad.

The first planned activity with the industry forum is a breakfast meeting on January 25, 2024, in the Visionen Arena (Campus Valla, Linköping University), where we will demonstrate the four new infrastructure initiatives within ELLIIT that are based at LiU.



# **ELLIIT Alumni**

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# 14. Alumni Statistics

One of the main goals of ELLIIT is to provide the Swedish industry with competence in information technology and mobile communications. The following chart shows the last known affiliation of ELLIIT former researchers (including postdocs and ELLIIT recruited faculty that moved) and Ph.D. students from the years 2010–2023. Most ELLIIT alumni stay in Sweden, and most work in industry, but a few work abroad and a few work in academia.



# ELLIIT Ph.D. Student Alumni

As shown in the following chart, most of the Ph.D. students from the ELLIIT environment (2010–2023) work in industry and most stay in Sweden:



The Ph.D. students funded by ELLIIT have been recruited by a wide array of companies, as exemplified in the following table:

Companies		
3Shape		
ABB	Ericsson	
AFRY	ETC	
Anacatum Design	Huawei	SAAB
Apple	HyperMathe	Savantic
Apptus Technologies	inriver	Sigma Technology
Arriver	Intel Corporation	SiliconIntervention
AutoX	InterDigital	Sleip Al
Axis Communications	Julia Hub	Sony
BorgWarner	MediaTek	Squarepoint Capital
Bosch	Meta	Syncore Technologies
Built Robotics	Mindcamp	Systecon
CellaVision	Mitsubishi Electric Research	Terranet
Cellink	NIBE	Toyota Material Handling
Cognibotics	NIRA Dynamics	Trijo
Combain Mobile	Nokia	Verisure
<b>Cross Technology Solutions</b>	Nordea	Volvo Group
Debricked	North Link	Waymo
Diet Doctor	NVIDIA	Xenergic
Eigenvision	NXP Semiconductors	Zenseact
EMEA	Orange Cyberdefense	
	PagoNxt	
	Pfeifer & Langen	
	RADICAL	

# 15. ELLIIT Alumni – Portraits

Alumni include Ph.D. students who graduated from the environment, postdocs, and senior researchers that have taken positions elsewhere. Here, we give a few examples of careers of alumni after they left ELLIIT.

### Ebo K. Bennin

Ebo K. Bennin joined BTH/DIPT as a postdoctoral researcher 2019 with a Ph.D. from City University Hong Kong. He is currently an Assistant Professor at Wageningen University & Research in the Netherlands. His work in defect prediction has been published in highly ranked journals in software engineering. In the latest bibliometric assessment of software engineering themes, scholars and institutions (2013–2020) published by the Journal of Systems and Software (vol. 180, 2021), Dr. Bennin has been ranked among the most active early-stage researchers in top-quality journals.

# Karl Berntorp

Karl Berntorp graduated with a Ph.D. from Department of Automatic Control, Lund University in 2014 with Karl-Erik Årzén as main advisor. The title of the thesis was "Particle Filtering and Optimal Control for Vehicles and Robots". Since then, he has worked for MERL – Mitsubishi Electric Research Laboratories in Boston, MA, where he currently is Senior Principal Research Scientist. Karl's research interests include statistical signal processing, Bayesian inference and learning, sensor fusion, and optimization-based control, with applications to automotive, transportation, navigation, positioning, and communication systems. Karl is an Associate Editor of IEEE Transactions of Control System Technology and a member of the IEEE Technology Conferences Editorial Board. He has been very productive both during his time as a Ph.D. student and during his industrial career. His Ph.D. thesis mentioned 20 publications, the majority from very prestigious journals or conferences in control, robotics, or signal processing. For 2021 only, his Google Scholar pages listed 23 entries, including 11 US patents, two journal publications (one in Automatica), and 10 conference publications, e.g., IEEE Conference on Decision and Control (CDC) and American Control Conference (ACC). To date, Berntorp has coauthored more than 160 research papers.

Emil Björnson joined LiU/ISY as an Assistant Professor (ELLIIT recruited faculty) in 2014. After working and being nurtured in the ELLIIT environment for eight years, he left to join KTH as a Full Professor of Wireless Communication in 2022, where he is also an Associate Director of the strategic research environment Digital Futures. His career at LiU was marked by several distinctions, including winning the SSF Future Research Leaders grant, becoming a Wallenberg Academy Fellow, receiving the IEEE Marconi Prize Paper Award in 2018, the IEEE Fred W. Ellersick Prize in 2019, and the Pierre-Simon Laplace Early Career Technical Achievement Award in 2020. He is cited more than 28000 times according to Google Scholar, and was named IEEE Fellow in 2022, at the age of only 38.

# Markus Borg

Markus Borg graduated from LU/CS with a Ph.D. in 2015, "From Bugs to Decision Support – Leveraging Historical Issue Reports in Software Evolution," with Per Runeson as the main advisor. Markus then joined the Software and Systems Engineering Laboratory at SICS (Swedish Institute of Computer Science). Based on the early research output, a bibliometric assessment of top software engineering scholars 2010–2017 listed Markus as one of the world's top 15 "Rising SE Stars" and "Most Active Early Stage SE Researchers." As an example of practical impact, a research prototype for machine learning-based issue assignment developed during the Ph.D. studies has evolved into an internal Ericsson product that has been operational for three years. Markus now works as a senior researcher with RISE Research Institutes of Sweden in the Humanized Autonomy unit in the Digital Systems Division and remains active at LU/CS as an adjunct lecturer. His current research focus is at the intersection of software engineering and applied artificial intelligence, collaborating with many Swedish companies such as Ericsson, Volvo Cars, and ABB. He is a board member of the trade organization Swedsoft (since 2018) and serves on the editorial board of the Springer journal *Empirical Software Engineering*.

# **Ricardo Britto**

Ricardo Britto joined BTH as a Ph.D. student in 2013 and graduated with a Ph.D. in 2017 (supervisor: Jürgen Börstler). After his Ph.D., he joined Ericsson AB where he became a manager in the area of data science. Since 2021, he has been head of the Ericsson BSS incubator and the BSS AI program. Ricardo has kept contact with academia and participated in several industry-academia collaborations. In addition to his work as manager, he is an active researcher with an excellent publication record since his Ph.D. Since 2019 he has rejoined BTH as a part-time adjunct senior lecturer (10%).

# Manon Kok

After receiving a M.Sc. in Applied Physics in 2009 Manon worked two years as research engineer at Xsens Technologies BV, Enschede, Netherlands. Manon started many different cooperations during her time at LiU, for example with Aalto University, Espoo, Finland where she was a visiting Ph.D. student in the Bayesian Methodology Group for 2.5 months in 2015, and worked with Dr. Simo Särkkä and Dr. Arno Solin. In 2016 she defended her thesis "Probabilistic modeling for sensor fusion with inertial measurements" with Thomas Schön as supervisor and Fredrik Gustafsson and Jeroen Hol as co-supervisors. Manon was greatly appreciated as a teacher during her time at LiU. Her research interests lie in the fields of probabilistic modeling for sensor fusion, signal processing, and machine learning, specifically sensor fusion using inertial sensors and magnetometers. She was postdoc at the University of Cambridge in 2017–2018 and is now Associate Professor at Delft University of Technology in the Netherlands. In July 2018 her paper "Scalable Magnetic Field SLAM in 3D Using Gaussian Process Maps" won the ISIF 2018 Jean-Pierre Le Cadre Best Paper Award at the 20th International Conference on Information Fusion. In 2021 she was awarded an NWO Talent Program Veni grant to work on sensor fusion for indoor localization using the magnetic field.

### Jonas Linder

In 2017 Jonas Linder defended his Ph.D. thesis "Indirect System Identification for Unknown Input Problems: With Applications to Ships". Jonas Linder's research topic was modeling and estimation of ship dynamics. As a postdoc at the division of automatic control at LiU he partially continued his Ph.D. research, mainly focusing on unknown inputs in a dynamic network setting and cancellation of non-linearities in mechanical systems by using indirect input measurements. He also started collaborating with ABB Corporate Research and ABB Marine in Finland. The project with ABB was related to state estimation for ships. In 2018 he joined ABB Corporate Research as a Senior Scientist where he was later promoted to Principal Scientist. This was an industrial research position in data-driven modeling, model-based control, simulation and sensor fusion mainly for applications in marine automation and mining. In the marine projects, the primary task has been to run the development of algorithms for data-driven dynamics modeling and optimal control related topics. The mining activity was towards the Sustainable Under-ground Mining (SUM) project with the focus on material tracking and simulation of mines. In 2022 he joined ABB Marine and Ports, where he works as lead developer of algorithms for the Marine Pilot Control product.

### Babak Mohammadi

Babak Mohammadi graduated from LU in 2017 with Joachim Rodrigues as main advisor. He is the CEO and co-founder of Xenergic, a spin-off company based on his research. Xenergic's memory solutions enable a reduction in power in digital devices of 70–90%, which allows one to extend the battery life of portable devices and reduce the heat and power consumption of high-speed communication and computation segments such as 5G/6G and large data centers. Moreover, their high-speed memory solutions cover clock frequencies beyond 6 GHz which is 2 to 3 GHz higher than other existing memory solutions. An officially announced customer is Bosch-Sensortec, a well-known sensor provider to major mobile phone manufacturers. Babak has formed and is driving a very strong team with 10 different nationalities, where 40% of the technical team members hold Ph.D. degrees with many years of industrial experience.

### Hien Q. Ngo

Hien Q. Ngo joined LiU in 2010 and graduated with a Ph.D. in 2015 with E. G. Larsson as main advisor. He is currently a Reader (Associate Professor) at Queen's University Belfast, UK. During his Ph.D. he wrote a number of seminar papers on the information-theoretic analysis of Massive MIMO, a concept that during the 2010's evolved from a wild academic idea to the core physical-layer technique in 5G, now being deployed world-wide. For this work, he won the IEEE ComSoc Stephen O. Rice Prize in 2015, the IEEE ComSoc Leonard G. Abraham Prize in 2017, and the Best Ph.D. Award from EURASIP in 2018. To date, Hien has co-authored more than 100 research papers, and the Cambridge textbook *Fundamentals of Massive MIMO* (2016). He was listed among the world's 100,000 most cited scientists across all scientific fields in 2017, 2019, and 2020 (according to PLOS Biology). Further distinctions include the IEEE CTTC Early Achievement Award in 2023, and the UKRI Future Leaders Fellowship (2019-2026), a highly prestigious Fellowship awarded to only 41 future leaders across the whole United Kingdom. He also won the QUB Vice-Chancellor's Early Career Researcher Prize (2020) and the VR Research Fellowship of the Swedish Research Council (2016).

### Sina Khoshfetrat Pakazad

Sina has a diverse background in a variety of domains, ranging from machine learning, deep learning, and statistical modeling to optimization and control. During his education and professional life, he has applied his knowledge to a wide range of challenges and use cases in different industries. More recently he has been mainly working on developing and designing large-scale optimization frameworks, and enhancing data science life cycles and decision making processes under uncertainty by developing approaches for providing better probabilistic views of predictions and interpretability, especially for deep neural networks. Sina was a Ph.D.

student in automatic control at LiU, and in 2015 he defended his thesis "Divide and Conquer: Distributed Optimization and Robustness Analysis" with supervisor Anders Hansson and co-supervisors Anders Helmersson and Torkel Glad. As a Ph.D. student, Sina cooperated independently with Anders Rantzer, LU, and Martin Andersen, DTU. Sina was much appreciated as a teacher during his time at LiU, and 2013 he received the best teacher award from the Y students. During 2015-2016, he was a Postdoctoral Fellow at LiU, and 2016-2017 he joined Ericsson, Kista, as an experienced researcher. He joined C3 AI, Redwood City, California, United States as a senior data scientist in 2017 to work on supply chain optimization. In 2019 he was promoted to senior data scientist, and in 2021 to principal data scientist. During 2021-2023 he worked as a Staff Data Scientist, at Waymo, San Francisco Bay Area. He is now back at C3 AI working as Data Science Vice President.

# Emma Söderberg

Emma Söderberg graduated from LU/CS with a Ph.D. in 2013, "Contributions to the Construction of Extensible Semantic Editors", with Görel Hedin as main advisor. She then spent four years at Google, working on developer tools. In particular, she was part of the team developing the Tricorder static analysis meta tool that is used on a daily basis by Google developers worldwide, and led to a highly cited ICSE publication. She then led the development of a similar tool Tricium, supporting the Chromium open source community developing the Chrome browser. In 2018, Emma rejoined LU/CS where she is now a Senior Lecturer since 2022 and Reader (Docent) since 2021. Her current research interests include programming tools, adaptive recommender systems, usability, and developer experience. She has received several prestigious grants, including a Future Research Leader grant from the Swedish Foundation of Strategic Research (SSF-FFL), and a starting grant from the Swedish Research Council (VR). She has been on the program committee of top conferences like ICSE, ASE, and ECOOP, chaired international conferences like <Programming> and ACM SIGPLAN SLE, and she is on the editorial board of the Programming Journal. As of 2023, she is part of the ELLIIT program group.

# João Vieira

João was one of the Ph.D. students who did much of the work on our massive MIMO testbed, LuMaMi. He defended his dissertation in November 2017, and received the Färs & Frosta Sparbank award for best LTH thesis in 2017 (a 100 kSEK cash award). Joao has since been at Ericsson Research in Lund where he leads a team of researchers doing research in 5G and 6G. He is also a prolific inventor with 50+ patent applications. Joao is driving the joint EU project, REINDEER, between LU, LiU and Ericsson (together with KU Leuven, Technikon, Telefonica, NXP, BlooLoc, and TU Graz) and can be seen as an excellent example of academic researchers who contribute to technology transfer between ELLIIT and industry.

