ELLIIT

Excellence Center at Linköping – Lund in Information Technology

ANNUAL REPORT 2022

Contact:

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INSTRUCTIONS

Within ELLIIT, we have defined the terms "core" and "environment". The core comprises, among others, individuals engaged in the ELLIIT management, PIs and co-PIs of ELLIIT projects, ELLIIT Recruited Faculty, as well as Postdocs and Ph.D. students working in ELLIIT projects. The expectation on ELLIIT's core is to normally report not only work directly funded by ELLIIT but also activities that are to some extent connected thereto, such as keynotes, courses, outreach, awards, patents, industry collaborations and open source software contributions. We ask that you to bear that in mind when completing the report.

Please do not change the document formatting.

1) ELLIIT Project PIs/co-PIs (Calls A-C) and ELLIIT Recruited Faculty:

- Go to "Input from ELLIIT Projects" and find your Project(s) **or your name**. Fill in the required information under the 14 specified sections. For sections where you do not have anything to report, please explicitly state N/A.
- Recruitments in connection to the project (students, postdocs, faculty, research engineers etc): here we ask that you report everyone who **has been involved** in the project at any point in time (i.e. **not only during 2022**).
- For the section "Main scientific achievements", please write a coherent story (2-3 paragraphs) about the most important results. No publication lists here.
- For the section "List of patent applications", please add (only) patent applications **published during 2022**
- At the end of the document, there is an Appendix to be completed by **all Project PIs/co-PIs and ELLIIT recruited faculty**. Please fill in information about "Other recruitments in the broader ELLIIT environment", "Guest researchers and visiting students" as well as "Ph.D. and licentiate defences".

2) PIs/co-PIs of ELLIIT Infrastructure Initiatives and ELLIIT Gender Projects:

- Please report your main achievements, status of the project, recruitments/ persons involved in the projects, etc.

Deadline: April 15, 2023.

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Introduction

The expansion of ELLIIT

ELLIIT underwent a significant expansion in 2020, with a total annual budget of currently 110 MSEK (2023). The funding is pre-allocated as 45 % to each of LiU and LU, and 5 % to each of BTH and HH. In June 2020 a new agreement between the four partners was signed, that outlines the forms of management and cooperation. A principle for the use of funding was established, which determines that 30-50% of the funding should be used for the support of projects and 30-50% of should be used to fund tenured and tenure-track positions in the ICT area covered by the scope of ELLIIT. 0-20 % of the funding should be used for special initiatives.

Management structure

The ELLIIT management structure and roles has evolved since 2020, to account for the extended funding and increase in scope. From July 2020, the program is governed by a Steering Group (SG) and a Program Group (PG). The PG is led by a Chair and includes the Director and the co-Director. These governing bodies are seconded by the ELLIIT Operations Team, that provide administrative, fiscal and communication support.

The steering group (SG) has had monthly meetings during 2022. The SG decides about the allocation of the project funding and oversees the appointment processes of the ELLIIT permanent positions. It monitors the development of the research projects, and takes initiatives to new project calls, as well as to twinning activities between the university sites and research groups. The SG members are nominated by the partner sites and formally appointed by LiU.

The Program Group (PG) is appointed by the ELLIIT SG and is composed of ELLIIT senior researchers. The PG is responsible for the day-to-day management of the program, follow- up of the scientific activities and planning future activities.

More details are available on the ELLIIT website, www.elliit.se

ELLIIT calls 2020-2022, approved projects

ELLIIT Call A

In 2020, ELLIIT invited proposals for postdoctoral projects to explore new directions within the scope of the ELLIIT Technology Foresight 2030. In total, 84 applications were submitted, and 22 postdoctoral projects were funded, listed below. These projects run for two years, 2020-2022.

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

PI: Alexey Vinel, Halmstad
Participating researcher: Maria Kihl, LU

Summary
Vehicle-to-everything (V2X) communications is a crucial component of future autonomous vehicles. Our objective is 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 is driven by the needs of Swedish automotive industry, specifically Volvo Cars.

1. Main scientific achievements during 2022

Connected and automated vehicles (CAVs) will be a key component for future cooperative intelligent transportation system (C-ITS). Since the adoption of C-ITS is not foreseen to happen instantly, not all of its elements are going to be connected at the early deployment stages. We consider a scenario, when the vehicles approaching traffic light are connected to each other, but the traffic light itself is not cooperative. Information about indented trajectories such as decisions on how and when to accelerate, decelerate and stop, is communicated amongst the vehicles involved. We provide an optimization-based procedure for efficient and safe passing of traffic lights (or other temporary road blockage) using vehicle-to-vehicle communication (V2V). We locally optimize objectives that promote efficiency such as less deceleration and larger minimum velocity, while maintaining safety in terms of no collisions. The procedure is computationally efficient as it mainly involves a gradient decent algorithm for one single parameter.

Formal models for the safety validation of autonomous vehicles have become increasingly important. To this end, we present a safety framework for longitudinal automated driving. This framework allows calculating minimum safe inter-vehicular distances for arbitrary ego vehicle control policies. We use this

framework to enhance the Responsibility-Sensitive Safety (RSS) model and models based on it, which fail to cover situations where the ego vehicle has a higher decelerating capacity than its preceding vehicle. For arbitrary ego vehicle control policies, we show how our framework can be applied by substituting real (possibly computationally intractable) controllers with upper bounding functions. This comprises a general approach for longitudinal safety, where safety guarantees for the upper-bounded system are equivalent to those for the original system but come at the expense of larger inter-vehicular distances.

2. Awards and recognitions

The article G. Sidorenko, A. Fedorov, J. Thunberg and A. Vinel, "Towards a Complete Safety Framework for Longitudinal Driving," in IEEE Transactions on Intelligent Vehicles, 7(4), 2022 has been “the most popular” in the journal according to the IEEE portal.

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
SafeSmart – Safety of Connected Intelligent Vehicles in Smart Cities (HH)	KKS	2MSEK KKS + 2MSEK HH + 2MSEK in-kind	4 years
EPIC – Emergency Vehicle Traffic Light Pre-emption in Cities (HH)	VINNOVA	1.2MSEK	2 years

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Taqwa Saeed (2 years postdoc)	0000-0002-0081-427X	2021-2023
Galina Sidorenko (PhD-student)	0000-0001-8587-2251	from 2021

5. Inter-university cooperation: summary for 2022

The main scientific results have been achieved in cooperation between Lund University (Aleksei Fedorov), Halmstad University (Alexey Vinel, Johan Thunberg, Galina Sidorenko, Felipe Valle). Taqwa Saeed was with Halmstad University and now with Lund University.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

N/A

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

N/A

8. International collaboration

N/A

9. Supervision of master thesis projects in collaboration with industry

N/A

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

N/A

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

N/A

13. Academic service activities, including chairing of conferences, editorships and similar

N/A

14. Open source software contributions

N/A

A2: Scalable Data Processing in Networked Systems

PI: Anders Rantzer, Lund
Co-PIs: Richard Pates, LU, Claudio Altafini, LiU, Anders Hansson, LiU

Summary

This project aims to develop scalable algorithms to monitor, predict, and analyze data from largescale dynamic networks. In line with ELLIIT focus theme Big Data and Network Science, the objectives are:
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. 2. To develop tools to support network operators monitoring the behaviour of networked systems, through scalable

algorithms with provable performance guarantees. They will build on classically established tools for small systems and focus on techniques for extension to large-scale settings. The theory will be supported by applications to emerging areas such as the operation of energy networks with increasing levels of renewable penetration, congestion predictions in city traffic and information propagation in social networks.

1. Main scientific achievements during 2022

Progress continued on two main fronts:
First, a methodology for designing structured optimal filters and control laws for transportation networks was developed. The method allows for the systematic and scalable implementation of globally optimal control laws and state-estimators. The results were applied to a range of transportation network models, with a particular emphasis on irrigation networks.
Continued research results with relevance to the optimal control of electric power systems, were presented at the Conference on Decision and Control, and published in Control System Letters. A further 15 project relevant journal and conference contributions from the PI and co-PIs were published.

2. Awards and recognitions

Plenary lecture at Reglermöte 2022, Luleå
Plenary lecture at 17th IEEE International Conference on Control and Automation, Neaples
Plenary lecture at 10th IFAC Symposium on Robust Control Design, Kyoto, Japan
Invited virtual seminar IFAC/IEEE webinar series on Nonlinear Control Systems
Invited virtual seminar at Peking University
Invited virtual seminar at Beijing Institute of Technology

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
Scalable Control of Interconnected Systems	ERC: European Research Council	0.5 MEUR	2019-2024
Statistical and Adversarial Learning in Continuous System Control	WASP collaboration project	1.1 MSEK	2019-2024
Throughput Control in Autonomous Networks	WASP PhD project	0.9 SEK	2019-2024

AI for Guidance, Navigation and Control (AI4GNC)	European Space Agency	35 kEUR	2021-2022
Learning in Networks: Structure, Dynamics, and Control	WASP NEST project	1.0 MSEK	2022-2026

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Johan Lindberg	0000-0001-9491-8354	2020-2022

5. Inter-university cooperation: summary for 2022

There were two main meetings between the PIs and coPIs in 2022 to discuss the key research directions for the project, at the ELLIIT Annual workshop, and the Swedish Control Conference.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

N/A

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

Research discussions with industrial partner emulate.energy were maintained through the year.

8. International collaboration

N/A

9. Supervision of master thesis projects in collaboration with industry

N/A

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
The CoPI developed new masters course starting Lund January 2022: FRTN75 Learning Based Control	MSc

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

N/A

13. Academic service activities, including chairing of conferences, editorships and similar

Member of the steering committee for the International Symposium on Mathematical Theory of Networks and Systems
Member of Editorial Board for the journal Annual Reviews in Control
Member of WASP research management group for Mathematics in AI
Member of review panel for completed projects funded by the European Research Council.
Member of the IEEE Control Systems Society Fellow Evaluating Committee
Member Evaluation Committee for Wallenberg Academy Fellows
Member of the Advisory Board for Lecture Notes in Control and
Information Sciences at Springer Verlag Heidelberg
Member of the IEEE Control System Society Technical Committee on
Nonlinear Systems and Control
Member of the IFAC Technical Committee on Nonlinear Systems
Member of the IPC for L4DC - Conference on Learning for Decision and Control, ETH Zürich, 2021.
General Co-chair for the organization of European Control Conferenence 2024 in Stockholm

14. Open source software contributions

N/A

A3: Autonomous Radiation Mapping and Isotope Composition Identification by Mobile Gamma Spectroscop

PI: Anders Robertsson, Lund
Participating researchers: R Johansson, LU, M Greiff, LU, R Tyllström, LU, E Rofors, LU

Summary

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 is 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 will be 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 School of Aviation (TFHS) providing the piloting and expertise during field experiments. The proposed project is well aligned with the priority item 1 in the 2030 ELLIIT foresight, as it will involve new models for decision-making and control with novel ways of representing and identifying the radiation intensity functions. This will be done with methods closely related to non-parametric machine learning, also aligning nicely with point A in the 2030 foresight. Consequently, we believe that this is a project ideally suited for ELLIIT due to its compatibility with the foresight, and we strongly believe that it will grant ELLIIT good exposure if the result is taken into active use at ESS.

1. Main scientific achievements during 2022

2. Awards and recognitions

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)

5. Inter-university cooperation: summary for 2022

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

8. International collaboration

9. Supervision of master thesis projects in collaboration with industry

10. List of patent applications published during 2022

Patent title	Application Number

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

13. Academic service activities, including chairing of conferences, editorships and similar

14. Open source software contributions

A4: Secure Transparent Communications in the Industrial Internet

PI: Andrei Gurtov, LiU

Summary

Industry 4.0 (Focus theme 4) 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. This project builds new collaboration with Lund University, Prof. Christian Gehrmann (Lund University) in the area of Industrial Internet for a postdoc position. It focuses and secure and scalable interworking of industrial equipment with assets protection and privacy control.

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.

1. Main scientific achievements during 2022

QUIC Throughput and Fairness over Dual Connectivity: 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. The results provide insights for network operators on how to deploy DC to achieve optimal performance and fairness for end-to-end service.

A user-centric privacy-preserving authentication protocol for IoT-AmI environments: We have developed a privacy-assuring authentication protocol for Ambient Intelligence (AmI) Internet of Things (IoT) applications. The protocol uses blockchain and fog computing for unforgeability, non-repudiation, and efficient bandwidth utilization. It also employs physically unclonable functions (PUF), biometrics, and Ethereum powered smart contracts for preventing attacks. The proposed protocol is computationally inexpensive and resource-efficient, providing a better solution than conventional centralized infrastructure-based authentication approaches.

Optimization of relay placement for scalable virtual private LAN services: This work focuses on providing secure connectivity for geographically dispersed devices to a protected LAN network through Virtual Private LAN Services. Traditional IP routing protocols are not sufficient for this, so encrypted HIP/IPsec tunnels are used. However, the number of tunnels can grow exponentially, so the introduction of relaying is proposed. The work studies 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.

Dew-Cloud-Based Hierarchical Federated Learning for Intrusion Detection: This work addresses the issue of securing data in IoT devices, which are increasingly being used due to the pandemic. 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. The proposed solution provides a higher level of data privacy and greater availability of critical IoT applications.

Towards 6G-Enabled Internet of Vehicles: Security and Privacy: The emergence of 6G mobile wireless networks will enable innovative applications, including the Intelligent Transportation System and Smart Cities. However, such systems have stringent requirements for ultra-low latency, high reliability, and massive connections. Providing security and privacy is a top priority, and this sudy discusses the potential role of enabling technologies such as AI, network softwarisation, blockchain, and physical layer authentication in ensuring the expected level of security and privacy for the Internet enabled physical systems.

A Wireless Caching Helper System Serving Heterogeneous Traffic with Secrecy Constraints: This research analyzes the performance of a wireless caching system with heterogeneous traffic and relaying capabilities while ensuring secrecy for one of two receiving users. The study investigates the impact of the relay's storage split and the presence of an eavesdropper on the system's average throughput and delay, considering various transmission parameters. The work provides valuable insights for designing wireless caching systems that meet secrecy requirements and improve their performance.

2. Awards and recognitions

- Prof. Andrei Gurtov, the principal investigator, has been recognized as one of the top 2% of scientists worldwide in the Scopus Database by Stanford University.
- Research.com, a highly regarded platform, has acknowledged Prof. Andrei Gurtov as a distinguished researcher in the field of computer science.

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
Automation Program II	Trafikverket	800,000 SEK	3 Years

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Ioannis Avgouleas	-	2020-12-17 to 2021-09-30
Gurjot Singh	0000-0002-0732-1478	2022-03-15 to 2023-03-15

5. Inter-university cooperation: summary for 2022

The LiU researchers in the project have been collaborating with Lund University (Prof. Christian Gehrmann).

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

We are working closely with Billy Josefsson from Luftfartsverket to secure the communication ecosystem in the aviation industry.

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

- We invited Joakim from Ericsson to give lectures to our bachelor's and master's students at LiU.
- We conducted cybersecurity research in cooperation with Ericsson and Knowit in Linköping.
- We have worked and are working closely with Shahid Raza (RISE AB) on various cybersecurity-related research problems.
- We had talks with Shiva Sander-Tavallaey from ABB and Axel Bååthe from SAAB - The Rainforest, discussing the possibilities of applying our cybersecurity solutions to their industrial problems.

8. International collaboration

There are many ongoing international collaborations. A few of them are listed below:

- Madhusanka Liyanage, University College Dublin, Ireland.
- Pardeep Kumar, Swansea University, United Kingdom.
- An Braeken, Vrije Universiteit Brussel, Belgium.
- Pawani Porambage, VTT Technical Research Centre of Finland, Espoo, Finland.
- Corinna Schmitt, Universität der Bundeswehr, München, Germany.
- Stuart W. Card, AX Enterprize, USA.

9. Supervision of master thesis projects in collaboration with industry

- Yousef Hashem and Elmedin Zildzic, 'Endpoint Intrusion Detection and Response Agents in Embedded RAN Products: A suitability and performance evaluation,' Ericsson AB, Linköping.
- Adrian Bystrom and Mattias Salo, 'An evaluation of eXpress Data Path from a 5G perspective: Offloading packet processing functions of a 5G simulator to a driver context,' Telefonaktiebolaget LM Ericsson, Linköping.
- Hanna Gustafsson & Hanna Kvist, 'Cyber Security Demonstrations using Penetration Testing on Wi-Fi Cameras,' Totalförsvarets forskningsinstitut – FOI, Linköping.

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
TDTS04: Computer Networks and Distributed Systems	Undergraduate
TDTS06: Computer Networks	Graduate
TDTS11: Computer Networks and Internet Protocols	Undergraduate
TDDE21: Advanced Project: Secure Distributed and Embedded Systems	Graduate

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

- Prof. Andrei Gurtov and his team developed the open-source protocol HIP, which anonymizes the identities of devices over the internet and was used as a core component by Tempered Networks. Recently, Tempered Networks was acquired by Johnson Controls.
- Prof. Andrei Gurtov, along with the team, prepared the IETF Draft on Drone Remote Identification Protocol (DRIP) Architecture, which is currently under review. Additionally, the research team also provided codes on GitHub for support, extension, and feedback.
- We received appreciation from both industry and academia for our work presented at the SIGCOMM conference.
- Prof. Andrei Gurtov delivered a talk on "Computer Science Research Today and in the Future" at Swedsoft.

13. Academic service activities, including chairing of conferences, editorships and similar

- Prof. Andrei Gurtov (PI) has served as an Associate Editor for the Sensors journal.
- Prof. Andrei Gurtov (PI) is currently serving as Chair of IEEE Sweden section.
- Prof. Andrei Gurtov served as a session chair at the 22nd Seminar of the Swedish IT Security Network (SWITS 2022) in Karlstad.
- Prof. Andrei Gurtov played a vital role in ensuring the quality of accepted papers and various activities as part of the program committee for the 30th IEEE International Conference on Network Protocols.
- Prof. Andrei Gurtov is currently serving as an Editorial Board Member for the Internet of Things Section in the Sensors Journal.
- Prof. Andrei Gurtov served as a Guest Editor for the special issue titled "Smartphone Sensors for Driver Behavior Monitoring Systems," published by the Sensors Journal.

- Prof. Andrei Gurtov also served as a Guest Editor for the special issue titled "Research and Practice Special Issue on Distributed Ledger Technology (DLT) for Beyond 5G Systems," published by ACM Transactions on Distributed Ledger Technologies.

14. Open source software contributions

- 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.
- Prof. Andrei Gurtov and his team developed DRIP, an open-source protocol, for the reliable identity verification of drones.

A5: Dynamics and Control of Data-Driven Networks

PI: Claudio Altafini, LiU
Participating researchers: Anders Rantzer, LU, Erik G. Larsson, LiU

Summary

The overall goal of this project is to interface control systems and network science methodology, with the purpose of investigating the following specific topics:

1. developing network-level graph learning approaches from big data;
2. predicting emerging global dynamical properties (e.g. “opinion” formation, polarization, clustering, etc.) on the resulting networks;
3. designing network control algorithms.

The project is in the focus theme Big Data and Network Science of the ELLIIT 2030 Technology Foresight. The requested funding is meant to cover a 2-year postdoctoral position.

1. Main scientific achievements during 2022

- 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.
- Emerging Global dynamical properties: We have 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. Discrete-time versions of the results have also been obtained, extending results valid for stochastic matrices (and inhomogeneous Makrov chains).

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
Multiagent dynamics and collective decisions on signed graphs	Vetenskapsrådet	1M SEK	4 years
Multi-resolution dynamical modeling of multiple sclerosis	Swedish Foundation for Strategic Research	8 M SEK	5 years

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Carmela Bernardo, postdoc		From 2022

5. Inter-university cooperation: summary for 2022

In 2022, we have collaborated with Univ of Sydney, Chinese Academy of Science, Tongji University in Shanghai, Univ of Sannio, Benevento, Italy.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

The PI collaborated with various groups at IFM 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 couple of journal papers.

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

N/A

8. International collaboration

N/A

9. Supervision of master thesis projects in collaboration with industry

N/A

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
Opinion Dynamics on Social Networks	PhD

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

Our research on climate negotiations was highlighted in a LiU news article entitled "A mathematical model may give more efficient climate talks", see https://liu.se/en/news-item/matematisk-berakningsmodell-kan-ge-mer-effektiva-klimatsamtal

13. Academic service activities, including chairing of conferences, editorships and similar

The PI served as Associate Editor for Automatica and for IEEE Trans 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 Trans. on Control of Network Systems". He was on the IPC committee of the 11th Int. Conference on Complex Networks and Their Applications, and of the 9th Workshop on Distributed Estimation and Control of Networked Systems (NecSys'22).

14. Open source software contributions

N/A

A6: Robust motion planning

PI: Daniel Axehill, LiU
Participating researchers: Johan Löfberg, LiU

Summary

The research considers motion planning problems in unstructured environments where there are non-negligible model uncertainties and disturbances present. There is a fundamental trade-off between performance and robustness of a motion plan. If the performance of a system is pushed to its limits in

terms of input, state, and collision avoidance constraints, any discrepancy in the a priori knowledge could result in dangerous situations. To avoid this, a conservative plan is often computed. In the research in this project, the aim is to, in different ways, incorporate more precise and up-to-date information about disturbances and to decrease uncertainties in the plan that traditionally often are handled by introducing conservativeness. The research considers four different directions to provide a better combination of performance and safety: disturbance-parameterized motion primitives to explicitly take into account disturbances, real-time 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.

1. Main scientific achievements during 2022

- A unifying complexity certification framework for active-set QP methods has been presented.
- A high-performing QP algorithm has been implemented in library-free C-code and made available at github under the name daqp. The algorithm and software have been shown to be very competitive compared to other state-of-the-art software commonly used for MPC.
- A novel integrated robust motion planning and control framework has been developed. The main idea is to introduce the notion of disturbance-parameterized motion primitives, which can be used on-line to optimally exploit disturbances and feedforward from them rather than to counteract them as previous approaches typically do. The work includes theory, algorithms, and a challenging marine application.
- We have developed an algorithm that is capable of exactly certifying the computation *time* for a standard active-set QP solver. This is a big step forward and has interesting applications in, e.g., model predictive control.
- Our work within exact complexity certification of MILP and MIQP solvers took important steps forward including, e.g., to include the possibility to compute suboptimal solutions.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
Predictive control for belief-space planning	EOARD	1,47MSEK	2 years
iDecide	FFI, Vinnova	1,1MSEK	4 years

Unified task planning and optimal-control-based motion planning	WASP industrial PhD	1MSEK	5 years
iQDeep	FFI, Vinnova	1MSEK	4 years
Real-time certification and self-optimization of interior-point and branch-and-bound software for predictive control	WASP academic PhD	1MSEK	5 years
Real-time certification and reinforcement learning code generation for model predictive control	Swedish Research Council (VR)	971kSEK	4 years

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Abhishek Dhar (Postdoc)	0000-0001-6061-7860	From September 2021

5. Inter-university cooperation: summary for 2022

During 2022, the PI and the post-doc within the project have collaborated with a researcher from ETH Zürich, a collaboration which continues during 2023.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

N/A

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

The PI has research collaborations with Scania CV, Saab Dynamics and FOI.

8. International collaboration

There has been collaboration with a researcher at ETH Zürich, which was initiated during the ELLIIT focus period during fall 2022. Furthermore, during the preparation of a PhD student study trip to the UK, the PI has collaborated with professors from University of Cambridge, University of Oxford, Imperial College London, and Kings College London.

9. Supervision of master thesis projects in collaboration with industry

- Hilding Gunnarsson & Adam Åsbrink. Intelligent Drone Swarms: Motion Planning and Safe Collision Avoidance Control of Autonomous Drone Swarms. Performed at Saab Dynamics.
- Ester Brandås & Sandra Ljungberg. Collision Avoidance for Complex and Dynamic Obstacles. Performed at Toyota Material Handling.
- Lloyd Kizito, An Adaptive Strategy For Short Term Stock Trading Using Reinforcement Learning. Performed at Celerus Capital AB.
- Axel Ek, Neural Network Based Control Design for a Unicycle System. Performed at Combine.

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
Automatic control project course TSRT10: several projects are strongly connected to research projects.	undergraduate

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

The PI led a PhD student study trip to the UK involving around 50 PhD students, including visits to University of Cambridge, University of Oxford, Imperial College London, and Kings College London.

13. Academic service activities, including chairing of conferences, editorships and similar

N/A

14. Open source software contributions

Daqp: https://github.com/darnstrom/daqp (now integrated into YALMIP)
ASCertain: https://github.com/darnstrom/ASCertain.jl
YALMIP: https://github.com/yalmip/YALMIP

A7: Effective Business Prototyping for Software Startups

PI: Elizabeth Bjarnason, LU

Summary

Software startups develop innovative software-intense products under uncertain conditions and with a severe lack of resources. While launching a startup is relatively easy through the availability of open-source software and pay-as-you-go services, acquiring paying customers and thriving in uncertain conditions are among their top challenges, and startups often waste precious time and resources on developing features that are not successful in the market and run a high risk of failing. 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, we propose exploring the use of different types of prototypes, their costs and benefits, through literature reviews, theory building and case studies. Our aim is to provide actionable guidelines that can 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. The project was finalised in June 2022.

1. Main scientific achievements during 2022

- Validated and revised our theoretical framework / model of prototyping aspects (first published in 2021). The revised version is currently under review at Empirical Software Engineering Journal.
- Explored prototyping technology in startups and identified challenges and opportunities for startups to improve their adoption of prototyping technology. The work was done in collaboration with Dr. V Gupta (Alcala, Spain). The results have been published in IT Professional.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

N/A

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Elizabeth Bjarnason	0000-0001-9070-0008	2020-2022

5. Inter-university cooperation: summary for 2022

- Collaboration with Dr. Ali, BTH, on model and criteria for selecting software.
- Initial dialog with Prof. Lavesson, BTH, on prototyping in relationship to AI and SMEs.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

N/A

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

- Collaboration with various startups in the Lund/Malmö region.

8. International collaboration

- Collaboration with Dr. V Gupta from university of Alcala, Spain.

9. Supervision of master thesis projects in collaboration with industry

N/A

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
ETSN15 Requirements Engineering: student projects in collaboration with local startup companies	Graduate
ETSF25 Business of Software: Expanded with a section on prototyping in software startups	Undergraduate

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

N/A

13. Academic service activities, including chairing of conferences, editorships and similar

- Reviewing for Requirements Engineering Journal, Transactions of Software Engineering, Information and Software Technology Journal, Software and Systems Modelling Journal
- Served on programme committee for the Int. Conf. On Requirements Engineering

14. Open source software contributions

N/A

A8: Gazing at Code Review(s)

PI: Emma Söderberg, LU
Participating researchers: Luke Church, Univ. Cambridge/LU, Diederick Niehorster, LU, Markus Nyström, LU, Johanna Persson, LU, Christofer Rydenfält, LU, Christoph Reichenbach, LU, Jürgen Börstler, BTH

Summary

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.

1. Main scientific achievements during 2022

The empirical code review study carried out in the project was wrapped up and the results were reported in two publications:

- Söderberg, E., Church, L., Börstler, J., Niehorster, D. C., and Rydenfält, C. (2022). "What's bothering developers in code review?" ICSE-SEIP'22: 44th International Conference on Software Engineering: Software Engineering in Practice, 2022.
- Söderberg, E., Church, L., Börstler, J., Niehorster, D. C., and Rydenfält, C. (2022). "Understanding the Experience of Code Review: Misalignments, Attention, and Unit of Analysis". EASE'22: 26th International Conference on Evaluation and Assessment in Software Engineering, June 2022.

The final pieces of the GANDER framework developed in the project came together during 2022 to a point where it's 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, along with the contribution of the platform which is now released as open-source as part of the publication:

- Saranpää, W., Apell Skjutar, F., Heander, J., Söderberg, E., Niehorster, D. C., Mattsson, O., Klintskog, H., and Church, L. (2023). "GANDER: a Platform for Exploration of Gaze-driven Assistance in Code Review". EMIP'23: International Workshop on Eye Movement in Programming, June 2023.
- https://gitlab.com/lund-university/gander

2. Awards and recognitions

N/A

3. External funding attracted

"DAPPER: Seamless, Tailored Code Review", academic PhD project funded by WASP 2023-2027, was proposed based on the results from the empirical code review study of this project.

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
ADAPT: Adaptive Developer Tools	VR	680k	2020-2024
ADAPT: Adaptive Developer Tools	SSF	2M	2020-2025

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Olivia Mattsson (amanuens)	0009-0008-4640-9326	2021
Hedda Klintskog (amanuens)	0009-0003-2683-154X	2021
William Saranpää (amanuens)	0009-0005-0811-3354	2022-2023
Felix Apell Skjutar (amanuens)	009-0001-4076-430X	2022-2023

5. Inter-university cooperation: summary for 2022

Joint collaboration between LU and BTH on the empirical code review study in the project.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

The empirical code review study in the project brought together researchers in the project working in Human-computer Interaction, Programming Tools, Software Engineering, Eye-tracking, and Psychology.

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

Collaboration agreement with Axis Communication.

8. International collaboration

N/A

9. Supervision of master thesis projects in collaboration with industry

N/A

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
EDAG05: Agile Software Development, which includes code review which connects to the GANDER project.	undergraduate

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

Söderberg contributed to the ELLIIT Tech Talk series and also presented results from the project at Lindholmen Software Days in Oct 2022 (“Making Code Review Fit for Purpose”).

13. Academic service activities, including chairing of conferences, editorships and similar

Söderberg was associate editor of volume 6 of the Programming Journal, PC chair of the <Programming> conference, and artifact evaluation co-chair for ICPE. She joined the steering committee of SLE and AOSD (overseeing the Programming Journal and the <Programming> conference).

14. Open source software contributions

The platform developed in the project has been shared as open-source at https://gitlab.com/lund-university/gander

A9: Safety and Resilience in Multi-Vehicle Behavioral Control for Autonomous Ground Vehicles

PI: Erik Frisk, LiU
Participating researchers: Lars Nielsen, LiU, Björn Olofsson, LiU

Summary

In this project we will develop 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.

1. Main scientific achievements during 2022

In addition to the PI and co-PIs, post-doc Victor Fors and PhD student Theodor Westny have been active in this project. Focus has been on safety and resilience in different multi-vehicle traffic situations. Main efforts have been directed to 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 safety and robustness of automated vehicles. The two key scientific achievements during 2022 have been 1) a method for acting in an uncertain world, published in IEEE Transactions on Intelligent Vehicles, and 2) methods for probabilistic prediction of intentions and actions of surrounding traffic.

Branching MPC in multi-vehicle scenarios with adversarial disturbance models

An approach to resilient planning and control of autonomous vehicles in multi-vehicle traffic scenarios has been developed in this research. The strategy called *Adversarial Disturbance-Sequence Branching Model Predictive Control (ADSB-MPC)* is based on model predictive control, where alternative predictions of the surrounding traffic are determined automatically such that they are intentionally adversarial to the ego vehicle. This provides robustness against the inherent uncertainty in traffic predictions and to reduce conservatism, an assumption that other agents are of no ill intent is formalized. Simulation results from highway driving scenarios show that the ADSB-MPC in real-time negotiates traffic situations out of scope for a nominal MPC approach and performs favorably to state- of-the-art reinforcement-learning approaches without requiring prior training. The results also show that the controller performs effectively, with the ability to prune disturbance sequences with a lower risk for the ego vehicle. The research has during 2022 been presented in a main scientific publication in the IEEE Transactions on Intelligent Vehicles:

Victor Fors, Björn Olofsson, and Erik Frisk, "Resilient Branching MPC for Multi-Vehicle Traffic Scenarios Using Adversarial Disturbance Sequences", in IEEE Transactions on Intelligent Vehicles, 2022, https://doi.org/10.1109/TIV.2022.3168772.

Intent and trajectory prediction of surrounding vehicles in complex multi-vehicle scenarios
One possibility to achieve resilient autonomous motion planning is robust predictions of surrounding road users' future behavior. The use of learning-based methods for such models and predictors is a promising research topic. For this purpose, a model has been developed and analyzed in

Westny, Theodor, Joel Oskarsson, Björn Olofsson, and Erik Frisk, "MTP-GO: Graph-Based Probabilistic Multi-Agent Trajectory Prediction with Neural ODEs." Preprint, 2023 (arXiv:2302.00735).

The model encodes the scene using temporal graph neural networks to produce the inputs to an underlying motion model. A key finding is that it is highly beneficial to preserve the graph structure both in the understanding of the scene and in the predictor part of the model. The motion model is implemented using neural ordinary differential equations where the state-transition functions are learned with the rest of the model. Multimodal probabilistic predictions are obtained by combining the concept of mixture density networks and Kalman filtering. The results illustrate the predictive capabilities of the proposed model across various data sets, outperforming several state-of-the-art methods on a number of metrics. In this work, the significant benefits of using differential-constraints in the predictor were shown. Then, it becomes natural to investigate what kind of motion constraints should be used for best performance. Examples of alternatives are simple kinetic models, kinematic vehicle motion models, or neural ODEs that are learnt in parallel to the predictor models. The more flexible models have the advantage of better capturing the motion of different traffic participants, e.g., cars, trucks, cyclists, or pedestrians. This research was accepted for presentation at a main conference in the area, the IEEE Intelligent Vehicles Symposium

Westny, Theodor, Joel Oskarsson, Björn Olofsson, and Erik Frisk, "Evaluation of Differentially Constrained Motion Models for Graph-Based Trajectory Prediction", accepted for publication at 2023 IEEE Intelligent Vehicles Symposium (arXiv:2302.00735).

2. Awards and recognitions

N/A

3. External funding attracted

N/A

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Victor Fors, post-doc	0000-0003-4034-2868	2021-2022
Jian Zhou, PhD student	0000-0002-1050-3037	2020-
Theodor Westny, PhD student	0000-0001-9075-7477	2020-

5. Inter-university cooperation: summary for 2022

Significant joint research has been performed between Div. Vehicular Systems, LiU and Dept. Automatic Control, LU. Björn Olofsson (LU) is a Senior Lecturer at Dept. Automatic Control and spends 20% at LiU, active in different ELLIIT activities (including projects A9, B14, and S4). The Ph.D. students Theodor Westny and Jian Zhou are active within the projects (with Björn Olofsson as co-supervisor). This organization of staff and supervision establishes a very strong connection between the two research groups involved in this subproject.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

N/A

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

- VTI (tire models and road geometry characteristics, Dr. Sogol Kharrazi)
- AB Berntec (efficient and safe motion planning, Dr. Karl Berntorp)

8. International collaboration

N/A

9. Supervision of master thesis projects in collaboration with industry

- AB Volvo (Motion Control and Planning for Heavy Vehicles)
- FOI (Automated landing of UAV on AGV)

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
Autonomous vehicles – planning, control, and learning systems	2nd cycle

The 2nd cycle course at LiU, "*Autonomous vehicles – planning, control, and learning systems*", developed by Erik Frisk, Björn Olofsson, and Jan Åslund at Div. Vehicular Systems, LiU, was given during the fall semester of 2022. Results from this ELLIIT subproject are used in the course, including guest lectures from ELLIIT researchers, and 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 over 90 students, and also this year received excellent grades in the course evaluation.

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

N/A

13. Academic service activities, including chairing of conferences, editorships and similar

- Erik Frisk is director of Zenith at LiU
- Erik Frisk is a member of IPC for IFAC Safeprocess, 2021 (postponed to 2022 due to COVID)
- Lars Nielsen is a member of ELLIIT steering group
- Lars Nielsen is a member of WASP-HS Board
- Lars Nielsen is a member of IPC for IFAC Advances in Automotive Control Conference 2022

14. Open source software contributions

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

A10: Privacy-Preserving Machine Learning for Synthetic Spatio-Temporal Trajectory Data Generation

PI: Fredrik Heintz, LiU

Summary

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 is 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 access to unique trajectory data of people, busses and trains through collaborations with organizations such as Telia, Trafikverket and Östgötatrafiken. These organizations are also very interested in applying the results of the research. The project will fund a postdoc and lies in topic A with strong connections to topics B and E in the ELLIIT 2030 Technology Forecast 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.

1. Main scientific achievements during 2022

Work done:

a. Co- Authored An **encyclopedia of the major scientific and technical terms related to Trustworthy Artificial Intelligence** under the chapter Fairness, Equity, and Justice by Design. (http://tailor.isti.cnr.it/handbookTAI/TAILOR.html)

b. **Bt-GAN: Generating Fair Synthetic Healthdata via Bias-transforming Generative Adversarial Networks –** 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). The results demonstrate that we achieve state-of-the-art accuracy with significantly better fairness and minimal bias amplification. Furthermore, we perform an explainability analysis to substantiate our study. This work is under review in 'AAAI/ACM conference on Ethics'.

c. **Fair Latent Deep Generative Models (FLDGM) for Syntax-agnostic and Fair Synthetic Data Generation - T**here 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. 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. This work is under review in ICML.

Work in progress:

a. **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. Writing in progress and planning to submit in IEEE Transactions on Neural Networks and Learning Systems.

b. **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. Planning to submit in ECAI.

2. Awards and recognitions

N/A

3. External funding attracted

N/A

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Resmi Ramachandran Pillai (postdoc)	0000-0002-4302-9327	2021-2023
William Ejnervall (master student)		2022-2023

5. Inter-university cooperation: summary for 2022

Active cooperated with other research institutes as part of the EU TAILOR Network developing the scientific foundations for Trustworthy AI. Contributed chapters to the TAILOR Handbook of Trustworthy AI.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

The TAILOR network includes researchers from many research fields, and the TAILOR Handbook of Trustworthy AI is an interdisciplinary collaboration.

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

The use of synthetic data is interesting to many companies and organizations. Discussions with Region Östergötland are ongoing. A Master thesis was completed with NFC on the use of synthetic faces for training face detection systems for the Swedish Police. Two Master theses were also completed with Sectra.

8. International collaboration

- Collaborated with the TAILOR network, an EU network developing the scientific foundations for Trustworthy AI, publishing an **encyclopaedia of the major scientific and technical terms related to Trustworthy Artificial Intelligence under the chapter Fairness, Equity, and Justice by Design.** (http://tailor.isti.cnr.it/handbookTAI/TAILOR.html)
- Presented on the topic "Generating fair synthetic healthcare data through information- constrained optimization" in **MIRAI2.0 TEG AI Workshop 4 on Industry 5.0 and Society 5.0 (https://www.mirai.nu/workshops-2022/) as part of Sweden-Japan collaboration.**

9. Supervision of master thesis projects in collaboration with industry

- Ted Gustafsson and Alfred Sporre from **NFC (Industry)** on "Synthetic face generation".
- Markus Wetterberg and Sebastian Flinck Lindström from **Sectra (Industry)** on "Uni-Modal Fusions Compared to Multi-Modal Classifiers on the Categorization of Medical Objects".
- Oscar Linnarsson from **Sectra (Industry)** on "Classification of Magnetic Resonance Imaging Sequence Type Using a Deep Multi-Modal Neural Network".

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

N/A

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

- Presented a poster at SSDL 2023
- Participated in the **ACAI-TAILOR Summer School 2022, Barcelona, Spain,** and actively involved in the discussions and collaboration sessions.

13. Academic service activities, including chairing of conferences, editorships and similar

- Keynote speaker in "International Conference on Advanced Information Science and Computing Systems" on 'Ensuring fairness in synthetic data generation – general overview' organized by ICFOSS and Christ Nagar College, Trivandrum, India.
- Advisory Committee member in "International Conference on Emerging Trends: Innovations & Challenges in Information Technology and Management" organized by BHARATI VIDYAPEETH'S Institute of Management and Information Technology (NBA Accredited).

14. Open source software contributions

N/A

A11: Novel Sounder Development, Parameter Estimation and Modeling for lower THz Radio Channels

PI: Fredrik Tufvesson, LU

Summary

The rapid evolution of wireless communication systems has significantly changed the daily life of people in the past decades. Fifth Generation (5G) and beyond 5G (B5G) wireless communication systems are expected to provide much higher network capacities, multi-Gigabit-per-second (Gbps) data rates, low latency and ultra-reliable communication while at similar cost and energy dissipation as today. The millimeter-wave (mmWave) and lower THz frequency bands (30-300 GHz) have been seen as the key enabler for B5G. Research for understanding the mmWave and lower THz propagation channel 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. 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 at 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 low-complexity channel models yet with high fidelity to the real channels. To fill the gaps, the project aims to explore the "new frequency bands" and the possibilities these open up for. The goal of the project is to create basic theory, technology and knowledge in channel characterization, parameter estimation, and modeling for the lower THz channel. We aim to gain the very first understanding, make breakthroughs and provide guidelines to open up for realistic system design and performance analysis of communication, positioning and sensing in the lower THz band.

1. Main scientific achievements during 2022

- 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. The corresponding high-resolution algorithm was also developed. Both the sounder and algorithm have been tested and verified in measurements and simulations. Summarizing papers have been submitted or are under preparation.
- Meanwhile, the progress of upgrading the sounder to 140 GHz band is smooth. We successfully monitored the output pulses from the mirror sensors.
- We have also acquired a LiDAR system, which was and will be used for channel measurement and data fusion-based research.
- In addition, we have successfully secured several grants from EU, VR and Kungliga fysiografiska sällskapet to continue the research work defined in A11.

2. Awards and recognitions
   - VR starting grant
   - MSCA postdoctoral grant
   - Kungliga fysiografiska sällskapet Grant
   - 2022 IEEE Antennas and Propagation Ulrich L. Rohde Innovative Conference Paper Award Finalist (Top 5), Paper: Zhang, G., Cai, X., Nielsen, J. O., Pedersen, G. F., & Tufvesson, F. (2022). A Scatterer

Localization Method Using Large-Scale Antenna Array Systems. In IEEE Conference on Antenna Measurements & Application.

- X.Cai, IEEE Senior membership

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
TALENT: Lower THz rAdio propagation channeL sounding, parameter Estimation and modeliNg Towards 6G and beyond	EU	110 kEUR	2022-2024
Breaking the Barriers of Terahertz Communications: Understanding Wave Propagation for 6G	VR	1 million SEK	2023-2027
Fast and Intelligent Modeling for Lower THz Radio Channels	Kungliga fysiografiska sällskapet	125 kSEK	2022-2024
MINTS, Millimeter-wave NeTworking and Sensing for Beyond 5G) (also relevant in B01)	EU, MSCA ITN	3.9 MEUR (LU: 564 kEUR)/4 years	2020-2024
Massive MIMO technologies and applications (also relevant in B01, B02, B03)	Ericsson		2019-2023

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Xuesong Cai	0000-0003-3353-2479	2021-2022 (postdoc), and onwards (assis. Prof.)

5. Inter-university cooperation: summary for 2022

The insights from this project will be used in the joint EU project 6GTandem where LU and LiU are partners. The project starts in January 2023.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

Milimeter wave and sub-THz channels knowledge is fundamental for reliable communication, radio based positioning and vehicular communication and positioning. Hence there are strong links to project B01, B11 (Local Positioning Systems) and B05 (6G wireless, vehicular communication).

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

Millimeter wave channel sounding is fundamental for our joint projects within the Vinnova/FFI project 5G-Pos (5G positioning for enhanced traffic safety) with Ericsson, Chalmers, Veoneer, Qamcom, CEVT and our bilateral project with Ericsson.

8. International collaboration

- Joint publication of LU and Peking university, China, regarding sub-THz channel modeling
- Hosted a visiting PhD student from Aalborg University, Denmark, joint publications of LU and Aalborg University on mmWave scatterer localization, Measurement data of mm-wave large-scale antenna array shared from Aalborg University
- Hosted a guest assis. prof. from Tongji University, China

9. Supervision of master thesis projects in collaboration with industry

- Linfeng Chen, Performance evaluation and modeling of a beam-simulation system for MIMO communications, with Ericsson
- Dexin Kong and Swaroop Nambala, Ray-tracing Based Investigations on the Deployment of RISs in Indoor Scenarios, with Sony (to be finished 2023)
- Guillermo Jiménez Alonso , Design and analysis of antenna selection in massive MIMO, with Ericsson

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
Wireless Systems design principles, course content is continuously updated with current research results	Master
Advanced Course in Electrical and Information Technology, the availabe hardware and measurement data are being used for students to conduct research-related projects	Master

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

- Wireless Communications meet Terahertz, NMT days at Lund University, Lecture for high school students and teachers (in March 2023)

13. Academic service activities, including chairing of conferences, editorships and similar

- Chaired a session in IEEE CAMA 2022
- Organizing two special sessions for IEEE CAMA 2023 and IEEE SPAWC 2023
- Editor of Wireless Communications and Mobile Computing

14. Open source software contributions

N/A

A12: Usable digital twins in healthcare

PI: Gunnar Cedersund, LiU

Summary

In 2019, the Swedish translation for “Digital twins” entered the public Swedish dictionary, SAOL. Digital twins are computer models, which can describe, e.g., the specific physiology in a patient. Nevertheless, all others’ digital twins only describe a single organ or function in the human body, such as blood flow. We have developed the only digital twin that combines such diverse aspects as brain activity, blood flow, metabolism, and inflammation into a single model. This is the result of almost 20 years of ongoing mechanistic modelling. A first prototype for this twin was launched at Almedalen last summer, and this has been followed by high-profile keynote presentations at the biggest medical institute in the world, the National Institute for Health (NIH), and by keynotes at national conferences such as “IT i vården”-dagen, ModProd, etc. However, to make this initial prototype usable in actual healthcare, there are remaining challenges that must be overcome. In this project, we will accomplish this in three steps. Step 1: to overcome the practical, legal, and ethical challenges with creating an information platform where patient-specific data and information from all relevant sources can be stored. This is made possible by Cory Robinson (CR, LiU), who is an expert on such ethical and legal issues, and by Erik Sundvall (ES, LiU), who is information architect at Region Östergötland, and responsible for handling electronic (EHR) and personal healthcare records (PHR). Step 2: to create 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. This is made possible by the main applicant Gunnar Cedersund (GC, LiU), who combines his unique models with expertise from the EU-network

Precise4Q (P4Q, precise4q.eu), where expertise on machine learning resides. Step 3: To design 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. This is made possible because we have started a spin-off company, SUND, and joined forces with the Visual Sweden MeDigiT project. The strength of this project is that we developed ground-breaking hybrid AI approaches (Topic A) to be able to extract information from a wide variety of Big Data sources (Topic 2); that we also deal with legal, ethical and commercial challenges (Topic B); and that we combine all of this into an Intelligent Assistant tool (Topic 5). Because of this unique combination, this project will result in usable digital twins for healthcare. The twins will be tested at LiU (GC, ES, CR), in Lund (Karin Stenkula, KS) and in Germany and Spain (P4Q).

1. Main scientific achievements during 2022

This project finished its activities in 2021.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

N/A

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Feras Faez Elias		
Valentin Kindesjö		
Gustav Magnusson		
Peter Thompson		

5. Inter-university cooperation: summary for 2022

N/A

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

N/A

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

N/A

8. International collaboration

N/A

9. Supervision of master thesis projects in collaboration with industry

N/A

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

N/A

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

N/A

13. Academic service activities, including chairing of conferences, editorships and similar

N/A

14. Open source software contributions

N/A

A13: Deepfakes and the curse of GANS

PI: Jeff Yan, LIu
This project did not start.

A14: Embodied Visual Active Learning

PI: Kalle Åström, LU
Participating researchers: Cristian Sminchisescu, LU

Summary

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.

1. Main scientific achievements during 2022

During 2022 we have 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 Gärtner, E. PhD 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, A., Johnander, J., Petersson, C., & Åström, K. (2022). “Learning Future Object Prediction with a Spatiotemporal Detection Transformer”. 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 for motion classification. We extend the Bootstrap Your Own Latent (BYOL) strategy for representation 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, A., Samuelsson, A., Backsund, J., & Åström, K. (2022). Aerial View Goal Localization with Reinforcement Learning.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
WASP (Industrial PhD student) Olivier Moliner	WASP (KAW) and Sony	600+ KSEK	2018-2023
WASP (Academic PhD student) Erik Gärtner	WASP (KAW)	750+ KSEK	2018-2022
WASP (Industrial PhD student) Adam Tonderski	WASP (KAW) and Zenseact	600+ KSEK	2020-2024
WASP-NTU Hangwei Qian	WASP (KAW) and NTU	800 KSEK	2021-2022

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Kalle Åström	0000-0002-8689-7810	2020-2022
Cristian Sminchisescu	0000-0001-5256-886X	2020-2022
Adam Tonderski	0000-0002-2160-4386	2020-2022
Hangwei Qian	0000-0003-4831-0748	2020-2022
Erik Gärtner	0000-0001-5139-7050	2020-2022
Olivier Moliner	0000-0002-2190-9307	2020-2022

5. Inter-university cooperation: summary for 2022

We have had several inter-university cooperations, for example between Lund and NTU, through the WASP-NTU project involving Hangwei Qian.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

N/A

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

Cooperation with industry and institutes include cooperation with the research institute RISE on reinforcement learning and with the companies Zenseact, Google and Sony.

8. International collaboration

International cooperation includes cooperation with Google in Zurich, NTU in Singapore and ETH in Zurich.

9. Supervision of master thesis projects in collaboration with industry

N/A

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

N/A

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

Kalle Åström participated in the ELLIIT tech talks theme 3, “Intelligent assistants and tools”.

13. Academic service activities, including chairing of conferences, editorships and similar

Kalle Åström served as Area Chair for ECCV 2022.

14. Open source software contributions

N/A

A15: Relation Extraction with Deep Neural Language Models

PI: Marco Kuhlmann, LiU
Participating researchers: ~~Pierre Nugues, LU~~ (did not participate)

Summary

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 will apply these models

to the task of extracting semantic relations between named entities from raw text. Our main goal is 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 are 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'.

1. Main scientific achievements during 2022

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, modeling the interactions between words within a sentence. 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 test, benchmarks while addressing the computational cost and the sharability issues of finetuning.

2. Awards and recognitions

N/A

3. External funding attracted

Swedish Interdisciplinary School in Computational Social Science (SISCSS). Research Environment Grant, Vetenskapsrådet. Main PI: Jacob Habinek (Linköping University). 2022–2025

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Ali Basirat	0000-0002-4718-886X	2021–2022

5. Inter-university cooperation: summary for 2022

During his employment, postdoc Ali Basirat cooperated with other research institutes such as the Research Institutes of Sweden (RISE), Uppsala University, Sweden, and Radboud University, Netherlands. The projects were connected to Ali's previous work on Universal Dependency parsing, a standard task in structure prediction, and the interpretability of word embeddings, a by-product of language models for word representation.

Related to this project, Marco Kuhlmann was involved in several other collaborations with researchers from Chalmers University of Technology (WASP Collaboration Project 'Interpreting and Grounding Pre-Trained Representations for Natural Language Processing'), Umeå University (WASP Collaboration Project 'A Practical Theory of Computation for Modern Neural Network Architectures') and KTH (WASP NEST STING: Synthesis and analysis with Transducers and Invertible Neural Generators).

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

Ali Basirat's had external collaborations with the Department of Linguistics and Philology at Uppsala University and the Department of Modern Languages and Cultures at Radboud University, Netherlands. Both groups work on the explainability and interpretability of representation learning developed in natural language processing from a linguistic point of view. The cooperation with Radboud University also led to a better understanding of the concept of "climate" in English literature.

Marco Kuhlmann collaborated with the Institute for Analytical Sociology at Linköping University, which resulted in a successful research proposal for a Research Environment Grant from Vetenskapsrådet (see above).

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

N/A

8. International collaboration

Ali has collaborated with Radboud University, Netherlands on a project studying the lexical meaning change of the concept climate.

9. Supervision of master thesis projects in collaboration with industry

Lukas Borggren. Automatic Categorization of News Articles with Contextualized Language Models. MSc in Computer Science and Engineering, 2021. Project commissioned by Bonnier News, Stockholm/Sundsvall.

Agaton Sjöberg. Extracting Transaction Information from Financial Press Releases. MSc in Computer Science and Engineering, 2021. Project commissioned by Modular Finance, Stockholm.

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
TDDE09 Natural Language Processing, student supervision	Advanced level
TDDE16 Text Mining, project supervision	Advanced level

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

N/A

13. Academic service activities, including chairing of conferences, editorships and similar

N/A

14. Open source software contributions

We will make our codes freely available in a public git repository. The code is now available in LiU's Gitlab repository.

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

Participating researchers: Anton Cervin, LU, Karl-Erik Årzén, LU, Anders Robertsson, LU, Emma Fitzgerald, LU, William Tärneberg, LU, Niklas Carlsson, LiU

Summary

The proposed project addresses 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.

1. Main scientific achievements during 2022

During 2022, two papers were written and submitted, but acceptance is still pending. The main work has been to validate the real-time performances of two published and well-known solutions industrial control systems, one for intrusion detection and one for distributed MPC. The solutions have previously only been analyzed using theoretical models and numerical investigations. In our work, the solutions were deployed in an edge-cloud testbed and analyzed. The results show several real-time challenges when taking the theoretical solutions to real systems.

2. Awards and recognitions

N/A

3. External funding attracted

N/A

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
SEC4FACTORY	SSF	5 MSEK	2018-2024
IMMINENCE	Vinnova (Celtic next)	1.8 MSEK in total	2021-2023

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Emma Cuthbert	0000-0001-5219-8248	2021-2022

5. Inter-university cooperation: summary for 2022

N/A

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

N/A

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

N/A

8. International collaboration

N/A

9. Supervision of master thesis projects in collaboration with industry

N/A

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

N/A

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

Maria Kihl participated in the ELLIIT tech talks theme 1, “Industry 4.0”.

13. Academic service activities, including chairing of conferences, editorships and similar

N/A

14. Open source software contributions

N/A

A17: Multistatic high-resolution sensing at THz

PI: Mats Pettersson, BTH
Participating researchers: Hans Hellsten, HH, Fredrik Gustafsson, LiU

Summary

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. All of these factors will ensure the project’s success. The topic relates to many areas in ELLIIT 2030 Technology Foresight but we have chosen topic area 3.

1. Main scientific achievements during 2022

In 2022 four journal papers and one conference paper associated with the project were published. The project focus was THz sensing and building efficient algorithms as described in the project proposal. In 2022 the main contribution was autofocus and bistatic research, and we contained algorithm development to improve the performance of the time-domain backprojection algorithms. We also published a paper on a new frequency domain UWB algorithm in collaboration with the University of Duisburg-Essen in Germany. Another publication focused on frequency domain algorithms for FMCW radars was also submitted. This work was done in collaboration between Blekinge Institute of Technology, Halmstad University and Linköping University and the work is pending a journal publication. During 2022 we also conducted experiments that will be published soon.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
Radio occultation for space weather by new constellation of commercial satellites	Swedish Space Agency	1 094 000kr	2023-2026

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Yevhen Ivanenko	0000-0002-3928-6064	2020-2023

5. Inter-university cooperation: summary for 2022

Collaboration in algorithm development and real measurements up to 1.5 THz with Aman Batra and Thomas Kaiser at the University of Duisburg-Essen in Germany.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

N/A

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

N/A

8. International collaboration

Collaboration in algorithm development and real measurements up to 1.5 THz with Aman Batra and Thomas Kaiser at the University of Duisburg-Essen in Germany.

9. Supervision of master thesis projects in collaboration with industry

N/A

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

N/A

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

N/A

13. Academic service activities, including chairing of conferences, editorships and similar

N/A

14. Open source software contributions

N/A

A18: Rational Oversampling in Coherent Optical

PI: Oscar Gustafsson, LiU
Participating researchers: Håkan Johansson, LiU

Summary

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. As such the project considers an area being a fundamental enabler for several of the ELLIIT topic areas (1, 2, 3, 4, A, D), although the area so far has not been directly addressed in the ELLIIT context. It is believed to be closest to topic 1. To obtain very high date rates, typically, very high sample rates are used,

limited by ADC/process technology. To maximize the utilization of available ADCs, only limited oversampling can be used. However, transmit and receive filters, synchronization, and most equalizer structures are expecting an integer number of samples per symbol. While possible to upsample in the receiver, this comes at a cost, both for the oversampling filters and for performing the signal processing at an even higher sample rate. The purpose of this project is to develop efficient algorithms and architectures performing the required signal processing at a fractional oversampling rate.

1. Main scientific achievements during 2022

The associated PhD student has continued the work though, resulting in evaluation of simplified time-domain FIR filters for chromatic dispersion compensation (CDC). In addition, techniques for designing CDC filters in the frequency-domain implemented using overlap-save techniques has been proposed. By not zero-extending the impulse response, but rather including those values in the design procedure, better compensation can be obtained at the same arithmetic cost. This builds on recent work, analyzing the effects of overlap-save implementation in practice. 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.
The recruitment work has continued and a postdoc recruitment round has been organized. Unfortunately, this was unsuccessful as the preferred candidate accepted another position late in the process.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
Large intelligent surfaces	SSF	6.5 MSEK	2021-2025
Calibration of Time-Interleaved ADCs	Huawei	1 MSEK	2020-2022
Receiver linearization techniques	Huawei	800 kSEK	2021-2023

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Cheolyong Bae, PhD student	0000-0003-3382-5175	From 2020

Krishna Chaitanya Patchava, postdoc	0000-0002-0987-1000	2021

5. Inter-university cooperation: summary for 2022

Per Larsson-Edefors, Chalmers, has been involved in some of the discussions related to the project. We expect an extended collaboration when a new postdoc is recruited.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

N/A

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

N/A

8. International collaboration

N/A

9. Supervision of master thesis projects in collaboration with industry

N/A

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
The PI has been involved in the program board of the Applied Physics and Electrical Engineering (Y) program	Undergraduate
A grant for developing a processor simulator was obtained from the pedagogical development group at LiU	Undergraduate and graduate

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

N/A

13. Academic service activities, including chairing of conferences, editorships and similar

N/A

14. Open source software contributions

The PI was promoted to a core developer of Matplotlib.

A19: Software Regression Testing with Near Failure Assertions

PI. Per Runeson, LU

Summary

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. 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 the 'surrounding' values, 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. The project will be conducted within our collaboration with BTH or extended with other relevant partners.

1. Main scientific achievements during 2022

The postdoc working in the project, Dr. Masoumeh Taromirad, has worked on the project during the full year and achieved three major outcomes.

1. A survey of the literature on assertions in software testing.
2. Exploration of a new concept for testing, Near Failure Analysis using Behavioural Dynamic Data
3. Presentation of the initial findings at the PROFES conference in Jyväskylä, Finland.

Firstly, the analysis of 95 articles on assertions, summarizing the state of research on the topic, indicates that there is little work directly focused on assertions and thus research is needed.

Secondly, the main concept of the project is explored and evaluated. 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. Validation on the Math project from Defects4J provided early indications of a precision and recall in the range of 85-95%.

Thirdly, these initial results were published at the PROFES conference in Jyväskylä, Finland, published by Springer.
The concept was further developed, and a journal publication is at the time of writing under review.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
Continuous Quality Assurance ML Pipelines for Trustworthy AI with coPI Dr. Markus Borg	WASP	1 MSEK	2022-2026

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Masoumeh Taromirad	0000–0002–0838–928X	2021-2023

5. Inter-university cooperation: summary for 2022

Participation in LU-BTH workshop in Karlskrona.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

N/A

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

N/A

8. International collaboration

N/A

9. Supervision of master thesis projects in collaboration with industry

Martin Hansson Tomicic, *Return on investment and maintenance in a mobile test automation implementation*, Robert Bosch Sweden AB https://lup.lub.lu.se/student-papers/search/publication/9103108
Thomas Rodenberg, *Optimizing regression benchmarking for network video products*, Axis Communications AB https://lup.lub.lu.se/student-papers/search/publication/9076590

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
One student at MSc level contributed to the research project by doing a project on data collection for the experiment.	Undergraduate

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

Per Runeson participated in the ELLIIT tech talks theme 11, “Digital business models and legal aspects”.

13. Academic service activities, including chairing of conferences, editorships and similar

N/A

14. Open source software contributions

Software framework for the experiments made available open source.

A20: Efficient and Reliable Training of Generative Adversarial Networks

PI: Pontus Giselsson, LU

Summary

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 program will provide a strong mathematical foundation for training of GANs. A starting point will be a recently submitted paper [CV:paper[S1]] by the project proposer. It introduces 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.

1. Main scientific achievements during 2022

In 2021, 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 algorithm framework. This research opens the possibility to explore these degrees of freedom to devise better algorithms with improved performance compared to existing alternatives.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
WASP PhD grant	WASP	1 MSEK	4 years
VR etableringsbidrag	VR	1 MSEK	4 years

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Oskar Larsson		2021
Martin Morin	0000-0003-4221-6873	2020-2021
Sebastian Banert	0000-0001-8110-6007	2021-2022

5. Inter-university cooperation: summary for 2022

Initiated cooperation with INRIA, Paris.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

N/A

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

N/A

8. International collaboration

Initiated cooperation with INRIA, Paris.

9. Supervision of master thesis projects in collaboration with industry

N/A

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

N/A

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

Created popular science video on optimization: https://www.youtube.com/watch?v=5puSzvO12jg&t=2s

13. Academic service activities, including chairing of conferences, editorships and similar

Editor (with A. Gibali and T. Humphries) of special issue in *Journal of Applied Numerical Optimization.*

14. Open source software contributions

N/A

A21: Protecting software against side-channel leakage

PI: Thomas Johansson, LU

Summary

We investigate attacks using side-channel leakage in software implementations, in particular, towards libraries implementing standard security protocols and cryptographic primitives such as OpenSSL. The focus is on cache-timing attacks of different forms and will include both developing attacks as well as different protection methods, such as guaranteeing a constant-time implementation. The work will continue a recently established research direction for the group.

1. Main scientific achievements during 2022

HQC is a candidate algorithm for standardization by NIST, currently in round 4 in the standardization process. We have developed the first chosen-ciphertext (CC) cache-timing attacks on the reference implementation of HQC. We build 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.
We show a general proof-of-concept attack, where we use the Flush+Reload technique and also derive, in more detail, a practical attack on an HQC execution on Intel SGX, where the Prime+Probe technique is used. We show the exact path to do key recovery by explaining the detailed steps, using the PC oracle. In both scenarios, the new attack requires much fewer PC oracle calls than previous work.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
Secure and Private Connectivity in Smart Environments	SSF	1100000	2019-2024
WASP: Lightweight cryptography for autonomous vehicles	WASP	1000000	2019-2022

Side-channel Vulnerability and threat analysis with machine learning awareness	MSB	950000	2021-2025
Strategic Mobility: New constructions of format-preserving encryption	SSF	550000	2023-2024
Analysis of emerging cryptographic algorithms	VR	1000000	2019-2023

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Senyang Huang, postdoc	0000-0002-5922-3685	2021-2023

5. Inter-university cooperation: summary for 2022

N/A

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

N/A

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

Collaboration with Ericsson.

8. International collaboration

Collaboration with University of Adelaide and University of Melbourne.

9. Supervision of master thesis projects in collaboration with industry

N/A

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
Advanced cryptography	graduate

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

Ongoing standardization work through Ericsson on the specification of the 3GPP 256-bit Confidentiality and Integrity Algorithms for the Air Interface based on the SNOW family of stream ciphers

13. Academic service activities, including chairing of conferences, editorships and similar

Co-chair PQCrypto 2022, 2023, Assoc. Editor IEEE Trans. On Information Theory 2021-

14. Open source software contributions

Attack implementations available as open source

A22: Human Interaction with Autonomous Minibuses (HIAM)

PI: Tom Ziemke, LiU
Participating researchers: Sam Thellman (LIU), Jan Andersson (VTI), Anna Anund (VTI)

Summary
The project is a collaboration between the Cognition & Interaction Lab at IDA/LiU (PI: Tom Ziemke) and human factors researchers at (VTI; co-PIs: Anna Anund and Jan Andersson), within ELLIIT Focus Theme 1 – Autonomous vehicles and robots. The project addresses the interaction of the autonomous minibus platform ELIN on LiU's Campus Valla with pedestrians, bicyclists, car drivers, and the safety drivers monitoring the buses' operation. The fact that the minibus platform has been operating on Campus Valla since late 2019 (with initial funding from LiU and VTI, among others) 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 at this point, 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 new postdoc carries out

empirical studies of how people interact with the minibuses (through behavioral observations, questionnaires, in-depth interviews, etc.) and focuses in particular on the development of quantitative and qualitative methods, experimental protocols, and measurements for the study of human interaction with autonomous vehicles. This is expected to generate new research directions for larger future projects in collaboration between LiU and VTI.

1. Main scientific achievements during 2022

The project started in January 2022. Three conference papers on human prediction of autonomous bus behavior as well as perceptual and cognitive perspective taking toward automated vehicles were submitted (and accepted) to the ACM/IEEE International Conference on Human-Robot Interaction (presented in March 2023).

Ziemke and Thellman in November 2022 received funding from VR (Swedish Research Council) for a new three-year project on “Social Cognition in Human-Robot Interaction”, which is broader (involving different types of robots), but also addresses human interaction with automated vehicles, based on the work in this project (A22).

2. Awards and recognitions

Tom Ziemke gave an invited talk on “Mental State Attribution in Social Robotics” at the workshop on “Behavior Adaptation and Learning for Assistive Robotics” (BAILAR), held in conjunction with the 31st International Conference on Robots & Human Interactive Communication (ROMAN 2022), held in Naples, Italy, in August/September.

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

N/A

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Sam Thellman (postdoc)	0000-0003-0098-5391	from January 2022
Franziska Babel (research engineer/ postdoc)	0000-0001-8249-7708	from April 2023
Philipp Hock (postdoc)	0000-0002-9831-9241	from April 2023

5. Inter-university cooperation: summary for 2022

N/A

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

The project is a collaboration of researchers in computer science, cognitive science, human factors and traffic psychology at LiU and VTI.

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

The project is carried out in collaboration with VTI. The project is very much in line with LiU and VTI's strategic collaboration, which aims to promote long-term mutual development and competitiveness, as well as the joint research inititiative *"Ride the Future"* (https://ridethefuture.se/).

8. International collaboration

N/A

9. Supervision of master thesis projects in collaboration with industry

N/A

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
Ethics of AI and interactive autonomous systems	graduate/PhD
Critical perspectives on AI	graduate/PhD

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

Tom Ziemke gave popular-scientific lectures on the public perception of AI and its limitations as part LiU's popular-science week in October 2022 (https://liu.se/artikel/popularvetenskapliga-veckan) as well as the Swedish Air Force Museum's theme day on "Tomorrow's Technology" in January 2023.

13. Academic service activities, including chairing of conferences, editorships and similar

Tom Ziemke served as program co-chair for the conference CogSIMA 2022, the *IEEE Conference on Cognitive and Computational Aspects of Situation Management*, held in Sorrento, Italy, in June 2022.

14. Open source software contributions

N/A

ELLIIT Call B

In December 2020 the ELLIIT Research projects had been running for five years and reached their intended closing date. The ELLIIT board decided to initiate 15 new projects, in mostly existing constellations of PIs/co-PIs, and that will run from 2021 to 2025.

B1: Ultra-reliable wireless for 6G applications

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

Summary
This project proposal combines a theoretical approach to ultra-reliable low latency communication for 6G, with channel characterization and modelling for the same purpose, a system wide perspective and hardware friendly approaches for distributed communication, all aiming to maximize diversity and point-to-point communication reliabilities better than 99,999% while still keeping the introduced latency below 100 us.

1. Main scientific achievements during 2022

We have been working on the topic of ultra-low latency grant-free random access. During 2022, his research focused on the development of a distributed activity detection algorithm in distributed multiple-input multiple-output (MIMO) systems and a learning-based random access control policy.
The first algorithm, called distributed approximate message passing (AMP), allows an access point to compute a local log-likelihood ratio (LLR) for each serving user. The activities are determined purely by aggregating the LLRs, resulting in a performance loss that is acceptable compared to fully coherent

processing while significantly reducing the fronthaul overhead. Additionally, heuristic user association and power control schemes were explored to enhance performance in realistic scenarios. This work was published in the IEEE Wireless Communications Letters.

The second algorithm empowers each user to make joint pilot selection and power control decisions based on real-time observations of the environment. Although originated from multi-agent reinforcement learning, the algorithm was substantially adapted to incorporate model knowledge for highly efficient training; the resulting performance is close to the case without pilot collision. This work resulted in a paper that is currently under review in an IEEE journal.

1.1. Plans for 2023

In 2023 we will continue develop refined algorithms for activity detection. Especially we have recently started work that departs from the block-fading assumption commonly used in much literature, and considers continuous variations of the channel response as function of time and frequency. Initial results are promising.

2. Awards and recognitions

E. G. Larsson highly cited according to ISI Web of Science, 2018, 2019, 2020, 2021, 2022

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
H2020 REINDEER	EU		2021-2024
SURPRISE (cyber security call)	SSF	1.1 MSEK	2018-2022
Wireless Communications and Sensing Wallenberg Technology Beyond 5G	KAW	3.6 MSEK	2020-2024
Adversarial attacks on the wireless physical layer	VR	1 MSEK	2020-2023
Commissioned research (LiU)	Ericsson	1.3 MSEK	2021-2022
Massive MIMO technologies and applications	Ericsson		2019-2023
“Optimizing Radio Access Networks for efficient massive MIMO operation	SSF industrial PhD student	0.5 MSEK	2019-2023
H2020 5G-SMART, 5G for smart manufacturing	EU	10.2 MEUR (LU: 249 kEUR)/3 years	2019-2022

MINTS, Millimeter-wave NeTworking and Sensing for Beyond 5G) (also relevant in A11)	EU, MSCA ITN	3.9 MEUR (LU: 564 kEUR)/4 years	2020-2024
MIMO-Sensor for Positioning and Autonomous Drive, MIMO-PAD (also relevant in B11)	Vinnova/FFI	22.7 MSEK (LU: 1.3 MSEK)/4 years	2019-2023
5G-Pos, 5G positioning for enhanced traffic safety" (also relevant in B06 and B11)	Vinnova/FFI	6.7 MSEK (LU: 2.5 MSEK)/4 years	2020-2022

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Sai Thoota, postdoc	0000-0001-9957-8467	2022-
Thanh Tung Vu, postdoc	0000-0002-8342-4567	2022-
Martin B. Andersson, Ph.D. student	0000-0002-3469-726X	2022-

5. Inter-university cooperation: summary for 2022

LiU and LU have cooperated within the EU-funded H2020-REINDEER project, where both are partners. They also together have the project "Large intelligent surfaces" funded by the SSF, focusing on development of large-scale distributed MIMO systems.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

The activities are highly interlinked with other ELLIIT projects and other external joint projects. Within ELLIIT there are strong connections to the A11 postdoc project and to the PhD student projects in B2 and vehicle and B positioning.

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

Under a bilateral agreement between Ericsson Research and LiU/ISY/Communication systems, continuing throughout 2021-2022, research is being undertaken on aspects of distributed massive MIMO, and on the design of wireless networks to support machine learning applications.
There is also a strong connection to the bilateral project Massive MIMO technologies and applications betweeen LU and Ericsson. Furthermore, There are industrial PhD students with Volvo cars, Terranet, Ericsson and joint Vinnova/FFI projects with partners Volvo cars, Terranet, Chalmers, Qamcom, Scania,

RISE, TietoEvry, related to the project. In the MSCA ITN MINTS we have been working with Sony on Reflective Intelligent Surfaces.

8. International collaboration

Co-authored papers with, among others, QU Belfast; Princeton Univ.; Univ. Southhampton; Polytechnic U. Hong Kong. KU Leuven, Aalborg University, TU Graz, University of Trento
In the related EU projects and MSCA ITN, there is of course an extensive international collaboration.

9. Supervision of master thesis projects in collaboration with industry

- Estimating Forest Variables from LiDAR Pointcloud Data Using a Deep Learning Approach, Digital Edge, Stockholm
- The Effect of Distortions Induced by Adaptive Antenna Arrays in GNSS-Applications, FOI , Linköping
- Energy-efficient monitoring system for fire extinguishers, Mikrodust, Lund
- Investigating and Modeling Uplink Processing in 5G NR Multisector Scheduler Simulator, Ericsson, Lund
- Beamformed Channel Matrix Positioning Using 5G Testbench CSI data With a Deep-Learning Pipeline, Ericsson, Lund
- Hybrid Wireless Positioning, uBlox, Malmö
- Simple RSRP Fingerprint Collection Setup and Indoor Positioning in 5G, Ericsson, Lund

10. List of patent applications published during 2022

Patent title	Application Number
Server and agent for reporting of computational results during an iterative learning process	WO2022214162A1
Methods, control node, wireless device and access node for estimation of path loss and channel response	EP4097895A1
Signal detection of a backscattering device	WO2022268331A1
Downlink synchronization signals	US11405877B2
Transmission of mu-mimo signals	WO2022214169A1

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
Project in wireless communication. Course content is continuously updated based on current research results	master

- Ema Beciroivic defended her Ph.D. thesis "Signal Processing Aspects of Massive MIMO", October 2022. Advisor: E. G. Larsson.
- Zakir Hussain successfully defended his licentiate thesis "Cell-Free Massive MIMO: Distributed Signal Processing and Energy Efficiency", March 2022. Advisor: E. G. Larsson.
- Unnikrishnan Kunnath Ganesan successfully defended his licentiate thesis "Distributed Massive MIMO: Random Access, Extreme Multiplexing and Synchronization", March 2022. Advisor: E. G. Larsson.
- Özgecan Özdogan successfully defended her Ph.D. thesis "Signal Processing Aspects of Massive MIMO and IRS-Aided Communications", February 2022. Advisor: E. Björnson (alumni ELLIIT recruited faculty)
- Xuhong Li successfully defended her PhD thesis “Parametric Radio Channel Estimation and Robust Localization”, June 2022, Advisor: F. Tufvesson
- Sara Willhammar successfully defended her PhD thesis” Massive MIMO for dependable communication”, Dec. 2022, Advisor: F. Tufvesson

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

ELLIIT tech talks have been successfully launched during 2022. Fredrik Tufvesson was initiator and project leader for the whole production with two specific contributions from this sub-project on 6G and on Big data by Fredrik Tufvesson and Erik G. Larsson.
The Wireless Future podcast hosted by Erik G. Larsson and former ELLIIT recruited faculty Emil Björnson continues to be a major success (>20,000 subscribers), with many of the episodes having thousands of views, and many high- profile international guests, Podcast: Wireless Future (All episodes)

Mobile Heights Invited Talk, “6G? We haven't deployed 5G yet", Mobile Heights, Malmö, April 2022.

13. Academic service activities, including chairing of conferences, editorships and similar

- E. G. Larsson co-guest editor of IEEE JSTSP special issue on Advanced Signal Processing in 6G Networks for Extended Reality – will appear in 2023
- E. G. Larsson advisory board member for IEEE Globecom workshop on distributed intelligence, 2022

14. Open source software contributions

Contributor and maintainer of the COST 2100 channel model and their extensions for massive MIMO

B2: Baseband Processing for Beyond 5G Wireless

PI: Liang Liu, LU
Co-PI: Håkan Johansson, LiU

Summary

This project focuses on efficient digital baseband processing algorithms and hardware for beyond 5G wireless systems. More specifically, the project will explore system-algorithm-hardware-software co-design to tackle new research challenges in the implementation of distributed massive MIMO technology for Large Intelligent Surfaces (LIS) and Cell-free massive MIMO. To achieve this objective, researchers from Lund University, Linköping University, and Halmstad University collaborate to conduct three PhD projects on distributed processing algorithm and architecture, low-complexity digital front ends, and high-level design methodologies using many-core processor architecture. The digital baseband research in this project will cooperate with other ELLIIT projects on system level exploration and analog electronics design to achieve overall implementation efficiency.

1. Main scientific achievements during 2022

Subtopic 1 Distributed processing algorithm and hardware architecture:

Distributed massive MIMO, e.g., cell-free MIMO and active large intelligent surfaces, is one of the enabling technologies for Beyond 5G and 6G systems. With antennas distributed in the environment and with the up scaling of number of antennas and signal bandwidth, it is becoming very difficult to implement the traditional centralized processing architecture for massive MIMO systems. Lund University has been looking into distributed processing architectures, including distributed MIMO processing algorithms as well as the topologies to connect different processing elements together. In [B2.1], algorithm-architecture co-design has been conducted to develop distributed interference cancellation algorithms for tree-based topology. [B2.2] has looked into machine learning based distributed algorithms for high-precision radio-based positioning, when a large number of antenna panels are deployed in an indoor environment. Within this topic, Lund University has also contributed to the Deliverable 2.2 of EU project REINDEER [B2.3]. Besides on the theoretical analysis of the distributed architecture, Lund University is also building a 6G testbed using AMD/Xilinx RFSoC technology. 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.

[B2.1] Sánchez, J.R., Rusek, F., Edfors, O. and Liu, L., Distributed and Scalable Uplink Processing for LIS: Algorithm, Architecture, and Design Trade-Offs. IEEE Transactions on Signal Processing, pp.2639-2653, 2022

[B2.2] Sánchez, J.R., Edfors, O. and Liu, L., 2021, December. Positioning for Distributed Large Intelligent Surfaces using Neural Network with Probabilistic Layer. IEEE Globecom Workshops, 2021

[B2.3] Edfors, O., Brazil, R., Petautschnig, H., Callebaut, G., Feys, T., Van der Perre, L., Larsson, E.G., Fitzgerald, E., Liu, L., Sanchez, J.R. and Tärneberg, W., 2022. Initial assessment of architectures and hardware resources for a RadioWeaves infrastructure.

Subtopic 2 Low-complexity digital front-ends (DFEs):
Three contributions:

Linearization: We have developed a low-complexity memoryless linearizer for analog-to-digital interfaces (ADIs). It is inspired by neural networks but has a substantially lower complexity than the neural-network schemes that have appeared earlier in the literature in this context. We have demonstrated that the proposed linearizer can outperform the conventional parallel memoryless Hammerstein linearizer even when the nonlinearities have been generated through a memoryless polynomial model. Further, we have proposed a design procedure in which the linearizer parameters are obtained through matrix inversion. Thereby, we avoid the costly and time consuming iterative nonconvex optimization that is traditionally used when training neural networks. Simulations have shown signal-to-noise-and-distortion ratio (SNDR) improvements of some 25 dB for multi-tone signals that correspond to the quadrature parts of OFDM signals with QPSK modulation. This work has resulted in a conference paper [B2.4].

Compensation of timing mismatch in two-channel time-interleaved ADCs: We have showed that substantial correction improvements of two-channel time-interleaved ADCs using first-order compensation schemes can be achieved when the two channels are appropriately matched to each other instead of viewing one channel as a reference and matching the other channel to this reference channel. This work has resulted in one journal paper [P2].

Low-complexity beamforming designs and channel estimation for passive intelligent surface (PIS) assisted MISO energy transfer: We have further worked on improving our earlier proposed channel estimation (CE) and low-complexity jointly-optimal transmit (active) and reflect (passive) energy beamforming (EB) design maximizing the efficacy of PIS assisted energy transfer (PET) from multiantenna power beacon (PB) to single-antenna users. This work has resulted in one journal paper [B2.6].

[B2.4] D. Rodriguez Linares and H. Johansson, “Low-complexity memoryless linearizer for analog-to-digital interfaces, 24th International Conference on Digital Signal Processing, Island of Rhodes, Greece, June 2023 (accepted).

[B2.5] Y. Wang, H. Johansson, M. Deng, and Z. Li, “On the compensation of timing mismatch in two-channel time-interleaved ADCs: Strategies and a novel parallel compensation structure”, IEEE Trans. Signal Processing, vol. 70, pp. 2460-2475, 2022.

[B2.6] D. Mishra and H. Johansson, “Low-complexity beamforming designs and channel estimation for passive intelligent surface assisted MISO energy transfer”, IEEE Internet of Things Journal, accepted Dec. 2022.

Subtopic 3 High-level design methodologies using distributed many-core processor architectures:
Halmstad University (HH) is concerned with finding suitable architectures for Massive MIMO algorithms used in Baseband processing of beyond 5G wireless communication systems. HH started by investigating different architectures of CNNs for a fingerprint based positioning system mMIMO algorithms used in Large Intelligent Services (LIS) for positioning services [B2.7]. The study focused on enhancing the accuracy (minimize the mean distance error) of these services in terms of accurate positioning of users using the Channel State Information (CSI) of a massive MIMO system as input data.

[B2.7] Ali Nada, Hazem Ismail Ali, Liang Liu and Yousra Alkabani. 2023. Enhancing the Accuracy of CSI-based Positioning in Massive MIMO Systems. Paper is under submission in IEEE BlackSeaCom 2023 conference.

1.1. Plans for 2023

Distributed processing algorithm and hardware architecture: Future 6G systems are supporting multiple wireless services including communication, sensing, positioning, and wireless power transfer. One of the potential topics for 2023 is to look into unified distributed processing architecture that can support multiple of these services to improve the implementation efficiency. The development of the RFSoC-based 6G testbed will continue. The plan for 2023 is to have the real-time communication service (e.g., spatial multiplexing of multiple users) implemented and verified.

Low-complexity digital front-ends (DFEs):

We will explore the proposed low-complexity linearizer and its extensions to memory linearizers, and investigate their possibilities and limitations for different classes of nonlinearities, signals, and effective resolutions (effective number of bits) both for ADIs and DAIs, in particular in the context of massive MIMO which comprises many parallel signal chains as well as crosstalk.

High-level design methodologies using distributed many-core processor architectures:

Our investigation will focus on accelerating mMIMO detection algorithms in both software and hardware domains. Regarding software, we plan to leverage potential parallelism within these algorithms and implement them using parallel languages and computational models to test them on commercial parallel platforms such as GPUs. As for hardware, we intend to create appropriate architectures that can efficiently utilize these parallel designs.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
Massive MIMO technology and application	Ericsson	One post-doc and one PhD student in the digital baseband processing	2018-2022
BEYOND5	EU ECSEL/Vinnova	~2 MSEK for ULUND	2020-2023
REINDEER: REsilient INteractive applications through hyper Diversity in Energy Efficient RadioWeaves technology	EU H2020		2020-2024
Scalable and Distributed Computing for Large Intelligent Surfaces	VR	~900kSEK	2020-2023
Large Intelligent Surfaces – Architecture and Hardware	SSF	~6 MSEK	2021-2025
Calibration of Time-Interleaved Analog-to-Digital Converters	Huawei	824 kSEK	2020-2022
Receiver Linearization Techniques	Huawei	800 kSEK	2022-2023

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Deijany Rodriguez Linares		From 2021

5. Inter-university cooperation: summary for 2022

Besides on the inter-university cooperation within the ELLIIT project, Lund University is collocating (in the EU H2020 project REINDEER), with Linköping University, KU LEUVEN, TU Graz on developing the RadioWeave concept and systems. Within the EU project BEYOND5, Lund University is together with KTH, TU Dresden, TU Delft working on developing mmWave massive MIMO testbed for in-flight cabin communication.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

The department of Electrical and Information Technology (EIT), LU are working together with the Computer Science and Automatic Control and Centre for Mathematical Sciences in Lund University to conduct a measurement campaign in Lund University Humanities Lab's motion capture studio for multi-sensory positioning for indoor environment. [Yaman, I., Tian, G., Larsson, M., Persson, P., Sandra, M., Dürr, A., Tegler, E., Challa, N., Garde, H., Tufvesson, F. and Åström, K., 2023. The LuViRA Dataset: Measurement Description. arXiv preprint arXiv:2302.05309.] This is very helpful to further understand and develop the new services in Beyond 5G and 6G systems.

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

Lund university: In the EU H2020 project REINDEER, the industry partners are Ericsson, Technikon, NXP, Telefonica. Within BEYOND5, Lund University is working closely with Ericsson, GlobalFoundries, Leti, MRK-IC. Linköping University has cooperated with Huawei.

8. International collaboration

Lund university is collaborating with many partners within EU project REINDEER and BEYOND5. Lund university is also collaborating with University of Michigan on efficient hardware implementation of 5G baseband processing algorithms. Linköping university cooperates with universities in Australia and China.

9. Supervision of master thesis projects in collaboration with industry

Lund University:

- With Ericsson “Beam-steered Modulation in Advanced Antenna Systems”
- With Ericsson "Investigating Machine Learning for verification of AMBA APB protocol"
- With Axis “Using Approximate Computing Circuits to Optimize Performance and Power of an ASIC”
- With Ericsson “Efficient implementation of a filter library targeted at multiple platforms”

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
Introduction to Structured VLSI Design (LU)	graduate
Computer Architecture (LU)	graduate
DSP-Design (LU)	graduate
Director of International master program on Embedded Electronics Enginering (Liang Liu)	graduate
Multirate Digital Signal Processing (LiU, Håkan Johansson)	graduate

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

Liang Liu gave invited talks “Low-power digital beamforming access point” at THE SEMICONDUCTOR RENDEZ-VOUS, Lund, 2022 and "Digital baseband implementation challenges in 6G distributed networks” at 6GSymposium, 2022. Yousra Alkabani and Liang Liu gave ELLIIT tech talk “Mobile Processing Architectures and Devices”

13. Academic service activities, including chairing of conferences, editorships and similar

Liang Liu served as Technical Committee member, IEEE Circuits and Systems (CAS) Society, Circuits and Systems for Communication and VLSI Systems and Applications Technical Committees. Håkan Johansson served as a member of IEEE Int. Symp. Circuits Syst. (ISCAS) DSP track committee.

14. Open source software contributions

N/A

B3: Energy-efficient ICs for 6G and radars transceivers

PI: Atila Alvandpour, LiU
Co-PI: Henrik Sjöland, LU

Summary

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.

1. Main scientific achievements during 2022

- During 2022, an innovative modular system-level testbench (in Matlab) has been developed for simulating and exploring next generations massive antenna arrays and beamforming transceivers architectures with near circuit-level fidelity. This has been done in a close joint research work between Linköping and Lund sites. 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. The work has so far resulted in one submitted conference paper. The testbench is under further development and more system-level investigations will be performed.
- In Lund, a chip with baseband filters suitable for 6G frequencies has been designed and fabricated, featuring both passive and active filters. Measurements are currently on-going, and the results indicate that the filters achieve state-of-the-art performance at multi-GHz baseband frequencies. Additionally, a journal paper was published on a phase shifting mm-wave frequency generator, which can be used in massive antenna arrays.
- In Linköping, a chip with a wideband pipeline ADC, suitable as a Sub-ADC for interleaved ADCs, has been designed and fabricated. The chip has been delivered, and measurement will be started as soon as the test setup and PCB fabrication are ready. Additionally, a conference paper has been submitted and is under review.
- In Lund, the industrial PhD student Christian Elgaard at Ericsson has performed a successful investigation of adaptive bias in mm-wave Doherty amplifiers. A larger transceiver chip has been designed and fabricated together with more people at Ericsson in Lund, featuring frequency up-conversion and phase shift, adaptive-bias Doherty power amplifier, as well as antenna switch and low noise amplifier for receiver. The adaptive bias shows clear linearity improvements in measurements,

also for very wideband 5G signals with 1.6GHz bandwidth, and a paper has been submitted to IEEE Journal of Solid-State Circuits.

- In Linköping, Alireza Saberkari, Atila Alvandpour and team have worked on 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. We have presented a method for increasing the separation distance between an external energy source TX antenna and micro-device RX antenna beyond 10 cm by utilizing various TX antennas.
- In Linköping, Alireza Saberkari and team have worked on an integrated tunable active all-pass filter-based true time delay (TTD) element covering a 3–5-GHz ultra-wideband (UWB) frequency. It achieves a tunable delay range of 385–540 ps with 6-ps delay steps and maximum 11% absolute delay error over the desired frequency band. Accordingly, a four-channel beamforming receiver realized by the proposed TTD element is designed and examined. The results reveal a maximum steering angle of ±45◦ with 5◦ (18 steps) steering resolution for the beamforming receiver with 2-cm antenna spacing.

1.1. Plans for 2023

The plan for 2023 is to further develop the above-described system-level testbench (in Matlab) to be able to consider even more detailed hardware imperfections and their impact on the entire system. 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.

For the above-mentioned baseband filters, the plan is to get the work published. The plan is also to submit a paper on a work about mm-wave quadrature frequency multipliers with digital calibration, for which the main part was designed previous years.

For the ADC mentioned above, the plan is to do the measurement and submit a journal paper. Also, a modified/improved version of the ADC is planned to be designed and fabricated, to be used as a sub-channel in a time-interleaved ADC.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
Micrometer-scale wireless cell fluorescence detection device	SSF	33 MSEK (about 15 MSEK for LiU)	2020-2025
Next generation distributed processing platform for sensor signal and avionics data processing	VINNOVA	1 MSEK for LiU	2018-2022
Nuclear Magnetic Resonance (NMR) Miniaturization for Spectroscopy: A Platform for Portable and Sensitive Probing	VR	3.6 MSEK (LiU)	2023-2026

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Alireza Saberkari (Associate Prof.)	0000-0002-3242-1462	From 2021
Rikard Gannedahl (PhD student)	0000-0003-4691-2120	From 2020
Javad Bagheri (PhD student)	0000-0001-7474-6428	From 2020

5. Inter-university cooperation: summary for 2022

As was briefly described under section 1, this project is based on close collaboration, joint research work between the project partners from Lund and LiU. During 2022 an innovative modular system-level testbench (in Matlab) was jointly developed for simulating and exploring next generations massive antenna arrays and beamforming transceivers architectures with near circuit-level fidelity. The work has so far resulted in one submitted conference paper, but the aim is to continue to work and generate more publications. The testbench is thus under further development and more system-level investigations will be performed. 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.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

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.

A new industrial PhD 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. 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.

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

Henrik Sjöland is the main supervisor of two industrial PhD 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 PhD students are Imad ud Din and Christian Elgaard.

A new industrial PhD 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.

8. International collaboration

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

9. Supervision of master thesis projects in collaboration with industry

Atila Alvandpour has been examiner and supervisor for several master projects in collaboration with Ericsson.

Henrik Sjöland has also been supervisor for several master projects in collaboration with Ericsson.

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
VLSI Chip Design (Alvandpour LiU)	undergraduate
Analog CMOS integrated circuits (Alireza Saberkari LiU)	undergraduate
Integrated radio frequency circuits (Alireza Saberkari LiU)	undergraduate
Radio electronics (Alireza Saberkari LiU)	undergraduate
Sigma-Delta data converters (Alvandpour, LiU)	graduate

- Atila Alvandpour is the director of the international master program in Electronics Engineering at LiU.
- Markus Törmänen is the director of the E program at LTH.
- Alireza Saberkari is the leader of Electronics profile for LiU undergraduate education programs.

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

Atila Alvandpour has been the main contact person for the national competence hub (kompetensnav) for Integrated Circuits and Systems in the VINNOVA/Energimyndigheten/ Fromas 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.

13. Academic service activities, including chairing of conferences, editorships and similar

Henrik Sjöland has been an associate editor of IEEE Transactions on Circuits and Systems – I, the term will end mid-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).

14. Open source software contributions

N/A

B4: 5G/6G Security

PI: Thomas Johansson, LU
Co-PI: Simin Nadjm-Tehrani, LiU

Summary

Applications deployed with 5G/6G will be facing several new security challenges. This project will span a variety of research activities in 5G/6G security. This includes development and analysis of cryptographic algorithms and protocols working in low latency and constrained environments and study of implementation weaknesses of security protocols through side-channels. This includes investigating the impact of quantum computers on 5G/6G security solutions. We also consider proofs for security of protocols and cross layer analysis of security as well as security mechanisms for 5G/6G IoT applications providing specified privacy features. The project has focus on security in the URLLC use case, where the goal will be end-to-end latencies of a few milliseconds with optimized use of resources and to show that this is possible in presence of some chain of viable security mechanisms.

1. Main scientific achievements during 2022

A promising solution as a part of security mechanisms for 5G/6G IoT applications is the Grain-128AEAD stream cipher that we have proposed before. We have further analysed properties of the Grain-128AEAD key re-introduction, as part of the cipher initialization. We considered several possible alternatives for key re-introduction and identify weaknesses, or potential weaknesses, in them. Our results show that it seems favorable to separate the state initialization, the key re-introduction, and the A/R register initialization into three separate phases. We now propose a new cipher initialization and have updated the cipher version to Grain-128AEADv2. Previously reported and published analysis of the cipher remains valid also for this new version.

With respect to protocol formalisation and verification a newly recruited PhD student at Linköping University (Navya Sivaraman) has studied the 5G handover protocols and formalised the variant of 3GPP

handover protocol that uses the Xn interface under the threat model of an untrusted base station. She has also formalised the forward security property which ensures that given the knowledge about a session key for one handover, the future handovers by the same user equipment attached to multiple base stations in the future cannot be compromised. The formal analysis of the Xn handover and the security property, given the threat model of untrusted source base station shows that forward security does not hold using the horizontal key derivation function. The proof has been constructed in the Tamarin theorem prover and a paper on the topic is currently under review.

1.1. Plans for 2023

We will further investigate the protocol level for 5G/6G IoT applications. We will analyse the sizes of key exchange and the per-packet message size overheads when using different security protocols to secure CoAP. Small packet sizes are important for reduced energy consumption, latency, and round-trip time in constrained radio networks. We will also investigate whether a new protocol Julia for authentication for small devices (as published in a paper by authors from Assa-Abloy) would benefit from a formalisation and proof of correctness. This would enable studying protocols with small resource footprints utilised in the IoT sector with respect to provable security. Identifying the relevant proof techniques for providing such assurances will be pursued in 2023.

2. Awards and recognitions

Simin Nadjm-Tehrani was awarded the IEEE Systems, Man, and Cybernetics (SMC) Society's Technical Committee on Homeland Security (TCHS) för "IEEE TCHS Women in Homeland Security Award in July 2022. The award is given to "women leaders who have demonstrated long-standing, sustained, and impactful contributions to homeland security practice or research, providing a female role model for young women pursuing a career in the field".

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
Secure and Private Connectivity in Smart Environments	SSF	1100000	2019-2024
WASP: Lightweight cryptography for autonomous vehicles	WASP	1000000	2019-2022
Side-channel Vulnerability and threat analysis with machine learning awareness	MSB	950000	2021-2025
Strategic Mobility: New constructions of format-preserving encryption	SSF	550000	2023-2024
Analysis of emerging cryptographic algorithms	VR	1000000	2019-2023
RICS: Research centre on Resilient Information and Control Systems (Phase 2)	MSB	2500000	2022-2024
Resource-efficient edge computing	CUGS	400000	2017-2022
Assurance for safety-critical systems that include machine learning	WASP (industry PhD student)	>1000000	2018-2023
Conceptual analysis of architectures for functional scalability, fault tolerance and security	Vinnova (NFFP)	1100000	2018-2023
Robust Deep Learning Using Symbolic Abstractions	WASP (NTU)	500000	2021-2023
WASP: Where AI meets safety and security	WASP	1000000	2022-2025

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Navya Sivaraman, PhD student		2021-
Dachao Wang, PhD student		2023-
Jing Yang, PhD student		2020-2021

5. Inter-university cooperation: summary for 2022

Co-supervision of one PhD at Linköping university.

6. Inter-disciplinary cooperation: summary, when relevant, for 2023

Ongoing joint work on the protocol Julia, suggested for fast and secure key agreement for IoT devices.

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

Collaboration with Ericsson at both Lund University and Linköping University.
Collaboration with Saab and FOI at Linköping University.

8. International collaboration

Collaboration with University of Cardiff, and ITA Brazil. Co-organiser of a Dagstuhl seminar on the topic of Digital Twins and security.

9. Supervision of master thesis projects in collaboration with industry

Supervised 3 master thesis projects (5 students) at Ericsson, Combitech, Knowit (at LiU).

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
Advanced cryptography	graduate
Real-time Systems	graduate
Green Computing	undergraduate

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

N/A

13. Academic service activities, including chairing of conferences, editorships and similar

Co-chair PQCrypto 2022, 2023, Assoc. Editor IEEE Trans. On Information Theory 2021-

PC Chair of European Dependable Computing Conference 2022, Associate Editor for IEEE Transactions on Dependable and Secure Systems. PC member for several conferences in the security and dependability field.

14. Open source software contributions

N/A

B5: 6G wireless, sub-project: vehicular communications

PI: Alexey Vinel, HH
Co-PI: Maria Kihl, LU

Summary

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 the vehicles, edge cloud coordination of small areas, such as an intersection, and global orchestration of larger areas, in order to fulfil 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 driving (when vehicles exchange their trajectories and intentions) to achieve the degrees of flexibility required for the designed decision-making algorithms.

1. Main scientific achievements during 2022

HH: 1 (Cooperative Maneuvering Safety). We provide a safety analysis for emergency braking scenarios involving consecutive vehicles. The vehicles use adaptive cruise control with a constant-distance policy together with additional vehicle-to-vehicle (V2V) communication for emergency braking. We provide explicit formulas describing how the minimum safe inter-vehicle distance, for avoiding rear-end collision, can be shortened with the use of decentralized environmental notification messages. More precisely, those formulas describe the dependency of such distances on V2V communication delay. We further show how these results can be used to compute probabilities of safe braking in the presence of packet losses.

HH: 2 (Collective Perception). Sensor data sharing enables vehicles to exchange locally perceived sensor data among each other and with the roadside infrastructure to increase their environmental awareness.

Objects filtering methods for inclusion in a message are necessary to avoid overloading a channel and provoking unnecessary data processing. To address the problem of information redundancy, several rules have been proposed, but their performance has not been evaluated yet comprehensively. In the present work, the rules are further analyzed, assessed, and compared. Functional and operational requirements are investigated. A performance evaluation is realized by discrete-event simulations in a scenario for a representative city with realistic vehicle densities and mobility patterns. A score and other redundancy-level metrics are elaborated to ease the evaluation and comparison of the filtering rules.

HH: 3 (Age of Information). We introduce a mathematical framework which allows characterizing the Age of Information (AoI) in networks governed by the Carrier-Sense Multiple Access protocol. Differently from existing work, we take into account the fact that update packets sent by mobile nodes are not necessarily periodic, since packet triggering is often coupled with agents' mobility. Our approach is based on the assumption that diverse mobility-triggered message generation patterns can be modeled by a wide class of update traffic arrival processes. We develop an accurate and efficient analytical model of nodes exchanging one-hop broadcast update messages with bursty arrivals to evaluate the moments as well as entire probability distribution of several performance metrics, including AoI. An asymptotic analysis for large networks suggests a simple way to control the update message rate to minimize the AoI. We show that the optimal update rate that minimizes the mean AoI coincides with the optimum of the wireless channel utilization.

LU: During 2022, there has been continued work on autonomous intersection management (AIM) strategies for cooperative vehicles. The main achievement in this area is a Hierarchical control strategy for AIM systems. The strategy combines a centralized global layer with a decentralized local layer. Each vehicle performs a local control of its speed and direction using its own sensors. The global layer takes a holistic view of the whole intersection and gives target speeds to each vehicle. By using a hierarchical control strategy, the AIM becomes both robust and safe.

1.1. Plans for 2023

HH: The work on safety of cooperative driving, collective perception and age of information in V2V settings will continue, and the PhD student Quentin Delooz will defend his PhD thesis in June 2023, Galina Sidorenko will complete her PhD thesis by the end of 2023.

LU: The work on robust control strategies for cooperative vehicles continues, and the PhD student Zahra Chamideh will complete her PhD thesis by the end of 2023.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
IMMINENCE (LU)	Vinnova / Celtic Next	1.8 MSEK in total	June 2021 – Dec 2023
SEC4FACTORY (LU)	SSF	5 MSEK	April 2018 – Dec 2024
SafeSmart – Safety of Connected Intelligent Vehicles in Smart Cities (HH)	KKS	2MSEK KKS + 2MSEK HH + 2MSEK in-kind	4 years
EPIC – Emergency Vehicle Traffic Light Pre-emption in Cities (HH)	VINNOVA	1.2MSEK	2 years

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Zahra Chamideh (LU)	0000-0001-8374-7764	Since start
William Tärneberg (LU)	0000-0003-1316-8059	Since start
Maria Kihl (LU)	0000-0003-3396-1652	Since start
Felipe Valle (HH)	0000-0002-2995-8322	Since start
Johan Thunberg (HH)	0000-0002-9738-4148	Since start
Galina Sidorenko (HH)	0000-0001-8587-2251	Since start

5. Inter-university cooperation: summary for 2022

There have been some cooperation activities between HH and LU, however, these activities have so far not resulted in published papers.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

There are strong links to B01 and B11 in the area of channel characterization, robust vehicular communication and vehicular positioning.

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

LU: Cooperation between LU and Volvo Cars in a Vinnova competence center proposal.

8. International collaboration

HH: Results on cooperative manuevering have been obtained with Hamburg University of Technology, Germany. Results on Collective Perception have been obtained with Technische Universität Braunschweig and Technische Hochschule Ingolstadt, Germany. Results on the AoI have been obtained with Luxembourg Institute of Science and Technology and Sapienza University of Rome, Italy.

9. Supervision of master thesis projects in collaboration with industry

N/A

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
ETSN10 Network Architecture and Performance (LU)	undergraduate

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

Outreach activities performed by Maria Kihl:

- March 2022: Tetra Pak Innovation and Science Talk
- April 2022: IVA Syd presentation
- October 2022: Presentation at Network for IT managers in Skåne
- Participated in the ELLIIT tech talks theme 1, “Industry 4.0”

Outreach activities performed by Alexey Vinel – keynote speaker at VEHITS-2022, ICCNT-2022 and SoCAV-2022.

13. Academic service activities, including chairing of conferences, editorships and similar

N/A

14. Open source software contributions

N/A

B6: Robust and Secure Control over the Cloud

PI: Anton Cervin, LU
Co-PI: Zebo Peng, LiU

Summary

The project will explore how the Cloud, with its virtually infinite compute capacity, can improve the security and performance of feedback control systems. In one part, we will research verifiable computation protocols (VPC) for secure outsourcing of cloud-based control computations. In another part, we will investigate the interplay between local and cloud-based control computations and derive guarantees on robustness and performance. There is an interesting trade-off between security, round-trip delay, and control performance that will also be studied. The design techniques will be verified in experiments, where physical processes are controlled remotely over the Cloud.

1. Main scientific achievements during 2022

We studied several issues related to the development of a cloud-based cyber-physical system platform, with a focus on ultra-reliable low-latency communication over the cloud, at LiU. We proposed to use 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 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 proposed two heuristic algorithms. The first one follows the basic idea of the 5G CG scheduling scheme that minimizes the control overhead. The second one enables increased scheduling flexibility while considering the involved control overhead. The effectiveness and scalability of the proposed techniques have been evaluated using a large number of generated benchmarks as well as a realistic case study for industrial automation.

We have also been working on scheduling techniques for Time-Sensitive Networking (TSN), which supports real-time and reliable Ethernet communication, commonly used in automotive and industrial automation systems. The proposed TSN techniques can be eventually integrated into our cloud-based CPS platform for local communication.

The Lund partner has studied different aspects of control over the cloud and control of the cloud. By control over the cloud, we mean offloading of controllers, e.g., Model-Predictive Controllers, from the local

devices to the edge or the cloud. By control of the cloud, we mean modeling and feedback-based resource management with the aim to increase the predictability and determinism of the cloud. From Dec 2021 to Nov 2022 four PhD these on these topics were defended: “Control over the Cloud: Offloading, Elastic Computing and Predictive Control” by Per Skarin at Ericsson, “Modeling and Control for Improved Predictability of Cloud Applications” by Tommi Berner, now at Modelon, “Resource Management in Distributed Camera Systems” by Alexandre Martins, now at Attitude, and finally “Dynamical Modeling of Cloud Applications for Runtime Performance Management” by Johan Ruuskanen, now at Ericsson. All of these were funded by WASP. The student funded by ELLIIT in the current project, Max Nyberg Carlsson, has during 2022 worked on a method for how to improve the temporal robustness of a controller to various timing complications, e.g., long delays or aborted computations. The core concept of the approach is to log successful sampling and actuation events and then, at discrete time points, use non-convex parametric optimization to improve the expected performance of the controller under the assumption that the future timing behavior will be like the current one. To reduce the time complexity of the optimization algorithm, automatic differentiation is integrated for efficient gradient descent. The approach is based on a new version of the JitterTime toolbox implemented in Julia. A paper summarizing this has been accepted for the IFAC World Congress 2023 in July in Nagasaki, Japan.

1.1. Plans for 2023

The following research issues will be our focus for 2023:

- Refinement of the developed 5G configured grant (CG) scheduling technique to make it more powerful for resource optimization, at LiU.
- Integration of the CG scheduling technique with JitterTime and JitterBug, developed by the LU partner, so that control performance optimization can be achieved. This will be joint work done by both partners together.
- Development of an incremental design approach so that a 5G CG schedule will be easily extended to handle future traffic, at LiU.
- Nonlinear control of controlled server queues based on new lumped low-order models, at Lund.
- Estimation of model parameters in the above-mentioned models, at Lund.

2. Awards and recognitions

Zebo Peng received the IEEE Computer Society Distinguished Contributor Award in 2022.

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project

Adaptive Software for the Heterogeneous Edge-Cloud Continuum	SSF	1.5 mSEK	2022-2027
AORTA – Advanced Offloading of Real-Time Applications	VINNOVA	1.3 mSEK	2023-2025

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Yungang Pan, PhD student	0000-0002-4647-2412	2021-2026
Max Nyberg Carlsson, PhD student	0000-0002-2608-1182	2021-2026
Ahmed Albayati will be hired as a PhD student in the AORTA VINNOVA project	Not available yet	From 2023
Martina Maggio, Full professor to co-supervise Max Nyberg Carlsson	0000-0002-1143-1127	From April 2023
Johan Eker, 50% Full professor to co-supervise Max Nyberg Carlsson	0000-0003-0181-3970	From April 2023

5. Inter-university cooperation: summary for 2022

The two partners in LU and LiU had close cooperation, with regular project meetings and common research activities. 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 been initiated.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

N/A

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

The LiU partner had a strong industrial collaboration with Motional (a technology leader in driverless vehicles), USA, via Dr. Soheil Samii, who is also an adjunct senior lecturer at LiU. This cooperation led to the following publications in 2022: Y. Zhou, S. Samii, P. Eles, and Z. Peng, “Time-Triggered Scheduling for Time-Sensitive Networking with Preemption,” Proc. 27th Asia and South Pacific Design Automation Conference (ASP-DAC’22), Virtual, Jan. 17-20, 2022, pp. 262-267.

The Lund partner has a strong collaboration with Ericsson. During 2022 this has resulted in a joint accepted VINNOVA proposal together with Mälardalen University and Cognibotics.

8. International collaboration

Besides the international cooperation with Motional, USA, described in Section 7, the LiU partner had also close cooperation with Prof. Sudipta Chattopadhyay, Singapore University of Technology and Design (SUTD), in developing symbolic execution-based frameworks to improve the performance of graphic processing units (GPU).

9. Supervision of master thesis projects in collaboration with industry

Several LiU master thesis projects took place in collaboration with Ericsson, Infor AB, and NIRA. Several Lund master thesis projects took place together with Ericsson.

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
Real-Time and Dependable Ethernet Communication with IEEE TSN standards – New Course	Graduate

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

N/A

13. Academic service activities, including chairing of conferences, editorships and similar

Zebo Peng is appointed Board Member of the European Design Automation Association (EDAA) and Associate Editor of Foundations and Trends® in Electronic Design Automation. Petru Eles is an Associate Editor of the IEEE Design & Test, the ACM Transactions on Embedded Computing Systems, and Real-Time

Systems. Karl-Erik Årzén is Associate Editor for Real-Time Systems, the Leibnitz Transactions on Embedded Systems (LITES), and the ACM Transactions of Cyber-Physical Systems.

14. Open source software contributions

B7: Quality assurance in continuous software engineering

PI: Nauman bin Ali, BTH
Co-PI: Emelie Engström, LU

Summary

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 version of a system 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 will explore the interaction between automated and manual data analysis in such contexts. We will investigate 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 will advance the work on improving the knowledge co-creation between industry and academia in software quality assurance.

1. Main scientific achievements during 2022

- **Source code quality:** We have completed an extensive and critical review of the evidence reported in the literature to connect the internal characteristics of source code to a software product's quality characteristics. This work has also led to the creation of a catalog of source code metrics.

We have also investigated what insights regarding source code quality and development practices can be attained using code review comments. A large number of comments makes it a challenge to identify interesting patterns manually. Therefore, to support such analysis, we have used an unsupervised machine learning approach to create clusters of review comments automatically.

- **Defect management**: We have used machine learning for both detecting defect reports that turn out to be invalid and identifying preventive actions to avoid their creation in the first place.
- **Test case quality:** We have conducted a survey to understand the perceived importance of various quality attributes of test cases. Through this survey we have also identified what are the major open research questions of practical relevance.

- **Architecture evaluation:** We have used scenario-based evaluation methods and prototyping to assess various quality attributes trade-offs in architectural decisions in the context of a dedicated network.
- **Continuous anomaly detection**: We have investigated the use of deep learning approaches for anomaly detection in multivariate monitoring data in distributed software systems. Through an industrial case study, we have conceptualized problems related to continuous monitoring in DevOps, overviewed unsupervised deep learning approaches for anomaly detection, and provided guidelines for selecting feasible methods for anomaly detection in time series. We deployed and evaluated the deep learning models in a real-world DevOps context using the Microsoft Azure cloud platform. The study demonstrated the effectiveness of timely anomaly detection through operation monitoring in DevOps for preventing severe failures in operations.
- **Critical scenario identification:** Critical scenario identification and testing are essential for assuring the safety and reliability of autonomous driving systems. Still, there is no standardization for identifying and using critical scenarios. We have conducted an extensive interview study with practitioners from 7 companies in the autonomous driving domain in Sweden to understand industry practices and challenges related to critical scenario identification and testing. We identified a need to combine different approaches and for more collaboration between different stakeholders and researchers to improve the situation. Through this study, we provide insights into current industry practices and identify challenges that will benefit future research.
- **Industry-academia knowledge co-creation:** Two successful cases of using interactive rapid reviews (IRRs) to initiate collaboration between academic researchers and industry practitioners were investigated, highlighting the importance of following predefined protocols to facilitate collaborative work, prioritizing analysis efforts based on the needs of practitioners, and the potential for spontaneous knowledge sharing and future studies within the company. We refined and published stepwise guidelines for performing IRRs to support researchers and practitioners in establishing effective partnerships.

1.1. Plans for 2023

Data and visual analytics have been proposed in software engineering to interpret large amounts of multi-dimensional data. However, their use in software quality assurance is insufficiently investigated. Furthermore, the cost of existing approaches is too high for practical use due to the following limitations: (a) tight coupling between analytical solutions and the underlying data collection mechanisms and (b) the need to interact with and integrate various data sources to collect all the necessary data. Using design science, we will identify and consolidate key stakeholders' information needs and develop analytical solutions to meet those needs. We will develop an information model to decouple the analytical solutions from the data sources and develop an effective and reusable data collection mechanism.

We will continue to explore the use of machine learning techniques to support software engineering tasks.

We plan to extensively review the literature on anomaly detection applied in practice to gain an overview of how different types of operational data have been used to identify early signs of software failure. We will also refine, implement, and evaluate our deep-learning solution in another industrial case.

We plan to initiate research exploring means to support AI alignment through continuous operational testing.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
SERT	KK-stiftelsen	5.99 MSEK	2018 - 2026
PLENG2	KK-stiftelsen	1.68 MSEK	2018 - 2022
OSIR	KK-stiftelsen	3.7 MSEK	2018 - 2023
WASP (PhD student)	KAW	750 KSEK	2019 - 2024
WASP (Industrial PhD student)	KAW	150 KSEK	2020 - 2024

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
PhD student Sergio Rico	0000-0002-9348-2912	2018 - 2023
PhD student Muhammad Laiq	0000-0002-5964-5554	2021 - 2026
PhD student Umar Iftikhar	0000-0003-3177-6138	2020 - 2025
PhD student Vi Tran	0000-0003-0066-1792	2018 - 2022
Dr. Muhammad Usman	0000-0002-8132-0107	2019 - 2023

5. Inter-university cooperation: summary for 2022

LTH (Sergio Rico, Emelie Engström and Martin Höst) continued their collaboration with BTH (Nauman bin Ali) on interactive rapid reviews and industry academia collaboration.
LTH (Elizabeth Bjarnasson) and BTH (Nauman bin Ali) continued their collaboration on software component selection.
LTH (Emelie Engström) and BTH (Kai Petersen, Jürgen Börstler and Nauman bin Ali) collaborated on investigating the role of theories and models for technology acceptance.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

N/A

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

BTH (Nauman bin Ali), LTH (Emelie Engström) continued collaboration with Axis, Ericsson and TestScouts on the role of visual and data analytics in software testing, a grant application has been submitted together.
BTH (Muhammad Laiq, Nauman bin Ali) continued their collaboration with Ericsson on software defect management.
LTH (Emelie Engström), RISE (Markus Borg) and Ericsson continued collaboration on adoption of automated bug assignment
LTH (Adha Hrusto, Per Runeson, Emelie Engström) and Skånetrafiken continued collaboration on anomaly detection in operations

8. International collaboration

BTH (Nauman bin Ali, Daniel Mendes) are collaborating with University of Groningen, Netherlands (Paris Avgeriou) and Pontifical Catholic University of Rio de Janeiro, Brazil (Marcos Kalinowski) regarding the teaching of empirical research methods in Software Engineering.

9. Supervision of master thesis projects in collaboration with industry

N/A

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

N/A

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

N/A

13. Academic service activities, including chairing of conferences, editorships and similar

Emelie Engström (LTH) served as associate editor of TOSEM (ACM Transactions on Software Engineering and Methodology)
Emelie Engström (LTH) served as a Program committee member for the 45th International Conference on Software Engineering (ICSE)

14. Open source software contributions

N/A

B8: Cloud Tooling for Large-Scale Cyber-Physical System Model-Based Development

PI: Görel Hedin, LU
Co-PI: Adrian Pop, LiU

Summary

By using high-level modeling languages like Modelica or Bloqqi, 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 specifications, general enough to handle the complex static semantics of cyber-physical modelling languages. 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.

1. Main scientific achievements during 2022

CodeProber and property probes: We have developed a new technique for interactive cloud-based exploration of static program analysis results, directly in terms of source code. The technique includes a new visual concept called *property probes*, used for displaying analysis results of individual source code elements, for example, inferred types of expressions, control-flow edges of statements, and bytecode of methods. The probes are live – they are immediately updated as the code is edited. The technique is embodied in a new open-source tool, *CodeProber*.

A Julia-based scientific metaheuristic optimization package (currently containing 10 algorithms) was developed. It can be applied to solve multiple-objective multiple-solution hard optimization problems. We have started experimenting using this package to optimize compilation phases in the OpenModelica compiler.

1.1. Plans for 2023

Test support in CodeProber: Current testing of static analysis tools is typically done using black-box testing, comparing actual tool output with an oracle. We will investigate how property probes can be extended to support robust white-box testing. Whereas white-box testing normally depends on internal representation details, making them very sensitive to implementation changes, our use of property probes will allow tests to be formulated at a high level of abstraction, overcoming this problem. We think this kind of testing will provide a very easy and flexible way to add and update fine-grained automated tests for analysis tools.

JuliaRAG framework: Reference Attribute Grammars (RAGs) is a powerful formalism for implementing static analysis tools. We will investigate how an internal domain-specific language for RAGs can be implemented in the Julia language. This will allow static analysis to be implemented at a high level directly in Julia. In this work we will combine the Lund expertise on RAGs and the Linköping expertise on Julia to develop a powerful and flexible framework, and try out the technique on the Julia parts of the OpenModelica tools.

We will continue the experimentation of using the Julia-based optimization package to improve the matching algorithm and tearing in the OpenModelica compiler. Better solutions for these optimization problems would allow much faster simulation of models as the system of equations to be solved can be minimized. When performing simulation-based verification of requirements one would need to run a large number of tests and optimally distributing the computation of the tests to different nodes in a cloud-based environment is very important. We will investigate if the new metaheuristic algorithms from the Julia-based optimization package can perform better at optimizing computation distribution than traditional algorithms.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2022.

Project title	Funding source	Granted amount per year	Duration of project
WASP PhD project. Explainable declarative program analysis.	WASP	1 MSEK	2019-2024
LargeDyn	VR		2019-2023
EMBrACE	ITEA/Vinnova		2019-2023

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
PhD student Anton Risberg Alaküla	0000-0003-0814-3367	2021-2026
PhD student Abdelazim Hussien	0000-0001-5394-0678	2021-2026

5. Inter-university cooperation: summary for 2022

A joint LU/LiU paper has been completed and published during 2022 about the property probing technique mentioned above. It was published at the ACM International Conference for Software Language Engineering, in Auckland, New Zealand.

Monthly joint project meetings have been held during the year, as well as a project workshop in August 2021. Further, we have had joint discussions about a new collaboration subproject concerning the library support for RAGs in Julia mentioned above.

In March 2022 we gave a Modelica tutorial at Växjö university.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

We have cross-disciplinary collaboration in a project on energy and sustainability mega-game (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 Energimyndigheten.

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

In June, we gave a tool demo of CodeProber at the workshop PRIDE (Practical Research IDEs) at the ECOOP conference in Berlin. We then got contacts with people from Amazon and Gitlab that were very interested in our tool. Subsequently, we gave an invited online technical talk at Gitlab's Vulnerability Research team (5-6 participants from Europe and SE Asia), and demonstrated CodeProber.

In October we gave a tutorial for the American Modelica Conference 2022: Introduction to Modeling, Simulation, Debugging, and Interoperability with Modelica and OpenModelica to both academia and industry participants. During 2022 we have collaborated with St Anna IT Research Institute and RISE – Research Institutes of Sweden on various projects and project proposals.

8. International collaboration

We have an ongoing collaboration with TU Dresden about using Reference Attribute Grammars for tool building. In November, we had a joint one-day workshop in Lund with presentations and demonstrations.

Our team has collaborated (via OSMC) 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 of Dynamic Overconstrained Connectors in Modelica 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.

9. Supervision of master thesis projects in collaboration with industry

We have supervised several MSc thesis projects in collaboration with industry. Examples include the following:

- Improving Tearing in a Modelica Compiler (collaboration with Modelon)
- The Evaluation of Using Backend-For-Frontend in a Microservices Environment (collaboration with Qlik).
- Visualising the outcome of an energy systems megagame (collaboration with Energimyndigheten).

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
We have introduced our new CodeProber tool in two advanced MSc courses in Lund: EDAN65 Compilers and EDAP15 Program Analysis. The students use CodeProber when doing lab assignments, to help debug their analyses.	Graduate
We have led the development of a new introductory programming course in Python (EDAA70), affecting the curriculum for a number of programs at LU. The course is currently given for the Chemistry, Bio Engineering, and Risk Management programs. A number of additional programs are switching from using Java to the new course next year.	Undergraduate
As part of our compiler course TDD44 we have discussed about optimization phases of OpenModelica. In the software design course TDDE45 we discuss OpenModelica in the part on domain-specific languages.	Undergraduate
In the graduate course: “Principles of Modeling and Simulation“, the OpenModelica tool has been used for the exercises and demonstrations.	Graduate

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

We have continued the development of the open Modelica standard, and contributed suggestions for improvements to the SSP standard together with SAAB. We are also working on proposing a new standard for requirements modeling called CRML to the Modelica Association.

13. Academic service activities, including chairing of conferences, editorships and similar

Görel Hedin (LU), 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 (LiU) and Adrian Pop (LiU) organized the 14th OpenModelica workshop while Peter Fritzson (LiU) has participated in the organization of the 16th ModProd workshop.
Martin Sjölund, Prof. Peter Fritzson, Lena Buffoni, Adrian Pop, Lennart Ochel have been quest editors for the Electronics, Computer Science & Engineering, Special Issue "Selected Papers from Modelica Conference 2021".

14. Open source software contributions

- CodeProber, a tool for source-code based exploration of program analysis results. https://github.com/lu-cs-sde/codeprober
- 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. https://openmodelica.org
- OpenModelica.jl – a Julia-based experimental framework for exploring new paradigms and extensions for physical modeling languages. https://github.com/JKRT/OM.jl
- OMSimulator – an open-source tool for co-simulation of composite models based of FMUs, supporting the FMI and SPP open standards. https://github.com/OpenModelica/OMSimulator

B9: Collaborative robotics

PI: Patrick Doherty, LiU
Co-PI: Elin Anna Topp, LU

Summary
Dynamic and seamless interaction between collections of humans and robotic systems 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. Additionally, one mechanism to achieve the appropriate communication between autonomous systems and humans is mixed–initiative interaction, as it allows for a genuine two–way communication through which it is possible to convey insights into the internal state of a system as well as to assess and resolve ambiguous situations in interaction. This project is multi-disciplinary in that it combines research with the topics of distributed situational awareness and mixed-initiative interaction. It also has as a goal to develop field tested systems in the area of emergency rescue using a combination of both robotic and human agents, in particular Unmanned Aircraft Systems and their interaction with human rescuers and support personnel.

1. Main scientific achievements during 2022

Lund University: 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. Linköping University: A journal paper titled "RGS: RDF Graph Synchronization for Collaborative Robotics" has been submitted to Autonomous Agents and Multi-Agent Systems and is currently under review. The Linköping team has been developing a system for gathering mission information using the concept of Active Queries. The system was demonstrated during the annual WASP WARA-PS workshop in September 2022, and a scientific publication is being prepared for journal submission.

1.1. Plans for 2023

The Lund team will continue to work on the VR-interface, later also to interpret human eye-gaze and gestures regarding underlying intentions. The scenario will be integrated with WASP's WARA PS tools for simulation and 3D visualisation of the respective environment, in which the Linköping team is heavily involved. The Linköping 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 and international visits in connection to activities with SAAB, among others (e.g. TeknikÅttan). Two journal publications are being prepared for submission. The first publication deals with an important issue of polygon decomposition in the context of collaborative robotic missions. The second publication proposes a data-driven approach to collaborative robotic mission generation. Mariusz Wzorek will defend his Ph.D. thesis in June 2023.

2. Awards and recognitions

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

3. External funding attracted

Elin A. Topp has received funding from WASP for a WASP-Aalto Collaborative PostDoc Project, which is currently started (April 2023)
Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
SELECTICA (LU)	EU		
Robotic Skill learning (LU)	WASP	~1MSEK	2019-2024

Autonomous Search System (LiU)	Vinnova	~1MSEK	2022-2023
WASP WARA-PS Research Arena (LiU)	WASP	~1MSEK	2017-2023

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Ayesha Jena, PhD student		Started April 2022
Mariusz Wzorek, Research Engineer/PhD student	0000-0003-2147-2114	From 2021
Piotr Rudol, Research Engineer/PhD student	0000-0003-3392-6742	From 2021
Cyrille Berger, Associate Professor	0000-0003-3011-1505	From 2021

5. Inter-university cooperation: summary for 2022

Close discussions re potential scenarios for an integration of the LU-efforts on mixed-initiative interaction with the so far existing system at LiU. The Linköping team has been informally co-advising two LU students (a master and PhD).

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

N/A

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

N/A

8. International collaboration

Within the RobotLab LTH at Lund University the LU researchers collaborate closely with researchers from the dept of Automatic Control.
The Linköping team collaborates with several academic and research institutions in Brazil within the AuSSys project. These institutions include IANA Tecnologia Ltda., Centers of Reference in Innovative Technologies Foundation (CERTI), Instituto Tecnológico de Aeronáutica (ITA), Comando da Aeronáutica (COMAER).

9. Supervision of master thesis projects in collaboration with industry

N/A

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
New Course LU: Advanced Applied Machine Learning (EDAP30)	undergraduate
Coordination of new WASP Course LU: Interaction, Collaboration, Visualisation	graduate

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

The Lund team has been involved heavily (as in previous years) in the European Robotics Week, with lab demonstrations for school classes during one week in late November. The Linköping together with Lund team performed demonstrations during Business Europe meeting in November in Stockholm.

13. Academic service activities, including chairing of conferences, editorships and similar

Elin 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) Elin A. Topp serves since summer 2021 as Associate Editor for the ACM Transactions on Human Robot Interaction (THRI)

14. Open source software contributions

N/A

B10: Geometrically Constrained Learning for Vision

PI: Michael Felsberg, LiU
Co-PI: Anders Heyden, LU

Summary

The project deals with using 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.

1. Main scientific achievements during 2022

Johan Edstedt presented a paper at ICPR 2022 in Montréal.

A paper concerning a dense correspondence learning approach for geometric matching was submitted to CVPR 2023, with Johan Edstedt as main author. The paper was subsequently accepted to CVPR 2023, and was one of the 2.5% of all submissions to be selected as a highlight.

A paper using minimal solvers for structure-from-motion problems including an IMU was presented at the WAD workshop held in conjunction with CVPR 2022 in New Orleans:
Trust Your IMU: Consequences of Ignoring the IMU Drift
Örnhag, M. V., Persson, P., Wadenbäck, M., Åström, K., & Heyden, A. In Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (pp. 4468-4477), 2022.

We are currently investigating the usage of ANN:s to estimate the relative scale between tentative point correspondencens in order to use fewer points and obataining a more robust RANSAC procedure. Preliminary investigations reveals that an ANN can estimate the relative depths better than using a simple estimator based on the SIFT features.

1.1. Plans for 2023

Johan Edstedt – Presentation at CVPR 2023.

2. Awards and recognitions

The paper by Johan Edsted was selected as highlight (top 2.5% of all submissions).

Michael Felsberg was serving as Area Chair for CVPR 2023, Program Chair for SCIA 2023, and was selected as Area Chair for NeurIPS 2023.

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
NEST _main_	WASP	Ca 1.5 mkr	4
Industridoktorand Zenseact	WASP	Ca 1 mkr	4
BUL AI	WASP	Ca 4 mkr	5
Future airprt control	Vinnova	Ca 0.5 mkr	3
Uncertainties in Transformers	VR	Ca 1 mkr	5

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Ioannis Athanasiadis (PhD student)	0000-0002-5213-6757	2022-2027
William Ljungbergh (industrial PhD student)	0000-0002-0194-6346	2022-2027
Bastian Wandt (ass. Prof)	0000-0002-1559-9496	2022-2027
Cuong Le (PhD student)		2022-2027
Hannah Helgesen (PhD student)		2022-2027
Jonathan Astermark		

5. Inter-university cooperation: summary for 2022

Physical project meetings have been held in Linköping (May and October) and in Lund (August).

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

In collaboration with Statens Medieråd and Luleå University, the dataset for the ICPR 2022 paper has been created.

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

Besides industrial PhD students with Zenseact, SAAB, and Husqvarna, we collaborate with Deep Forestry AB, Maxar Sweden, IKEA, Arriver (Qualcomm), Trafikverket, and Scania.

8. International collaboration

Michael Felsberg is part of the VOT committee organizing the yearly workshops and challenges on visual object tracking and segmentation together with delegates from Ljubljana, Prague, Zürich, and Birmingham. Furthermore, Michael Felsberg co-organized a visit of the ML-cluster (WASP) to Amsterdam, regarding the topic of geometry+deep learning.

9. Supervision of master thesis projects in collaboration with industry

CVL supervises on average 26 theses each year, most of these with industry.
CVML supervises on average 20 theses each year, most of these in collaboration with industry, such as Cellavision, Axis, Sony, Precise Biometrics, Volvo, etc.

10. List of patent applications published during 2022

Patent title	Application Number
Method for Surveillance and Analysis of Farm Animals and Arrangements for Such Surveillance and Analysis	P4885SE00

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
Computer Vision for Video Analysis	2 (Master)
Computer Vision	2 (Master)

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

Interview on Deep Fakes (August 2022 SVT-Play), Presentation at "Pint of Science".

13. Academic service activities, including chairing of conferences, editorships and similar

Michael Felsberg:
PC SCIA 2023
AC CVPR 2023
AC NeurIPS 2023
AE Plos One
AE CVIU
Anders Heyden:
AC BMVC 2022

14. Open source software contributions

All code from papers is published on GitHub.

B11: Local Positioning Systems

PI: Kalle Åström; LU
Co-PI: Fredrik Gustafsson, LiU
Researchers: Gustav Hendeby, Magnus Oskarsson, Viktor Larsson, Erik Tegler, Gustav Zetterqvist, Fredrik Tufvesson, Bo Bernhardsson, Isaac Skog.

Summary
Mapping, positioning and localization are key enabling technologies for a wide range of applications. Within ELLIIT there are several strong research groups that do fundamental research within this area for many sensor modalities, e.g. vision, radio, audio, magnetometers, radar and sonar. Within this ELLIIT project "Local Positioning Systems 2021-2025" we will concentrate on two PhD student projects, (i) Machine learning for Structure from Sound and (ii) Wearable Microphone Arrays.

1. Main scientific achievements during 2022

During 2022 we made several advances on the structure from sound problem, both improving the pipeline by improving the signal processing part by extending the traditional GCC-PHAT algorithm with a shift-equivariant neural network, by new geometric results concerning multi-path components in the presence of a dominant reflective plane, by new results on trilateration using motion models, and by new results on multiple offsets multilateration, see for example the papers “Extending GCC-PHAT using Shift Equivariant Neural Networks”, “Sensor node calibration in presence of a dominant reflective plane”,“Trilateration Using Motion Models” and “Multiple Offsets Multilateration: a new paradigm for sensor network calibration with unsynchronized reference nodes”. We also made some mapping advances utilizing IMU in fast minimal solvers, by new results on minimal solvers for map merging, and integrated mapping,

localization and path planning in a prize winning paper “Quadrotor Control on $\text {SU}(2)\times\mathbb {R}^{3} $ with SLAM Integration”, but also in “Trust Your IMU: Consequences of Ignoring the IMU Drift” and “Minimal Solvers for Point Cloud Matching with Statistical Deformations”. We have made several results on SLAM and feature extraction for lidar data, see "Survey on 2D Lidar Feature Extraction for Underground Mine Usage", "Multi-Hypothesis SLAM for Non-Static Environments with Reoccurring Landmarks", "Linearized Direction of Arrival", "Feature Based Multi-Hypothesis Map Representation for Localization in Non-Static Environments" and "A Tightly-Integrated Magnetic-Field aided Inertial Navigation System".

Plans for 2023

The two recruited PhD students (Erik and Gustav) are now well established in their respective research groups at Lund and Linköping and have had some interaction during 2022 in terms of joint ELLIIT/WASP workshop and a few zoom meetings. During 2023 we plan to step up the interaction by having bi-weekly joint zoom meetings with the researchers in Lund and Linköping. We also plan for visits between PhD students and researchers in Lund and Linköping as well as organizing a yearly workshop on positioning and localization.

2. Awards and recognitions

Greiff, Marcus, et al. "Quadrotor Control on SU(2)xR3 with SLAM Integration." 2022 IEEE Conference on Control Technology and Applications (CCTA). IEEE, 2022. Outstanding student paper award.

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
Semantic Mapping and Visual Navigation for Smart Robots	SSF	6 200 KSEK	2016-2022
WASP (AcademicPhD student) David Gillsjö	WASP (KAW)	700 KSEK	2016-2022
WASP (Industrial PhD student) Malte Larsson	Wasp (KAW) and Combain	600+ KSEK	2017-2021
WASP (Industrial PhD student) Axel Berg	WASP (KAW) and ARM	600+ KSEK	2018-2022
WASP (Industrial PhD student) Olivier Moliner	WASP (KAW) and Sony	600+ KSEK	2018-2022

ADACORSA - Airborne data collection on resilient system architectures	EU	4000 KSEK	2020-2023
WASP (Industrial PhD student) Kristin Nielsen	WASP (KAW) and Epiroc	600+ KSEK	2018-2022
Link-Sic (Industrial PhD student): Robin Forsling	Link-Sic	600+ KSEK	2018-2023
WASP (Industrial PhD student)	WASP (KAW) and Zenseact	600+ KSEK	2021-2026
Vinnova (PostDoc): Jeong Min Kang	Vinnova	1200 KSEK	2022-2023
VR (PhD student): Chuan Huang	VR	800 KSEK	2021-2026
WASP (Academic PhD) Hedieh Khosravi	WASP (KAW)	700 KSEK	2020-2024

4. Recruitments in connection to the project (students, postdocs, faculty)

We recruited two PhD students already in 2021 and had no more recruitments to the project in 2022.

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Kalle Åström	0000-0002-8689-7810	2021-
Fredrik Gustafsson	0000-0003-3270-171X	2021-
Magnus Oskarsson	0000-0002-1789-8094	2021-
Gustaf Hendeby	0000-0002-1971-4295	2021-
Erik Tegler	0000-0002-8730-8301	2021-
Gustav Zetterqvist	0000-0001-6672-4472	2021-
Fredrik Tufvesson	0000-0003-1072-0784	2021-
Bo Bernhardsson	0000-0002-6629-1889	2021-
Isaac Skog	0000-0002-3054-6413	2021-
Viktor Larsson		2021-
David Gillsjö	0000-0001-7661-1631	2021-
Malte Larsson		2021-
Axel Berg	0000-0003-4401-989X	2021-
Olivier Moliner	0000-0002-2190-9307	2021-

Kristin Nielsen		2021-
Jeong Min Kang		2021-
Chuan Huang		2021-
Adam Tonderski		2021
Hedieh Khosravi		2021-

5. Inter-university cooperation: summary for 2022

There are extensive inter-university cooperation within Sweden, most notably between Lund-Linköping, but also with collaborations with Chalmers, KTH. Also we have for several years held yearly workshops to gather Swedish researchers interested in localisation and positioning. In the last years this has also been done in collaboration with the WASP Localization and Navigation Area Cluster.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

Localization and positioning are enabling technologies with use cases for example in biology and medicine. Here we are cooperating with researchers in Biology in Lund and Munich and with researchers in Medicine in Lund.

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

Kalle Åström and Erik Tegler held a commissioned education course 'AI för civilingenjörer' for industry during 2022.
We are working together with the startup KATAM on map-making, positioning in forestry.
In Linköping there is cooperation with FOI on sound source localization. Anaechoic chamber experiments.

8. International collaboration

We have international collaborations with Wasa and Aalto (Kalle Åström and Magnus Oskarsson are working together with PhD student Luca Ferreira and supervisors Jani Boutellier and Juho Kannala), with the Max Planck Institute outside Munich (Kalle Åström and Magnus Oskarsson are working together with PhD student Beleyur), with Brown University (Kalle Åström and Viktor Larsson are working together with professor Kimia), with Kenya (Fredrik Gustafsson are working with Kenya Wildlife Service on wildlife preservation).

9. Supervision of master thesis projects in collaboration with industry

Gustav Zetterqvist and Fredrik Gustafsson supervised an MSc thesis on using geophones for combating the problems with human wildlife conflicts in Africa, see (Elephant detection using a geophone network). This involved detection of the seismic waves from the elephant footstep, small array of geophones and multilateration to estimate the direction of arrival and using several geophone arrays to triangulate the position of the elephant. The work is continued by Gustav, to extend this to a conference paper that is to be submitted. A second pair of MSc students have been recruited to make a new implementation based on this paper. Fredrik has presented this work for the Kenya Wildlife Service, and we are invited to test the concept in Kenya during 2023. Magnus Oskarsson and Kalle Åström supervised Emil Eliasson on a project on Global Indoor Positioning Using Crowdsourced Data, which was done together with Combain. In another master's thesis project Leonardo Carrera and Ziliang Xiong studied radar detection Using Deep Learning. Anton Almqvist and Anton Kuusela worked on pose classification of people using high resolution radar indoor and Hjalmar Lind and Robin Bernståle studied segmentation, classification and tracking of objects using LiDAR Point Cloud Data in another project.

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

N/A

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

- Erik Tegler - Inspirational talk to math-teachers (15/6 - 2022) arranged by Arne Ardeberg
- Kalle Åström participated in the ELLIIT tech talks theme 3, "Intelligent assistants and tools".

13. Academic service activities, including chairing of conferences, editorships and similar

- During 2022 we worked on a bid for organizing ECCV – European Conference on Computer Vision in Malmö/Copenhagen in 2026. We will continue this work in 2023.
- Kalle Åström was area chair for ECCV 2022.
- Fredrik Gustafsson and Gustaf Hendeby were general chairs for FUSION 2022 in Linköping. An international conference with approximately 350 participants.
- Gustaf Hendeby is an associate editor for IEEE Transactions on Aerospace and Electronic Systems.

14. Open source software contributions

For several of the research results we publish open source software, for example

- https://github.com/atonderski/lidarclip - software for paper "LidarCLIP or: How I Learned to Talk to Point Clouds"

B12: Visual Feature Based Data Reduction

PI: Ingrid Hotz, LiU
Co-PI: Bo Bernhardsson, LU

Summary
Developing Brain-Computer interfaces (BCIs) is a challenging goal that, however, is becoming more and more realistic. Brain imaging and measurement methods provide valuable data to gain the necessary knowledge about the complex functionality of the brain. The goal of the project is to make such brain data accessible for effective exploitation in medical and technological applications. The underlying concept is to develop sparse representations that can be used to guide a visual exploration process. We plan to approach this challenge by combining geometric and topological methods for dimension reduction, with learning methods to classify the obtained features, and modern interaction and rendering facilities to communicate the results.

1. Main scientific achievements during 2022

Withing the project we developed feature-based data reduction and analysis methods for different kinds of Brain activity measurement and imaging data.

A: Sparse representation of HARDI Data towards visual exploration: Diffusion-weighted magnetic resonance imaging (dMRI) is a technique to measure the diffusion of water, in biological tissues. It is used to detect microscopic patterns, such as neural fibers in the living human brain, with many medical and neuroscience applications e.g. for fiber tracking. In this paper, we consider High-Angular Resolution Diffusion Imaging (HARDI) which provides one of the richest representations of water diffusion. It records the movement of water molecules by measuring diffusion under 64 or more directions. However, thereby it generates high-dimensional, large, and complex datasets. Sparse representations exploit the correlations in the data by approximating it using a sparse set of coefficients and an over-complete dictionary consisting of a set of "atoms". They have been proven successful in a large number of applications. If the original signal is sparse, it allows reconstructing the original signal with significantly fewer samples than required by the classic Nyquist–Shannon sampling. This inspired us to explore the use of sparse representation in context with HARDI data. We present a work-in-progress on sparse representation of HARDI data towards

fiber tracking and the detection of fiber crossings. (Published at 40th **Swedish Symposium on Image Analysis** (SSBA). Authors: Danhua Lei, Ehsan Miandji, Jonas Unger, Ingrid Hotz)

B: Subject-Specific Brain Activity Analysis in fMRI Data Using Merge Trees. A method for detecting patterns in time-varying functional magnetic resonance imaging (fMRI) data based on topological analysis has been developed. The oxygenated blood flow measured by fMRI is widely used as an indicator of brain activity. The signal is, however, prone to noise from various sources. Random brain activity, physiological noise, and noise from the scanner can reach a strength comparable to the signal itself. Thus, extracting the underlying signal is a challenging process typically approached by applying statistical methods. The goal of this work is to investigate the possibilities of recovering information from the signal using topological feature vectors directly based on the raw signal without medical domain priors. We utilize merge trees to define a robust feature vector capturing key features within a time step of fMRI data. We demonstrate how such a concise feature vector representation can be utilized for exploring the temporal development of brain activations, connectivity between these activations, and their relation to cognitive tasks. (Presented at *IEEE* Vis collocated Workshop TopoInVis, Best Paper award. Authors: Farhan Rasheed, Daniel Jönsson, Emma Nilsson, Talha Bin Masood, and Ingrid Hotz)

C: Development of an Open-Source Human-in-the-Loop BCI Research Framework (BCI-HIL)

We have developed an open-source framework with a modular and customizable hardware-independent design, comprising a human-in-the-loop (HIL) model training and retraining, real-time stimulus control, transfer learning, and cloud computing to enable a distributed BCI-HIL research framework for online classification of electroencephalography (EEG) data. Stimuli for the subject and diagnostics for the researcher are shown on separate displays using web browser technologies. Messages are sent using the Lab Streaming Layer standard and websockets. Real-time signal processing and classification, as well as training of machine learning models, is facilitated by the open-source Python package Timeflux. While online analysis is the main target of the BCI-HIL framework, offline analysis of the EEG data can be performed with Python, MATLAB, and Julia through packages like MNE, EEGLAB, or FieldTrip. The work is summarized in a journal paper currently under review (authors: Martin Gemborn Nilsson, Pex Tufvesson, Frida Heskebeck and Mikael Johansson) The BCI-HIL framework is released under MIT license with examples at https://bci.lu.se/bci-hil.

D: Real-time Bayesian Control of Reactive Brain Computer Interfaces

A method has been developed that utilizes Bayesian optimization and feedback control to improve statistical convergence in a real-time EEG classification task. (To be presented at IFAC World Congress 2023, Authors: Pex Tufvesson, Martin Gemborn Nilsson, Kristian Soltesz, Bo Bernhardsson)

1.1. Plans for 2023

2. Awards and recognitions

- Ingrid Hotz was awarded the Dr Ram Kumar IISc Distinguished Visiting Chair Professor position at the Indian Institute of Science (two month stay)
- Ingrid Hotz Co-authored three papers that reveived best paper/honourable mention awards
  - Local bilinear computation of Jacobi sets, second best paper, Journal 'The Visual Computer'.
  - Reduced Connectivity for Local Bilinear Jacobi Sets, second best paper, IEEE Vis collocated Workshop TopoInVis.
  - Subject-Specific Brain Activity Analysis in fMRI Data Using Merge Trees, Second best paper, ***IEEE*** Vis collocated Workshop TopoInVis.

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year [kSEK]	Duration of project
Visual Data Analytics in e-Science Applications (Hotz)	Swedish e-Science research center (SeRC)	3500	2018-2022
Topological descriptors for tracking, comparison and visual exploration of complex scientific data (Hotz)	VR grant 2019-05487	850	2020-2023
Robust topological methods for analysis of dynamic large-scale data for modern material design (Hotz)	VR grant 2018-07085	300	2020-2022
A topology-based approach to patterns in dynamic network data for decision support (Hotz)	WASP, academic PhD	1 PhD	2021-2024

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Danhua Lei. PhD for ELLIIT project, Visual Feature Based Data Reduction	0000-0002-6134-0258	From oct 2021
Martin Falk	0000-0003-1511-5006	Part of ELLIIT since 2022
Martin Gemborn Nilsson	0000-0002-5758-7362	From Jan 2021

5. Inter-university cooperation: summary for 2022

- Within ELLIIT there has been a cooperation with Michael Doggett and Bo Bernhardsson from Lund University in relation to the ELLIIT project sparse representations for brain imaging data.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

- *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. SeRC is one of our major funding sources and it is funding interdisciplinary cooperation by bringing together IT research and scientists from application areas. Under this umbrella we have interdisciplinary cooperation with the center for medical image science and visualization (CMIV) at LiU, the physics department LiU, the fluid mechanics group at KTH and the climate research at SU.

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

- Ericsson AB, finances an industrial PhD student, Pex Tufvesson, working on EEG-based brain computer interfaces. He works closely together with the ELLIIT PhD student Martin Gemborn Nilsson at Automatic Control in Lund.

8. International collaboration

   - The most important international collaborations are:
     Ingrid Hotz has collaborations with the University of Utah (USA), the Indian Institute of Science IISc, Bangalore (IN)

9. Supervision of master thesis projects in collaboration with industry

The following theses concern the use of EEG signals for improving hearing aids and have been conducted in cooperation with Oticon AB

- Julia Adlercreutz, “Brainstem response estimation using continuous sound”.
- Sara Enander and Louise Karsten, “Computation Models for audiovisual attention decoding”.

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
Mathematical foundations for visualization (new course)	graduate

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

The framework BCI-HIL, described above, has been demonstrated on several occasions, including: ELLITT Annual Workshop, Ericsson Research Days, Ericsson in Lund internal research meeting. A video presenting the work for the general public has also been produced.
Ingrid Hotz participated in the ELLIIT tech talks theme 6, “Big data and network science”.

13. Academic service activities, including chairing of conferences, editorships and similar

N/A

14. Open source software contributions

Open-source software for visual analysis is as the years before still plays an important role in the group. Currently developed softwares are: **Inviwo – An open-source Visualization System with Usage Abstraction Levels,** **https://inviwo.org** a software framework for rapid prototyping visualizations. 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 year we have been especially focusing on the integration of the open-source software TTK in inviwo. The results have been presented during diverse tutorials at major visualization conferences.
The BCI-HIL framework described under point 1D is available at https://bci.lu.se/bci-hil

B13: Scalable Optimization for Learning in Control

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

Summary

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, manufacturing and 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.

1. Main scientific achievements during 2022

The PI and the co-PI have collaborated with Daniel Cederberg, a MSc student at LiU, on developing efficient optimization routines for synthesis of minimax adaptive controllers, which was presented at the 2022 IEEE Conference on Decision and Control. The co-PI also presented another major result at the same conference; a new class of linear positive systems for which explicit formulas of scalable controllers can be derived. The PI submitted the book Optimization for Learning and Control, written together with Mats Andersen, DTU, to Wiley.

1.1. Plans for 2023

The PI is together with Lieven Vandenberghe, UCLA, supervising Daniel Cederberg on his Masters' thesis project, which is about Bregman proximal-gradient method for optimization over positive definite matrix polynomial matrices on the unit circle. The PI is also collaborating with Martin Andersen, DTU, and one of his PhD students on developing optimization algorithms for maximum likelihood system identification for networked systems. Together with the PhD student Felix Agner, the co-PI is developing scalable methods for control of district heating systems subject to capacity constraints.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
Filtering for Situation Awareness and Safe Autonomy	WASP	~1MSEK	2023-2027
Scalable Control of Interconnected Systems	ERC: European Research Council	0.5 MEUR	2019-2024
Statistical and Adversarial Learning in Continuous System Control	WASP collaboration project	1.1 MSEK	2019-2024

Throughput Control in Autonomous Networks	WASP PhD project	0.9 SEK	2019-2024
AI for Guidance, Navigation and Control (AI4GNC)	European Space Agency	35 kEUR	2021-2022
Learning in Networks: Structure, Dynamics, and Control	WASP NEST project	1.0 MSEK	2022-2026

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Yannick Strocka, PhD student	N/A	2021-2022
Alba Gurpegui, PhD student	N/A	From 2022

5. Inter-university cooperation: summary for 2022

N/A

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

N/A

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors: Sub-contractor in project "AI for Guidance Navigation and Control" at European Space Agency

N/A

8. International collaboration

Prof. Lieven Vandenberghe, UCLA, Prof. Martin Andersen, DTU.

9. Supervision of master thesis projects in collaboration with industry

N/A

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
Optimal Control and Reinforcement Learning by PI	PhD
The CoPI developed new masters course starting Lund January 2022: FRTN75 Learning Based Control	MSc

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

N/A

13. Academic service activities, including chairing of conferences, editorships and similar

The PI organized together with Fredrik Heinz and Elina Rönnberg the ELLIIT focus period Hybrid AI – Where data-driven and model-based methods meet.

14. Open source software contributions

N/A

B14: Autonomous Force-Aware Swift Motion Control

PI: Anders Robertsson, LU
Co-PI: Lars Nielsen, LiU

Summary

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, i.e., the dynamic behavior, is of importance, e.g., if heavy-duty vehicles with their inherent roll sensitivity or mobile platforms with heavy manipulators onboard are considered. The new perspective has high potential to lead to new significant results with regard to 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.

1. Main scientific achievements during 2022

In addition to the PI and co-PI, Erik Frisk, Björn Olofsson, Theodor Westny, Jian Zhou, and Zheng Jia have been active in the project. During 2022, the second year of this project, the research by Ph.D. student Jian Zhou on model predictive control of autonomous vehicles in traffic environments with uncertain motion of surrounding vehicles has continued. The research initiated in 2021 by Ph.D. student Theodor Westny targeting extensions of previous research on force-centric methods for passenger cars to heavy vehicles has continued and has been published at a conference. Moreover, the research initiated during 2021 aiming at planning and control for force-interaction with mobile manipulators by Ph.D. student Zheng Jia has continued.

Integrated traffic-environment prediction and model predictive control
This research investigated 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 moving targets as they 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 during the summer of 2022

> *Zhou, J., Olofsson, B., & Frisk, E. (2022). "Interaction-Aware Moving Target Model Predictive Control for Autonomous Vehicles Motion Planning". In 2022 European Control Conference (ECC), 2022, pp. 154-161. IEEE.*

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 can be achieved by tuning

a safety-awareness parameter in the MPC. The proposed method is evaluated in simulations of challenging highway driving scenarios and a scenario from recorded real traffic data. The research has been submitted for journal publication.

Research targeting truck-and-trailer combinations

Research by Theodor Westny, Björn Olofsson, and Erik Frisk has continued during 2022 on the topic of truck-and-trailer combinations and uncertainty predictions related to such vehicles in highly dynamic situations. Here, the involved dynamic forces and the effect of those on the movement of the vehicle chassis are essential, and in particular how uncertainty in terms of vehicle parameters of the ego vehicle influences the ability to perform certain maneuvers under given constraints (e.g., on swept area implied by available road space). Such functionality would be a valuable component for autonomous control functions in trucks to enable dynamics-based prediction with uncertainty consideration, so as to achieve proactive motion planning and control. The overall research goal is to extend the methods for force-centric control, developed for passenger cars in previous ELLIIT projects, to the case of trucks. Research during the year included further analysis and parameter-uncertainty prediction in aggressive maneuvers exciting the dynamic modes of the vehicle, resulting in at-the-limit motion of the truck-and-trailer system. The research was collected in a conference publication during 2022 and presented at a major vehicle-dynamics control conference (AVEC 2022)

> *Westny, T., Olofsson, B., & Frisk, E. "Uncertainties in Robust Planning and Control of Autonomous Tractor-Trailer Vehicles", In AVEC'22 The 15th International Symposium on Advanced Vehicle Control, 2022.*

Dynamics-Based Optimal Motion Planning of Multiple Lane Changes using Segmentation

Avoidance maneuvers at normal driving speed or higher are demanding driving situations that force the vehicle to the limit of tire–road friction in critical situations. Research to address these aspects has been performed by Pavel Anistratov, Björn Olofsson, and Lars Nielsen. A planning strategy based on dynamic optimization and segmentation of multiple lane-change maneuvers has been developed. The alternating augmented Lagrangian method has been adopted to coordinate the solution of the segmented subproblems. The developed method includes computation of an initially feasible motion that is found to use obstacle positions and progress of vehicle variables to its advantage. Secondly, the integration with a subsequent step with segmented optimization showed clear improvements in paths and trajectories. Overall, the combined method is able to handle driving scenarios at demanding speeds, where the force interaction between the tires and ground is of critical importance. This research was published at the IFAC Conference on Advances in Automotive Control (IFAC AAC) 2022

> *Anistratov, P., Olofsson, B., & Nielsen, L. (2022). "Dynamics-Based Optimal Motion Planning of Multiple Lane Changes using Segmentation". 10th IFAC Symposium on Advances in Automotive Control (AAC), IFAC-PapersOnLine, 55(24), 233-240.*

Research on force-centric path tracking for mobile manipulators

Research by Zheng Jia, Björn Olofsson, Lars Nielsen, and Anders Robertsson has continued during 2022 around the topic of force-centric path-tracking control for combinations of mobile platforms and robot manipulators. The problem is characterized by the interaction of force control and simultaneous satisfaction of path constraints. An example is a situation where path tracking of the robot tool is desired along certain Cartesian directions whereas control of the force interaction of the robot tool is desired along other Cartesian directions. There are also scenarios where path tracking needs to be traded against force constraints along the same dimensions. Specific research problems addressed during 2022 concern model-based predictive path-velocity adaptation with consideration of control-input limits. In addition, representation and parameterization of the surface on which the path is located have been investigated for control-design purposes.

1.1. Plans for 2023

The research by Jian Zhou, Björn Olofsson, and Erik Frisk regarding traffic environment modeling and prediction in multi-vehicle scenarios, will be further investigated. A particular aspect that will be addressed is how uncertainty of the motion of surrounding vehicles explicitly can be quantified online, and subsequently incorporated in a model-predictive control design. Here, integration of research from project A9 by PhD student Theodor Westny, is planned where data-driven prediction methods of traffic environments can be combined with advanced control techniques. Experimental evaluations are planned in the ELLIIT infrastructure Joint Autonomous Systems Lab at LiU and LU.

The research by Zheng Jia, Björn Olofsson, Lars Nielsen, and Anders Robertsson 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 are considered, and thus there are interaction forces also between the platform and the ground. Experimental evaluations are also expected in the ELLIIT infrastructure Joint Autonomous Systems Lab at LiU and LU. The results are planned for submission to conference during 2023.

2. Awards and recognitions

Lars Nielsen was invited 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”.

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project

SelectiCa	EuroStars	1 MSEK	2021-2022
Semantic Mapping and Visual Navigation for Smart Robots	SSF	6 MSEK	2016-2022
KAW project	KAW	2 MSEK	2018-2022

4. Recruitments in connection to the project (students, postdocs, faculty)

Two Ph.D. students, Theodor Westny and Jian Zhou, were recruited to the Division of Vehicular Systems at LiU during 2020, and they are sharing the efforts in this ELLIIT project starting in 2021.
Zheng Jia was recruited to this ELLIIT project as a Ph.D. student at Dept. Automatic Control, Lund University in September 2021.
Björn Olofsson was recruited as Senior Lecturer at Dept. Automatic Control, Lund University in 2022, continuing as affiliated researcher 20% at Linköping University within ELLIIT.

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Theodor Westny, PhD student	0000-0001-9075-7477	2020-
Jian Zhou, PhD student	0000-0002-1050-3037	2020-
Zheng Jia, PhD student		2021-
Björn Olofsson	0000-0003-1320-032X	2020-

5. Inter-university cooperation: summary for 2022

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 within the project (with Björn Olofsson as co-supervisor). Lars Nielsen (LiU) is 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 involved in this subproject of ELLIIT.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

N/A

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

- VTI (tire models and road geometry characteristics, Dr. Sogol Kharrazi).
- AB Berntec (efficient and safe motion planning, Dr. Karl Berntorp).
- AB Volvo (research discussions)
- NIRA Dynamics (research discussions)

8. International collaboration

LiU collaborates with Stanford University. The former ELLIIT PhD student Victor Fors is now 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 2022.

9. Supervision of master thesis projects in collaboration with industry

- Toyota Material Handling (Master's thesis project)
- OMotion AB (Master's thesis project)
- 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)

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
TSFS12 Autonomous vehicles – planning, control, and learning systems at Linköping University	2nd cycle
FRTF20 Applied robotics at Lund University	1st cycle

The 2nd cycle course "Autonomous vehicles – planning, control, and learning systems" at LiU developed by Erik Frisk, Björn Olofsson, and Jan Åslund at Div. Vehicular Systems, LiU, was given the fourth time during the fall semester 2022. Results from this ELLIIT project are used in the course and the 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 over 90 students, and also this year received excellent grades in the course evaluation. Björn Olofsson was responsible for the 1st cycle course Applied Robotics during the fall semester 2022, given within the undergraduate education at LU.

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

RobotLab LTH at LU (Anders Robertsson director) is a research platform for industrial, mobile, and aerial robotics, which also is used extensively in education on both undergraduate and graduate level. 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 EURobotics Week. During the EURobotics Week in November 2022, several school classes and company representatives visited the lab and experienced 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 for industry, the public sector, and colleagues at Lund University.

13. Academic service activities, including chairing of conferences, editorships and similar

- Anders Robertsson is Director of the Robot Lab at LTH.
- Lars Nielsen is a member of ELLIIT steering group.
- Lars Nielsen is a member of the WASP-HS Board.
- Lars Nielsen is a member of IPC for IFAC Advances in Automotive Control Conference 2022.

14. Open source software contributions

N/A

B15: Information Handling in Industrial IoT

PI: Nikolaos Pappas, LiU
Co-PI: Emma Fitzgerald, LU

Summary

This proposal aims at a joint consideration of information generation, processing, transmission, and reconstruction in beyond 5G (B5G) massive and mission critical IoT networks by taking into account the information value. So far, in 5G networks, those processes are treated separately, and the importance and usefulness of the generated and transmitted information is ignored. This project will develop theoretical and algorithmic foundations of goal-oriented, data importance-aware communication to depart from the

separated and conventional content-agnostic paradigm which will help to reveal the potential of future hyperconnected intelligent systems. The solutions we design will be further transformed into functioning protocols, and they will be implemented in a real-world testbed that is available at Lund's site with all the components needed to mimic a smart factory scenario.

1. Main scientific achievements during 2022

The main achievements

A Perspective on Time toward Wireless 6G: The notion of latency got a prominent role in wireless connectivity, serving as a proxy term for addressing the requirements for real-time communication. As wireless systems evolve toward 6G, the ambition to immerse the digital into physical reality will increase. Besides making the real-time requirements more stringent, this immersion will bring the notions of time, simultaneity, presence, and causality to a new level of complexity. A growing body of research points out that latency is insufficient to parameterize all real-time requirements. Notably, one such requirement that received significant attention is information freshness, defined through the Age of Information (AoI) and its derivatives. In general, the metrics derived from a conventional black-box approach to communication network design are not representative of new distributed paradigms, such as sensing, learning, or distributed consensus. In this article we investigate the general notion of timing in wireless communication systems and networks, and its relation to effective information generation, processing, transmission, and reconstruction at the senders and receivers. We establish a general statistical framework of timing requirements in wireless communication systems, which subsumes both latency and AoI.

- P. Popovski, F. Chiariotti, K. Huang, A. Kalor, M. Kountouris, N. Pappas, B. Soret, ''A Perspective on Time toward Wireless 6G", Proceedings of the IEEE, vol. 110, no. 8, 2022.

Semantics-Aware Active Fault Detection in IoT: In this work we address the problem of active fault detection in an IoT scenario, whereby a monitor can probe a remote device in order to acquire fresh information and facilitate fault detection. However, probing could have a significant impact on the system's energy and communication resources. We utilize Age of Information as a measure of the freshness of information at the monitor and adopt a semantics-aware communication approach between the monitor and the remote device. In semantics-aware communications, the processes of generating and transmitting information are treated jointly to consider the importance of information and the purpose of communication. We formulate the problem as a Partially Observable Markov Decision Process and show analytically that the optimal policy is of a threshold type. We use a computationally efficient stochastic approximation algorithm to approximate the optimal policy and present numerical results that exhibit the advantage of our approach compared to a conventional delay-based probing policy.

- G. Stamatakis, N. Pappas, A. Fragkiadakis, A. Traganitis, ‘‘Semantics-Aware Active Fault Detection in IoT", 20th International Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks (WiOpt), 2022. (Journal under revision in IEEE Transactions on Comm.)

Semantics-Aware Source Coding: We consider a communication system in which the destination receives status updates from an information source that observes a physical process. The transmitter performs semantics-empowered filtering as a means to send only the most “important” samples to the receiver in a timely manner. We explore a simple policy where the transmitter selects to encode only a fraction of the least frequent realizations of the observed random phenomenon, treating the remaining ones as not not informative. For this timely source coding problem, we derive the optimal codeword lengths in the sense of maximizing a semantics-aware utility function and minimizing a quadratic average length cost. Our numerical results show the optimal number of updates to transmit for different arrival rates and encoding costs and corroborate that semantic filtering results in higher performance in terms of timely delivery of important updates. Then, we extended this work to a system with two users with heterogeneous goals.

- P. Agheli, N. Pappas, M. Kountouris, ‘‘Semantic Source Coding for Two Users with Heterogeneous Goals", IEEE Global Communications Conference (GLOBECOM), Dec. 2022.
- P. Agheli, N. Pappas, M. Kountouris, ‘‘Semantics-Aware Source Coding in Status Update Systems", IEEE ICC Workshop on Semantic Communications, 2022.

Measurements of delays in real 5G systems As a step towards a system for measuring and improving Age of Information, we first measure delays in real 5G networks and how they affect industrial communications.

- A. Rao, L. Corneo (Aalto, A. Zavodovski, W. Tärneberg, E. Fitzgerald, C. Kilinc, O. Rai, S. Johansson, V. Berggren, H. Riaz, and A. Johnsson, Prediction and Exposure of Delays from a Base Station Perspective in 5G and Beyond Networks, 5G and Beyond Network Measurements, Modeling, and Use Cases (5G-MEMU), pp 8–14, 2022
- H. Peng, W. Tärneberg, E. Fitzgerald, F. Tufvesson, and M. Kihl, Evaluation of Control over the Edge of a Configurable Mid-band 5G Base Station, 6th International Conference on Fog and Edge Computing, IEEE, pp. 1–5, 2022

Solutions for industrial IoT communication Methods for meeting the stringent requirements of industrial IoT applications in real systems with network delays. In the work on punctual cloud, we adapt the application to the realities of cloud system by predicting and mitigating delays. In the second paper below, we group IoT nodes in a factory based on their channel characteristics to allow for faster scheduling and more robust communications. In the third paper we consider intrusion detection for industrial cloud control systems.

- H. Peng, W. Tärneberg, E. Fitzgerald, and M. Kihl, Punctual Cloud: Unbinding Real-time Applications from Cloud-induced Delays, IEEE International Symposium on Networks, Computers, and Communications, pp. 1–8, 2022
- E. Fitzgerald, M. Pióro, H. Tataria, G. Callebaut, S. Gunnarsson, and L.Van der Perre, A Light Signaling Approach to Node Grouping for Massive MIMO IoT Networks, Computers, pp. 1–21, 2022
- F. Akbarian, W. Tärneberg, E. Fitzgerald, and M. Kihl, Detection and mitigation of deception attacks on cloud-based industrial control systems, 25th Conference on Innovation in Clouds, Internet and Networks (ICIN), IEEE, pp. 106–110, 2022

1.1. Plans for 2023

The plan for 2023 is that LiU and Lund side will have short visits to each other's premises to continue the plan for implementing in Lund's testbed the AoI metric, AoI-aware and importance-aware scheduling algorithms. There will be one visit from Lund to LiU during spring/summer and a visit from LiU to Lund during the fall. We expect two joint conference papers to be submitted within 2023. In LU, we will continue building the AoI testbed.

2. Awards and recognitions

N. Pappas got the following awards:

- 2022 Best Student Conference Paper Award in Swedish Communication Technologies Workshop (Swe-CTW 2022)
- 2022 Top 2% scientists list, single year impact, in the area of Networking and Telecommunications
- 2022 Journal of Communications and Networks (JCN) Best Paper Award

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
"Physical Layer Secrecy for IoT Networks with Heterogeneous Traffic"	Swedish Research Council (VR)	350ksek	2 years
"Low Latency Communications for Wireless Networks: Exploiting Traffic Characteristics"	Zenith	480ksek	6 years
"Semantics-Empowered Communication for Networked Intelligent Systems"	Swedish Research Council (VR)	980ksek	4 years
"ETHER - sElf-evolving terrestrial/non-Terrestrial Hybrid nEtwoRks"	Horizon Europe	2600ksek for 3 years	3 years

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Mehrdad Salimnejad, PhD student, LiU	0000-0002-0111-0717	From 2022
Ali Nikkhah, PhD student, LiU	0000-0001-8883-6926	From 2022
Suleyman Sadikhov, PhD student, LU		From 2022

5. Inter-university cooperation: summary for 2022

We are collaborating with Emma Fitzgerald and Maria Kihl from Lund.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

N/A

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

We are in contact with ERICSSON for more close collaboration in the topics of this project.

8. International collaboration

N. Pappas has active collaboration with:

- M. Kountouris, EURECOM, France
- H. Dhillon, Virginia Tech, USA
- A. Ephremides, University of Maryland, College Park, USA
- H. Yang, ZJU-UIUC Institute of Zhejiang University, China
- P. Popovski, Aalborg University, Denmark
- X. Dimitropoulos, University of Crete, Greece
- T. Charalambous, University of Cyprus, Cyprus
- T. Quek, SUTD, Singapore
- P. Mankar, IIIT Hyderabad, India
- P. Mohapatra, Indian Institute of Technology Tirupati, India
- Osvaldo Simeone, King's College London, UK
- Yansha Deng, King's College London, UK

9. Supervision of master thesis projects in collaboration with industry

T. Aspegårdh and L. Gardebrand, "Machine Learning-based Prediction of Handovers and Unnecessary Handovers in a Long-Term Evolution Network", ERICSSON, Linköping

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

N/A

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

N. Pappas is

- Secretary for the IEEE Tactile Internet TC
- Co-chair for the Special Interest Group on IoT in Tactile Internet (IEEE Technical Committees)
- Voting Member at the IEEE Working Group P1918.1 - Tactile Internet: Application Scenarios, Definitions and Terminology, Architecture, Functions, and Technical Assumptions

13. Academic service activities, including chairing of conferences, editorships and similar

N. Pappas was the keynote chair for the IEEE SPS - EURASIP summer school on “Defining 6G: Theory, Applications, and Enabling Technologies”, Linköping, 2022.

N. Pappas

Chair/co-chair:

- IEEE International Conference on Communications (ICC) 2022
- IEEE Wireless Communications and Networking Conference (WCNC) 2022
- IEEE SECON 2022 Workshops Co-Chair
- IEEE Future Networks World Forum 2022 Workshop on Incorporating Physical Layer Security in 6G Security Protocols

Editorial:

- Area Editor, IEEE Open Journal of Communications Society
- Expert Editor for Invited Papers, IEEE Communications Letters
- Editor, IEEE Transactions on Machine Learning in Communications and Networking
- Editor, IEEE Transactions on Communications
- Editor, IEEE/KICS Journal of Communications and Networks

Tutorials:

- 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
- Spring School 2022: Emerging and future communication networks: technologies, architectures, and tools: Semantics Communications for Future Wireless Communications

14. Open source software contributions

Pizza: Node Grouping for Massive MIMO: https://bitbucket.org/emmafitzgerald/pizza

ELLIIT Call C

The ELLIIT steering committee 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. In total, 44 applications were submitted, and 9 PhD projects were funded. These projects will from 2021 to 2025.

C1: Dynamics of complex socio-technological network systems

PI: Claudio Altafini, LiU
Co-PI: Emma Tegling, LU

Summary

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.

1. Main scientific achievements during 2022

At LiU, 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, whose 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 stubborn behavior in the early discussions of the sequence.

In Lund, a version of the concatenated Friedkin-Johnsen model was studied, where the stubbornness of each agent was adjusted depending on the outcome of a vote taked at the end of each discussion. The idea is to capture a feedback process from an observation of where the group’s opinion is headed, to the behavior of agents. The work was presented at the 2022 IEEE Conference of Decision and Control in Cancun, Mexico.

In Lund, we also focus on describing network structures for the purpose of structure inference based on data. For this purpose, we study the class of effective resistance matrices and their potential use as an alternative description of networks. We also study a novel class of growing networks with degree bounds, which have relevance both in engineered and social networks.

1.1. Plans for 2023

In LiU, we plan to apply the methodology to climate negotiations, where the concatenated FJ model is of relevance.
In Lund, the focus on network structures is combined with a focus on new models for opinion dynamics that capture large-scale political phenomena, e.g. polarization, normalization of extreme opinions and urban-rural conflicts.
We will host the Focus period on Network Dynamics in September 2023, hopefully initiating many new collaborations.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
Multiagent dynamics and collective decisions on signed graphs	Vetenskapsrådet	1 M SEK	4 years
Multi-resolution dynamical modeling of multiple sclerosis	Swedish Foundation for Strategic Research	8 M SEK	5 years

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)

Luca Gino Claude Lebon (PhD student)		From 2022
Luka Bakovic (PhD student)		From 2022
David Ohlin (PhD student)		2021 (Since 2022 funded by another project)

5. Inter-university cooperation: summary for 2022

N/A

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

The PI collaborated with various group at IFM 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 couple of journal papers.

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

N/A

8. International collaboration

We have collaborated with Univ of Sydney, Chinese Academy of Science, Tongji University in Shanghai, Univ of Sannio, Benevento, Italy.

9. Supervision of master thesis projects in collaboration with industry

N/A

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
Opinion Dynamics on Social Networks	PhD course

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

Our research on climate negotiations was highlighted in a LiU news article entitled "A mathematical model may give more efficient climate talks", see https://liu.se/en/news-item/matematisk-berakningsmodell-kan-ge-mer-effektiva-klimatsamtal

13. Academic service activities, including chairing of conferences, editorships and similar

The PI served as Associate Editor for Automatica and for IEEE Trans 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 Trans. on Control of Network Systems". He was on the IPC committee of the 11th Int. Conference on Complex Networks and Their Applications, and of the 9th Workshop on Distributed Estimation and Control of Networked Systems (NecSys'22).

The Co-PI participated in the development of the report "Control for Societal-Scale Challenges: Roadmap 2030" (edited by A. Annaswamy, K.H. Johansson and G. Pappas) in an initiative from the IEEE Control Systems Society (CSS). She was on the IPC committee of the 9th Workshop on Distributed Estimation and Control of Networked Systems (NecSys'22) (among others) and co-organized the inaugural CSS Day.

14. Open source software contributions

N/A

C2: Developing core-technologies for tree-based models

PI: Krzysztof Bartoszek, LiU
Co-PI: Niklas Wahlberg, LU

Summary

Graph learning is an important topic in science and technology. In this project we will develop new methods for tree-structured graphs, motivated by phylogenetics but with potential use in other network-based applications e.g. network routing, and discovery and analysis of gene-regulatory networks. We will develop probabilistic models for tree-structured graphs that enable learning these graphs from data while reasoning about the uncertainties in the learnt structures. We will also contribute to the development of probabilistic programming languages (PPLs), on which there is currently a lot of focus in the AI and ML communities, for automatic and efficient inference in these models.

1. Main scientific achievements during 2022

Under 2022 we have continued work on developing Bayesian inference methods for tree-structured Gaussian models. Mr. Brahmantion has completed implementing a method for 1D data, and has been working on the multivariate case . The key component, is that in different time epochs, different Gaussian models are permitted.

We have explored datasets using the maximum likelihood PCMFit estimation package, that furthermore can estimate the change points of the Gaussian processes on the tree. Our experiments showed that its detected change point correspond well to coherent clades of species.

1.1. Plans for 2023

Finalize the Bayesian approach for multivariate data. Explore effects of missing tree leaves when inferring networks from a collection of trees.

2. Awards and recognitions N/A

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
Inference for branching Markov process models - the mathematics and computations of phylogenetic comparative methods	VR	700kkr	2018-2021

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Bayu Beta Brahmntio (PhD student)		From 2021
Etka Yapar (PhD student)		From 2021
Krzysztof Bartoszek (faculty PI)		From start, 2021
Niklas Wahlberg (faculty, co-PI)		From start, 2021

5. Inter-university cooperation: summary for 2022

Collaboration with Prof. Wahlberg in the sciope of the ELLIIT grant

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

We are closely collaborating with biological groups concerning the analysis of tree structured data, and development of analysis methods. We are also in touch with matheticians from the Polish Academy of Sciences on building networks from collections of trees.

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

N/A

8. International collaboration

Nicolaus Copernicus University, Poland collaboration wth Dr. Marcin Piwczyński.
University of Oslo, Norway collaboration with Dr. Kjetil Lysne Voje.
Florida International University, USA collaboration with Dr. Jason Pienaar and Dr. Jesualdo Feuntes-Gonzalez.
University of Gdańsk, Poland collaboration with Dr. Monika Mioduchowska.
University of the Balearic Islands, collaboration with Dr. Joan Carles Pons Mayol.
Collaboration with the YUIMA team (various Japanese, Italian Universities) on running the YUIMA Conference and SDE school in Linkoping (took place in March 2023).
Polish Academy of Sciences, discussions on starting a joint project with Prof. Paweł Dłotko

9. Supervision of master thesis projects in collaboration with industry

N/A only academic master theses

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
Advanced R Programming	masters
Computational Statistics	masters
Bioinformatics	masters

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

N/A

13. Academic service activities, including chairing of conferences, editorships and similar

Organizing the Statistics part of the LiU Seminar Series in Statistics and Mathematical Statistics

14. Open source software contributions

Continued development work on the mvSLOUCH, RMaCzek, pcmabc open source R packages on CRAN.
Continued developmen of code for analyzing COVID19 data, code is publicly available on GitHub.

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

Summary
Augmented and Virtual Reality will have a major impact on future Human Computing Interfaces. This project aims to solve the challenges of generating the realistic images necessary to ensure the level of immersion to make these new 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.

1. Main scientific achievements during 2022

At Lund University n 2022 reseach was performed on lighting for Augmented Reality working with a Microsoft Hololens 2. This research showed how a fast representation of light sources can be captured interactively by a camera running on a RaspberryPi attached to the Hololens. This representation of light can then be used to light Virtual objects to match objects that exist in the real world. This work resulted in the submission of a paper entitled, “Sparse Spatial Shading in Augmented Reality”.
Also during 2022 research work begun on Neural Rendering with a focus on NeRFs. We hope this to be a major area of research in 2023. Michael Doggett PhD student, Pierre Moreau, defended his Ph.D. on 2022-01-14, with a title, “Towards Fully Dynamic Surface Illumination in Real-Time Rendering using Acceleration Data Structures”.

1.1. Plans for 2023

In January 2023 Michael Doggett (LU) meet with Peter Westerdahl (LiU) and Karljohan Lundin Palmerius (LiU) to discuss the future for the project going forward. Karljohan will take the place of Patric Ljung as the Co-PI for the project. Karljohan is actively working to employ a PhD student to work on the LiU side of the work so that collaborative work can proceed in 2023.
At LU research will focus on Neural Rendering, in particular on NeRFs.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
Efficient GPU Programming for Visual and Autonomous Software Systems	WASP	800,000sek	2018-2022

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Rikard Olajos (PhD student, LU)		Since 2021

5. Inter-university cooperation: summary for 2022

N/A

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

N/A

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

Michael Doggett and Rikard Olajos (LU) participated in the ELLIIT meeting in Linköping 19-20 October.

8. International collaboration

N/A

9. Supervision of master thesis projects in collaboration with industry

At Lund University, “Simulating optical depth for participating media using ray tracing”, by Lukas Mattsson, in cooperation with Calle Lejdförs, Tencent R&D Europe, supervised by Michael Doggett.
“Graphical Overlay based on Web Technologies for Live Streams”, by Daniel Pendse and Gustav Sjölin, at Spiideo AB, supervised by Erik Zivkovic, and Michael Doggett at Lund University.

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

N/A

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

13. Academic service activities, including chairing of conferences, editorships and similar

Michael Doggett was ACM SIGGRAPH Symposium on Interactive 3D Graphics and Games ACM SIGGRAPH I3D 2022 Conference Co-Chair.
Michael Doggett was an associate editor for Computers and Graphics Journal.

14. Open source software contributions

N/A

C4: Brain-Based Monitoring of Sound

PI: Martin Enqvist, LiU
Co-PI: Maria Sandsten, LU

Summary

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 Centre (part of the world-leading HA manufacturer Oticon A/S).

1. Main scientific achievements during 2022

During 29 August to 1 September, Oskar Keding and Maria Sandsten participated in the European Signal Processing Conference (EUSIPCO 2022) in Belgrade, Serbia, presenting the submission: "Robust Phase Difference Estimation of Transients in High Noise Levels".

In 2022 a major focus in Oskar Keding's project has been development of novel methods for robust coherence estimation, especially for estimating coupling between EEG and speech envelope. Conference papers within this scope are submitted to EUSIPCO 2023 and INTERSPEECH 2023. Extended work in reassigned spectrograms for phase difference estimation has been performed using multitapers and has been submitted to EUSIPCO 2023.

During 2022, Johanna Wilroth has primarily worked on estimation of linear filters for EEG source localization in a competing-talker scenario and a paper about this has been accepted for the IFAC World Congress 2023. Furthermore, a paper about domain adaptation for EEG-based auditory attention decoding has been finalized and submitted to the Journal of Neural Engineering. Johanna has also presented posters at Reglermöte in Luleå and at the International Conference on Cognitive Hearing Science for Communication (CHSCOM) in Linköping.

1.1. Plans for 2023

Oskar Keding and Johanna Wilroth will participate in the Winter School in Hearing Acoustics in Oldenburg, Germany. Johanna Wilroth will submit a paper to the IEEE Conference on Decision and Control about nonlinear modeling and compensation for EEG-based speech tracking. Furthermore, Johanna Wilroth will be involved in pilot tests carried out by a postdoc in a related project.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
LINK-SIC (two projects within this center)	VINNOVA	1800 kSEK	2017-2023

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Oskar Keding		PhD student at Lund University since 2021
Johanna Wilroth	0000-0002-1762-7454	PhD student at Linköping University since August 2021

5. Inter-university cooperation: summary for 2022

- Regular meetings on Teams every month
- Doctoral students and supervisors participated in CHSCOM 2022 in Linköping 12-15 June.
- Doctoral students and supervisors participated in the ELLIIT meeting in Linköping 19-20 October.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

An established collaboration with Eriksholm Research Centre and Oticon A/S via Martin Skoglund and Emina Alickovic.

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

- Regular meetings on Teams every month
- Doctoral students and supervisors have regular biweekly meetings.
- Several visits to the Eriksholm Research Center, Oticon A/S, Denmark, where training and exchange of research results took place. Johanna Wilroth gave a talk about Domain *Adaptation for Attention Steering* at an Eriksholm symposium and participated in the Demant Summer School on Translational Research at Eriksholm Research Center.

8. International collaboration

In 2022, Oskar Keding and Emina Alickovic participated in Coghear 2022 in Washington, DC between June 6th and 10th.

9. Supervision of master thesis projects in collaboration with industry

Oscar Hermansson: *A deep learning approach to brain tracking of sound* (Martin Skoglund examiner, Emina Alickovic and Johanna Wilroth supervisors)

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
Martin Enqvist is vice chairman for the committee for electrical engineering, physics and mathematics at Linköping University.	

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

N/A

13. Academic service activities, including chairing of conferences, editorships and similar

Martin Enqvist is associate editor for IEEE Control Systems Letters.

14. Open source software contributions

N/A

C5: GPAI – General Purpose AI Computing

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

Summary

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. We will 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.

1. Main scientific achievements during 2022

The LiU group contributed new results in systematic design-space exploration in energy-efficient hardware-software co-design of parallel streaming computations on heterogeneous parallel systems, and in analyzing the performance portability of single-source high-level parallel programs.
We also compiled a first collection of computational patterns in mixed AI+X computations to guide further software developments in the project. This led to initial ideas for extending the SkePU high-level programming framework targeting heterogeneous computer systems (which is developed as a long-term open-source effort by the LiU group) towards special support for DNN computations to obtain a first mixed-domain pattern-based programming framework for practical evaluations in the project.

The LU group (LU) continued exploring actor networks and dataflow computational models as candidate models for programming GPAI infrastructure. To that end, LU considered the problems of mapping and scheduling of streaming task graphs to multicore and heterogeneous architectures. The goal is an automated design space exploration flow, using causation traces for informing design choices both in hardware and in software. Working in close cooperation with LiU, LU began improving on the “crown scheduling” technique to leverage data dependent behaviour in streaming programs and actor networks (ongoing work).

The BTH group has published a survey paper on 79 low-power AI accelerators published during 2019-2022 and their properties. The output from that survey highlights that very few accelerator proposals break the 10 TOPS/W barrier, which calls for novel approaches to improve the performance per Watt. Further, focus for accelerator development in recent years has been on CNNs and deep learning, while acceleration support for transformers and neuromorphic accelerators (e.g., spiking neural networks) are on the raise.

1.1. Plans for 2023

We have concrete plans for energy-efficient adaptive scheduling of parallel streaming computations on homogenous multicore CPUs, combining the LiU team’s crown scheduling approach with trace-driven analysis and scheduling techniques developed by the LU team. We also plan to add and evaluate support for DNN computations in SkePU, see above.

LU plans to collaborate more closely with BTH and LiU, which has already started. The plan is to develop tools and algorithms for simulation, instrumentation, mapping and scheduling of programs described through the design patterns discovered and delineated by LiU onto GPAI hardware defined by BTH.

To take the next steps in the project, we are currently performing a comparative study where we evaluate different simulation and evaluation frameworks for

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
Adaptive Software for the Heterogeneous Edge-Cloud Continuum (ASTECC) (Kessler, IDA/LiU)	SSF	6 MSEK	Dec. 2022-Nov. 2027
HINTS: Human-Centered Intelligent Realities (CS/BTH)	Knowledge Foundation	6 MSEK	2022-2028
Directed Air Data Link (CS/BTH)	VINNOVA	800kSEK	2020-2023

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Sehrish Qummar (PhD student, LiU)	0000-0003-0179-0238	Since March 2022
August Ernstsson (postdoc, LiU)	0000-0001-6514-4601	Since autumn 2022
Christoffer Åleskog (PhD student, BTH)	0000-0002-0476-4177	Since Jan. 2022
Michail Boulasikis (PhD student, LU)	0000-0003-1982-0773	Since 2021

5. Inter-university cooperation: summary for 2022

We have had monthly meetings with all partners during 2022, as well as physical meetings. Further, we have had joint discussions on papers, providing cross-site input and feedback on studies and results, and joint PhD courses. The inter-university cooperation will deepen during 2023 through inter-site visits by the Ph.D. students.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

N/A

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

CS/BTH has ongoing collaborations with, e.g., Ericsson and City Network (submitted project applications), Saab (ongoing project, "Directed Air Data Link"), and several other companies in the ongoing HINTS project.

8. International collaboration

Cooperation of the LiU group (Kessler) with the group of Prof. J. Keller at FernUniversität in Hagen, Germany, about systematic design-space exploration in energy-efficient hardware-software co-design of parallel streaming computations on heterogeneous multi-core systems, resulting in two open-access articles (one in 2022, one in 2023).
Cooperation of the LiU group (Kessler) with the group of Prof. D. Griebler at PUCRS, Brasil, about evaluating performance portability in single-source high-level parallel programs.

9. Supervision of master thesis projects in collaboration with industry

LiU: R. Andersson: *Optimization of hardware trace processing on a clustered 5G multicore CPU architecture by multi-threading.* External project at Ericsson Linköping. Presentation 15 jan 2022.
BTH: Anton Dewitz and William Olofsson: "The Hare, the Tortoise and the Fox: Extending Anti-Fuzzing," with TrueSec, Faculty of Computing, Blekinge Institute of Technology, Sweden, June 2022.

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
Parallel Software Quality (new PhD course in spring 2022)	Graduate (LiU/IDA)
Advanced Computer Architecture (PhD course, May – Nov. 2022)	Graduate (CS/BTH)

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

Invited presentation by C. Kessler on "Pseudorandom number streams as a shared resource in heterogeneous parallel computing" at the annual meeting of the H2020 COST action CERCIRAS in Copenhagen, 2022.

13. Academic service activities, including chairing of conferences, editorships and similar

N/A

14. Open source software contributions

N/A

C6: In situ real-time characterization of large 5G and beyond antenna systems

PI: Mats Gustafsson, LU
Co-PI: Magnus Berggren, LiU

Summary

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 is made possible by a non-intrusive metasurface constructed to transform radiation to heat imaged by an infrared camera. With the suggested technique very low power levels corresponding to devices in consumer products can be measured.

1. Main scientific achievements during 2022

We have manufactured several mm-wave metasurfaces based on screen printing technology to investigate sensitivity to image electromagnetic fields for different patterns and ink mixtures. Initial measurements are promising and indicate good performance for 22-30GHz radiation. We have also developed algorithms for array processing and calibration of the recorded IR images. Results have been presented at EuCAP 2022 and IEEE APS 2022.

1.1. Plans for 2023

Improving sensitivity of the system by tuning the multiphysics problem of tradeoff between electromagnetic, thermal, and infrared properties of the metasurface. Initially, we will investigate different substrates for increased emissivity and reduced thermal conductivity. We will also investigate 3D printing to enable increased flexibility in manufacturing of the surfaces.
We have also planned for validation measurements together with industrial partners during 2023.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
DCC - Digital Cellulose Center	VINNOVA	2,34 MSEK (LiU part)	2022-2027

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Isak Engquist, faculty LiU, acting LiU PI	0000-0001-5635-6140	From 2021
Deyu Tu, faculty LiU, acting LiU PI from 2023	0000-0002-8875-408X	From 2023
Marzieh Zahibipour, PhD student, LiU		2021-2022
Hamza Khalid, PhD student, LiU		Recruited 2022, starting 1 Feb 2023
Johan Lundgren, post doc, LU		From 2021

5. Inter-university cooperation: summary for 2022

Bi-weekly meetings on zoom have been arranged, providing a forum for discussions and coordination. The project group met physically at the ELLIIT workshop in Linköping, October 19-20, 2022. We also had a project meeting 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.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

Circuits and systems: Prof. R Forchheimer (LiU, SE); **Paper electronics** (displays and identification): Profs. L. Wågberg (KTH, SE); **Nano sensors:** Mattias Borg (LU)

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

Collaboration with DP Patterning in Norrköping for manufacturing of metasurfaces.
Collaboration with RISE in Norrköping for screen printing of metasurfaces.
Scheduled a test measurement with Torleif Martin at QAMCOM about using the developed metasurface surfaces for evaluation of satellite array antennas. Ongoing discussions with Ericsson for validation of base station and EMF performance at mm-waves. Hopefully, have test measurements in 2023.

8. 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. 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)

9. Supervision of master thesis projects in collaboration with industry

One master thesis (Arvid Bläser, supervised by Deyu Tu) in collaboration with Ligna Energy AB was successfully defended at LOE-LiU in June 2022. The thesis reports a self-autarkic IoT label to monitor indoor temperature and humidity without the need of change/charging the battery.
Master thesis “Wide-Angle Radome Design for Low-Cost Additive Manufacturing”, Martin Fajerberg and Mattias Nylander, Axis Communications AB, successfully defended at LU in June 2022. Supervised by Johan Lundgren.

10. List of patent applications published during 2022

Patent title	Application Number
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

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
EITN90 Radar and remote sensing: Development of class room mm-wave synthetic aperture radar labs	Graduate
PhD courses Organic Electronics 1 and 2: Lectures on printing methods and ink properties for printed electronics	Graduate

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

- M. Gustafsson was a keynote speaker at Singapore Workshop on Antennas 2022
- M. Gustafsson taught a short course on 'Optimal inverse design' at APS 2022 in Denver
- M. Gustafsson and J. Lundgren supervised the 'BirdFeeder Collective Team' in the IEEE APS student design contest (3rd place)
- M. Gustafsson co-organized a workshop 'Functional Electromagnetic Structures Workshop' together with SAAB AB and IEEE, May 5

13. Academic service activities, including chairing of conferences, editorships and similar

- M. Gustafsson, IEEE Antennas and Propagation best paper award committee member.
- M. Gustafsson, ERC panel member
- M. Berggren, SPIE Conference Committee Member, SPIE, San Diego
- 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

14. Open source software contributions

FE2MS (Fast and Efficient ElectroMagnetic Solvers), Niklas Wingren, https://github.com/nwingren/fe2ms: Finite element - boundary integral hybrid code based on FEniCSx.

SDCM (Scattering Dyadic Characteristic Modes) Open source package implementation in commercial full-wave solvers. Miloslav Capek, Johan Lundgren, Mats Gustafsson, Kurt Schab, Lukas Jelinek https://github.com/kschab/scattering-dyadic-characteristic-modes#readme

C7: The DiaVoc project: Diagnosing vocal characteristics to track patients' health

PI: Andreas Jakobsson, LU
Co-PI: Johan Sanmartin Berglund, BTH

Summary

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 recordings, matched with medical information, we will develop mathematical vocal features, distance measures, and machine learning techniques suitable for tracking

and classifying relevant vocal changes. These features will improve clinical assessments of underlying health conditions and increase treatment efficacy and prediction of prognosis. A key strength of the project are our transdisciplinary perspectives in the cross-section between health science and engineering technology.

The project has employed two Ph.D. students, Niloofar Momeni (LU) and Alper Idrisoglu (BTH). During parts of 2021 and 2022, Niloofar Momeni has been on parental leave.

1. Main scientific achievements during 2022

In 2022, 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 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 the Ana Luiza Dallora, PhD (supervisor). The SLR analyzed the trends in the research and was successful in identifying gaps in the literature of the area that ground the work that will come next. The findings have been submitted for publication in JMIR, and the team is currently responding to the reviewers' feedback. 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 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 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 2023. 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).

1.1. Plans for 2023

During 2023, the LU group plans to finalize an 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 conducted 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 2023.

In 2023, the BTH team has commenced the analysis of the voice data that has been collected, with the goal of creating and evaluating a voice dataset for an automated system that can diagnose and monitor Chronic Obstructive Pulmonary Disease (COPD). The team's objective is to complete the experimental procedures, finalize the results, and summarize their findings for publication. Furthermore, the team plans to continue the process of collecting new data alongside this analysis.

2. Awards and recognitions

N/A

3. External funding attracted

None related to the ELLIIT project (LU).
Itemized list of external projects that were active at some point during 2022

N/A

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Niloofar Momeni, PhD student LU	0000-0002-9435-9772	2021-2027
Alper Idrisoglu, PhD student BTH	0000-0003-1558-2309	2021-2025
Gustaf von Grothusen, MSc student LU		2022
Marlon Almström, MSc student LU		2022
Hoa Tran, MSc student LU		2022
Mira Kjellin, MSc student LU		2021-2022
Rebecca Svensson, MSc student LU		2022

5. Inter-university cooperation: summary for 2022

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 Åbo academy in Finland.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

The LU group have during 2022 extensively collaborated with speech therapist and neurologist, the latter related to both speech and motions. The latter collaboration has resulted in a joint publication that will be submitted during the spring of 2023 on how different motion patterns for PD patients may be determined using a worn mobile phone.

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

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.

8. International collaboration

Åbo academy, Finland.

9. Supervision of master thesis projects in collaboration with industry

N/A

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
Time series analysis, LU (illustrative examples based on research)	Undergraduate (4^{th}/5^{th} year)

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

Prof. Jakobsson has during 2022 and 2023 given several popular science presentations. In these, he commonly refers to this ongoing project to illustrate the potential in AI research. In the year 2022, Alper Idrisoglu attended the ELLIT 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 a course, in a workshop, and conference held at BTH.

13. Academic service activities, including chairing of conferences, editorships and similar

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

14. Open source software contributions

N/A

C8: Situation Aware Perception for Safe Autonomous Robotics Systems

PI: Volker Krueger, LU
Co-PI: Per-Erik Forssén, LiU

Summary

This project will address the areas of sensing, analytics and learning. We will develop a modular adaptable situation-aware approach for perception, such that autonomous robotic systems (ARS) such as 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).

1. Main scientific achievements during 2022

The PhD student Simon Kristoffersson Lind has published his first paper where he proposed a method to adapt camera parameters according to a normalizing flow-based out-of-distribution detector. A small-scale study was conducted that showed that adapting camera parameters according to this out-of-distribution detector leads to an average increase of 3 to 4 percentage points in mAP, mAR and F1 performance metrics of a YOLOv4 object detector. As a secondary result, this paper also showed that it is possible to train a normalizing flow model for out-of-distribution detection on the COCO dataset, which is larger and more diverse than most benchmarks for out-of-distribution detectors.

The PhD 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 ELLIT workshop in Linköping, October 2022. A paper is currently in preparation with 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.

1.1. Plans for 2023

Simon Lind's has implemented the normalizing flow-based out-of-distribution detection on the Heron robot (see Project S1) to investigate the performance 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 we need to investigate how the NF can be computed locally.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
Smart Twins for Forest Environment	Visual Sweden	34kkr	202102-202306
Augmented operator	Visual Sweden	230kkr	202101-202212
Dorsal stream robot vision	Swedish Research Council	900kkr	202301-202612

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Simon Kristofferson Lind		Started 2021-07
Ziliang Xiong		Started 2022-09

5. Inter-university cooperation: summary for 2022

There was little collaboration between LU and LiU due to the leaving of the LiU PhD student. LiU has hired a new PhD student, and we already had a first meeting in Oct. 2022. We will start to have more regular meetings in the project in 2023, initially over video, but we may also have the occasional on-site meeting

when this is called for. In the autumn of 2023 we plan to have a project where LiU students test the SkiROS system developed in Lund, on the Heron robot available in Linköping (see ELLIIT Projects S1 and S4).

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

N/A

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

LU has submitted an application for an industrial collaboration with Tetra Pak where image processing reliability is of high priority. Simon Lind's results will be of importance here.
LiU has submitted an application to Formas with VTI and NOSP. The project will study uncertainty representation and characterisation for large scale mapping and semantic segmentation in city environments, and connects to the ELLIIT project in this respect.

8. International collaboration

N/A

9. Supervision of master thesis projects in collaboration with industry

LU has a master thesis project collaboration with ABB for exploring the idea of the situational fingerprint. The goal of the project is to focus first on an industrial environment with limited complexity.

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
Per-Erik has given one of the modules in the WASP course Learning Feature Representations, autumn 2022	WASP PhD
Per-Erik has developed a new master's course "3D Computer Vision"	Master

Volker is using results in his course Intelligent Autonomous Systems	Master

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

Per-Erik Forssén has given a Popular Science talk on ”Populärvetenskapliga veckan” October 2022, on the topic of ”3D vision in self-driving cars and humans”.

13. Academic service activities, including chairing of conferences, editorships and similar

Per-Erik Forssén was general chair for the Swedish Symposium on Image Analysis and Deep Learning 2023, March 2023.

14. Open source software contributions

N/A

C9: Data Sharing for Industry 4.0 Machine Learning

PI: Per Runeson, LU
Co-PI: Christian Kowalkowski, LiU

Summary

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 – supporting data ecosystems. We 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 project has employed two Ph.D. students, Konstantin Malysh (LU) and Tanvir Ahmed (LiU).

1. Main scientific achievements during 2022

During 2022, the project team has initiated collaboration with companies in different industry sectors.

- The team at LiU presented their first work on data affordance for inter-firm data sharing in industrial settings at an international conference on servitization. Having reviewed the literature on

affordance, Tanvir Ahmed's proposed an affordance lens to identify the action possibilities of data for firms, a measure that has not yet been used for intangible artifacts, such as data. A revised conceptualization was submitted to and accepted for presentation at the leading academic marketing conference (AMA Winter). In parallel, Christian Kowalkowski has conducted complementary research on digital platforms and subscription business models in business-to-business markets.

- The team at LU has approached the topic from the angle of open source tools and ecosystems. Konstantin Malysh has reviewed the literature in search for findings on tool support for data ecosystems, and concluded that there is very limited availability of such tools. Therefore, a multiple case study is planned to explore industry practice on data sharing, with a dual focus on business models, and tools and governance of data sharing. Malysh is accepted as an affiliated PhD student with the WASP program, which implies attending PhD courses and partaking in a study trip in Swedish industry.

- As a concluding contribution from earlier projects on open data, Linåker and Runeson published a paper entitled *Sustaining Open Data as a Digital Common - Design principles for Common Pool Resources applied to Open Data Ecosystems* at OpenSym 2022 https://doi.org/10.1145/3555051.35550. This paper applies Ostrom's design principles for Common Pool Resources to open data and provides a foundation for further work on open data ecosystems governance.

1.1. Plans for 2023

During the Spring of 2023, the project team jointly plans to finalize the multiple case study on data sharing. We aim for 7-10 case companies to understand the current state (practices, experiences, challenges) of data sharing as the driver of the informational flow inside and between companies.

The LiU group plans to finalize at least two case studies how manufacturing companies are managing data sharing with ecosystem partners and customers for data-driven service innovation. The units of analysis are manufacturing companies and their governance of digital platforms for service innovation. Overall, the aim is to conduct three to four comprehensive case studies in different business-to-business industries, analyze the material, and prepare for the submission to an A level management journal. In parallel, the group will be involved in conceptual research on customer experience management in business-to-business markets, together with a team of leading marketing and service scholars.

The LU group aims to explore current tools for data sharing, to investigate their matching with the needs identified in the company case study.

2. Awards and recognitions

Christian Kowalkowski was a Highly Cited Researcher 2022 by Clarivate, as the only Sweden-based scholar in Economics and Business.

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

N/A

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Tanvir Ahmed	0000-0002-4798-4823	2021-2026
Konstantin Malysh	0000-0002-3659-3093	2021-2026

5. Inter-university cooperation: summary for 2022

LU and LiU have collaborated in planning of the multi case study, which is executed spring 2023. We have had project meetings in conjunction with the ELLIIT workshop and digitally three other times during the year.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

The project is interdisciplinary in nature, with researchers from the computer science and industrial marketing disciplines.

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

Case studies ongoing in several industry domains.

8. International collaboration

Professor Wolfgang Ulaga, INSEAD, France

Professor Bård Tronvoll and David Sörhammar, Norway Inland University, Norway

9. Supervision of master thesis projects in collaboration with industry

Christian Bilevits, Adam Hägglund, *Data Ecosystem as a solution for Intra-Organizational Data Sharing: Benefits and Challenges and Requirements*, Axis Communications AB, https://lup.lub.lu.se/student-papers/search/publication/9076585

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

N/A

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

Per Runeson and Christian Kowalkowski participated in the ELLIIT tech talks, theme 11. Digital business models and legal aspects, talking about Open source and open data and Digitalization and servitization respectively.

13. Academic service activities, including chairing of conferences, editorships and similar

Christian Kowalkowski served as editor (together with Prof Tim Baines and Dr Ali Z. Bigdeli, Aston University) for a 2022 special issue on "Servitization in the digital era" in the *Journal of Service Management.* He will also co-edit a forthcoming special issue on "Extending and sustaining B2B engagement in a digitalized and automated world" in *Industrial Marketing Management*.

Per Runeson and Johan Linåker served as editors (together with Anneke Zuijderwijk and Amanda Brock) for a 2022 special issue on Collaborative Aspects of Open Data in Software Engineering in *IEEE Software*.

14. Open source software contributions

N/A

ELLIIT Call D

The ELLIIT Steering Group (SG) decided in 2022, to allocate up to 10 MSEK per year during five years for new Ph.D. student projects to commence early 2023. In total, 48 applications were submitted, and 11 PhD projects were funded. Following the same instructions, a call for proposals from Halmstad University was launched in November 2022. Eight applications were received, of which one were funded. A total of 12 projects will run from 2023 to 2027.

D1: Protocol security verification using dynamic key structures

PI: Mikael Asplund, LiU
Co-PI: Christian Gehrmann, LU

Summary
Provably secure communication solutions will be needed for the continued trust in future digital services. In this PhD project we propose 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. We leverage previous and ongoing work in secure protocol analysis with two recently started industry-oriented research projects involving Sectra, Ericsson and Saab.

D2: Integrated reactive motion planning and motion control

PI: Daniel Axehill, LiU
Co-PI: Anders Robertson, LU

Summary
The objective with the proposed research is to significantly extend the recent work by the PI's former PhD 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.

D3: ACRE - Approximate Computing Reducing Energy

PI: Oscar Gustafsson, LiU
Co-PI: Joachim Rodrigues, LU

Summary
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.

D4: Visual analytics of large and complex multilayer technological networks

PI: Andreas Kerren, LiU
Co-PI: Richard Pates, LU

Summary
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 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; we will study and develop novel visual analytics approaches for the exploration and analysis of multilayer technological networks, which is not only highly relevant for the field of visual analytics, but also for the energy efficiency of power systems.

D5: Discrete optimisation for automatic decision-making in large-scale complex systems

PI: Elina Rönnberg, LiU

Co-PI: Susanna F. de Rezende, LU

Summary

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.

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

PI: Amir Aminifar, LU
Co-PIs: Christoph Kessler, LiU; Petru Eles, LiU

Summary

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. We believe that 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.”

D7: DDoS detection in 5G/6G networks

PI: Christian Gehrmann, LU
Co-PI: Mikael Asplund, LiU

Summary

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 PhD 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.

D8: Revisiting data associations in large-scale mapping

PI: Viktor Larsson, LU
Co-PIs: Mårten Wadenbäck,LiU; Michael Felsberg, LiU

Summary
This project concerns 3D mapping methods which are used to enable re-localization and navigation in large-scale environments. In particular, we will 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.

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

PI: Buon Kiong Lau, LU
Co-PI:

Summary
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. EMPTIS, our proposed project, 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.

D10: Optimal estimation and control at scale

PI: Richard Pates, LU
Co-PI: Anders Hansson, LiU

Summary

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 systematically investigate optimal estimation and control approaches through the lens of sparse linear algebra. 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.

D11: Near memory computing for data-centric architectures

PI: Joachim Rodrigues, LU
Co-PI: Oscar Gustafsson, LiU

Summary

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, we propose hardware/software co-optimized near memory computing (NMC) techniques, having the advantage of being scalable for various architectures and applications (e.g., ML/AI or baseband processing). Our 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.

D12: Static Analysis of Energy Usage in Software

PI: Wojciech Mostowski, HH
Co-PI: Christoph Reichenbach, LU

Summary

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.

ELLIIT Infrastructure Initiatives

The ELLIIT management has identified infrastructure as a critical part for further development of the research activities within ELLIIT. They have therefore investigated the needs for infrastructure support within the ELLIIT research environment. In order to get a broad view for further strategic discussions, the SG and PG invited researchers from the ELLIIT environment to suggest infrastructure support initiatives.
The ELLIIT Infrastructure Initiatives are important platforms that enable experimental research as well as demonstration and real-world validation of research results. All infrastructures are open to all researchers in ELLIIT.

S1: LTH Robotics Lab Infrastructure

PI: Volker Krueger, LU
Co-PI: Anders Robertsson LU

Summary

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:

1. use a variety of sensory data such as vision, force and torque from sensors across the entire robot,
2. use machine learning and AI-based reasoning for reliable interpretation of the sensory data and autonomous decision making for

3. controlling safely, with suitable forces, its actuators.

A key focus of LU is to maintain and support the software SkiROS for enabling the ARS.

Lund University and Linköping University collaborate with the same robot platform (Heron) to allow easy replication of results for indoor environments. The robot platform Heron is based on a MIR200 mobile robot and a UR5e universal robot. In addition, Lund University 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.

Main achievements so far and status

* Marcus Klang was hired in Oct. 2022 at LU as a robotics software engineer.

* We had our first international hackathon at LTH in January 2023 with participants from Aalborg University in DK, from ABB and LiU. The goal was to exchange software knowledge between collaborating partners, in particular the ELLIIT partners LU and LiU. Dr. Marcus Klang was leading the hackathon. The hackathon also kicked off the concrete collaboration between the two software engineers at LU and at LiU, Marcus Klang and Ola Johansson (see Project S4).

* Considerable extensions were done to the code-base that resulted into multiple submissions to IEEE conferences.

* A funding application for a collaboration with Tetra Pak was submitted, the project will be based on the SkiROS software base.

* We had this year the first master students at LU who actively and successfully working with the SkiROS software base. This is the first example where students are able to achieve advanced project results with complex robotic hardware within the short duration of a master thesis thanks to the software SkiROS that is able to hide-away hardware complexity.

S2: LISA – Large Intelligent Surface testbed with remote Access

PI: Ove Edfors, LU
Co-PIs: Fredrik Tufvesson, LU; Liang Liu, LU

Summary

LISA provides a remote-access interface to a Large Intelligent Surface (LIS) testbed at Lund University. 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, link reliability, etc., while substantially reducing transmitted energy. This makes LIS technology a prime candidate for future wireless systems, such as 6G and beyond.

S3: Research Platform for 6G, Sub-THz Radar, and Beyond

PI: Lars Ohlsson Fhager, LU
Co-PIs: Henrik Sjöland, LU; Daniel Sjöberg, LU; Buon Kiong Lau, LU

Summary

This platform is useful for laboratory validation of hardware research in wideband millimetre wave (mmW) and sub-THz technology. It enables probed and free-space characterisation of emerging hardware for 6G wireless, quantum computing, and sub-THz radar. The platform provides a route towards next generation efficient sub-THz hardware, providing equipment that can be used beyond the low-end mmW range. A new testbed with high-end modular equipment unlocks laboratory validation of circuit, antenna, device, and materials innovations. This platform establishes infrastructure nodes for 6G, sub-THz radar, and research beyond.

Main Achievements

We have finalized seven public procurement procedures, or similar, for the purchase of modern measurement equipment. Many of the instruments are of modular build and can thereby be further reconfigured and upgraded. To extend the scope of the research platform and to combat adverse economic developments, the project acquired additional co-funding from LTH in the fall of 2022.

Status of the Project

The research platform is primarily awaiting order delivery from main equipment suppliers, but a few instruments have already been delivered. We aim to finalize the last orders for small equipment in the coming months. The equipment of the research platform, listed below, adds to that previously available in EIT Research Lab, LU, and ECH, HH.

- EIT Research Lab, LU
  - SQA (delivered)
  - VNA+EXT
  - RTO
  - ...
- ECH, HH

S4: Joint Autonomous Systems Lab at Linköping and Lund

PI: Erik Frisk, LiU
Co-PI: Björn Olofsson, LiU and LU

Summary

The overall objective of the joint lab with Lund University is the development of research platforms that features:

A. use of a variety of sensory data such as vision, force, and torque from sensors across the entire robot,
B. force-aware planning and control for safety and efficient sensing,
C. 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 Linköping University mirrors a combined autonomous ground vehicle and robot-arm setup already available at Lund University. 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 will be integrated with the ELLIIT infrastructure Visionen 2.0.

The current status is that a research engineer, Ola Johansson, has been recruited to the lab during 2022. The work building up the lab, including procuring and acquiring all needed equipment, is progressing well. During 2022, several orders of equipment have been made, and delivery will take place during the first half of 2023. Operation of the robot and sensing system, including synchronization with the activities in Lund, is expected during 2023.

S5: Connectivity and compute lab for edge computing – the 5G lab

PI: Maria Kihl, LU
Co-PIs: Fredrik Tufvesson, LU; William Tärneberg, LU; Haorui Peng, LU

Summary

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.

Main achievements and status

The core of the 5G-lab, the self-contained 5G base station with edge cloud, has been in operation during the whole 2022. The lab has been used for research, education, and collaboration with academia, industry and other actors. With the 5G-lab, realistic experiments can be performed for cloud-controlled mobile robots. We have developed a remote-controlled modified hoverboard connected over 5G, which has been used in several experiments. Further, the 5G-lab is part of a VR application within the call for national research infrastructures. Currently, we have two master thesis students working with the 5G-lab. One of the students is performing a master thesis in collaboration with the Swedish Sea Rescue Society (SSRS). The other student will make the hoverboard self-driving, with the intelligence in the cloud. Further, we are planning for an extension of the radio range, by placing radio units (Ericsson Dots) in the LTH Robot lab. This extension will enable experiments of cloud-controlled industrial robots.

Personnel

The following persons were involved in the project: Prof. Maria Kihl (PI), Prof. Fredrik Tufvesson (main contact with Ericsson AB), Haorui Peng (PhD student and main responsible for the base station), Oscar Sanner (student employed to develop the hoverboard solution), Ass. Prof. William Tärneberg (key researcher), Assoc. Prof. Emma. Fitzgerald (key researcher).

S6: AIOps: A scalable research platform for artificial intelligence

PI: Fredrik Heintz, LiU
Co-PI: Fredrik Lindsten, LiU

Summary

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 large-scale 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.

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, to 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.

In 2022, Dr. Daniel de Leng was hired by LiU as a research engineer for the AIOps infrastructure initiative. In preparation for future support, the platform was deployed on an *ad-hoc* AI cluster (the Stellar environment) consisting of powerful AI workstations. This resource is actively used in the context of both student projects (including in Linköping University's AI Academy) and research activities (including by external research groups). Our experience thus far has shown that Stellar is especially useful as a complement to large clusters like Berzelius in situations where interactive sessions are difficult to get allocated, or when scheduled maintenance prevents usage close to major ML conference deadlines. Going forward, we intend to further integrate the disparate platform components and improve the ease of use by external groups.

S7: Visualization Support and Consulting – Infrastructure, Software, and Competence

PI: Ingrid Hotz, LiU
Co-PI: Martin Falk, LiU

Summary

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-of-the-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, is developed, mainly driven by research needs. Inviwo is now used by researchers not just at Linköping University, but also at other universities in Europe.

The mission of this initiative is to support ELLIIT researchers with visualization competence: Visualization consultancy, access to the state-of-the-art software, hardware infrastructure available at the Visualization

Center C in Norrköping, assistance in developing applications in software packages like Inviwo. More information can be found on the dedicated website: ELLIIT visualization infrastructure support.

Activities in 2022:

In the past year, this project supported the ***Usable Digital Twins in Healthcare*** project headed by Gunnar Cedersund. This involved two projects, namely biomechanics simulation combined with marker-based tracking for character animation and the visualization of liver steatosis dynamics (fatty liver dynamics) based on lifestyle changes. The involvement resulted in co-supervision of two Master theses together with Gunnar Cedersund. We furthermore established a contact between *Usable digital twins in healthcare* and the InfraVis initiative of the Swedish Science Council (VR). The aim was to extend the idea of biomechanically animated characters toward interactive displays for public dissemination.

ISY projection system update

This project also provided consulting with respect to the projection system update at ISY at LiU in the planning phase.

Interstellar Jets

The visualization support also facilitated a project concerned with interstellar jets, that is mass ejection from black holes. Our contribution was to visualize the different fields of a plasma physics simulation by Mark E. Dieckmann in our visualization software package Inviwo. The visualizations enabled the discovery of new insights and findings within the data. The resulting figures and animations were included as part of the publication (under submission).

Public outreach

We reached out to the ELLIIT community during the yearly ELLIIT meetup in Linköping by advertising the Visualization Infrastructure Support project, its aims, and who can benefit. The associated poster raised some interest and sparked a number of discussions.

During the WASP Community Building Summer School 2022, we offered an afternoon session on "Data Visualization – an introduction —" to educate young researchers regarding the basic principles of visualization. More recently, we introduced and showcased Inviwo within the VR InfraVis initiative in order to promote Inviwo and identify potential contact points.

Software development

Regarding sustainable software development, considerable time was spent in improving and maintaining Inviwo (inviwo.org), in particular a more seamless Python integration and plotting capabilities. Since Inviwo is mostly written in C++, a Python integration allows for prototyping utilizing already existing Python

modules and attracting a wider audience. Inviwo's plotting was extended to be able to make more compelling plots including annotations.

S8: Visionen 2.0

PI: Daniel Axehill, LiU
Co-PI: Michael Felsberg, LiU

Summary

The Visionen arena at LiU is a large modern research arena with an indoor positioning system and projectors directed towards the floor and (currently) one wall. The facility is by its combination of size and technical capabilities in terms of combined positioning and projection, a nation-unique demonstrator arena for drones as well as ground robots. Furthermore, it invites for advanced motion capture and interaction with AI systems through, e.g., body gestures.

As a result of the support from ELLIIT, the positioning system has been upgraded to increase the performance and the projection system will be upgraded to cover two additional walls. Furthermore, a research engineer is available to maintain the arena and support researchers working in the arena.

Input from ELLIIT recruited faculty

Jörn Janneck, Associate Professor in Embedded System Design (LU)

(On sick leave)

Bo Bernhardsson, Professor in Automatic Control (LU)

1. Main scientific achievements during 2022

My main research focus during 2022 has been on statistical learning in combination with control. The main application area is on efficient training of EEG-based brain computer interfaces, where three PhD students are working: Frida Heskebeck (WASP), Martin Gemborn Nilsson (ELLIIT) and Pex Tufvesson (industrial PhD, financed by Ericsson). I have also started to work more in the field of data driven life science. During the year a new project was started in pharmacometric modeling where a postdoc Jesper Sundell was recruited working in cooperation with Mats Karlsson's group in Uppsala, this is financed as a WASP-DDLS synergy project with financial support from the KAW foundation. The result of this project is collected here, and a

short presentation is available here here. During 2022 my PhD student Christian Rosdahl presented his licentiate thesis "Learning-Based Controller Design with Application to a Chiller Process". In the licentiate thesis Rosdahl studied dual control and an application in control of Chiller systems, the latter in cooperation with Carrier AB. Rosdahl after this left academia and now works at Axis Communications AB. Another PhD student, for which I have been cosupervisor, finished during 2022: Martin Morin. He now works at Iternio Planning AB. I also continued to co-supervise two of Fredrik Tufvesson's PhD students: Dino Pjanic and Guoda Tian at the EIT department. The work here concerns machine learning in massive MIMO systems.

2. Awards and recognitions

N/A.

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
Efficient Learning of Dynamical Systems	WASP	1MSEK	2018-2022
Optimizing the Next Generation Brain Computer Interfaces using Cloud Computing	WASP	0.7MSEK	2019-2024
Learning pharmacometric model structures from data	WASP-DDLS	1MSEK	2022-2024
Visual Feature Based Data Reduction B12	ELLIIT	1MSEK	2021-2026
Real-time Brain-Computer Interface (industrial PhD)	Ericsson AB	(Pex Tufvesson's salary)	2021-2025

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Martin Gemborn Nilsson	0000-0002-5758-7362	from 2021

5. Inter-university cooperation: summary for 2022

Arranged and gave a course in Autonomous Systems for 40 PhD students in the WASP program. This was done in cooperation with Patric Jensfelt KTH and Gustaf Hendeby LiU.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

Member of the WASP-DDLS (data-driven life science) collaboration management group, main activities during 2022 concerned preparing a 2nd joint call for synergy project to be announced in 2023.

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

I continued co-supervising two of Fredrik Tufvesson's PhD students: Dino Pjanic and Guoda Tian at the EIT department. These students are financed by Ericsson in an industrial cooperation project and work on machine learning methods for efficient massive MIMO communication and positioning. I am also supervising Pex Tufvesson, an industrial PhD student financed by Ericsson.

8. International collaboration

During 2022 the most intense collaborations have been with Gerard Besson, France (Dimension reduction) and Bryan Eisenhower, USA (Chiller control).

9. Supervision of master thesis projects in collaboration with industry

Supervised 5 master students in projects in collaboration with Eriksholm's research center, part of Oticon AB: Julia Adlercreutz, Viktor Andersson, Nelly Ostreus, Sara Enander and Louise Karsten. Their projects all concerned the use of EEG-signals for improvements on hearing aids. Another master thesis project was supervised in collaboration with Ericsson AB and Fredrik Tufvesson: Andre Rath's thesis had the title "Beamformed Channel Matrix Positioning Using 5G Testbench CSI data with a Deep-Learning Pipeline".

10. List of patent applications published during 2022

Patent title	Application Number
Sistema, método para calibrar a saída acústica de campo distante de um vibrador marinho e vibrador marinho	BR112016015181B1

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)

Course in Statistical Learning and Visualisation – ELLIIT focus period Lund	PhD course
Vice Program Director for the international master program *Machine Learning, Systems, and Control* at LU.	International master's program

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

In an epidemiological modeling workshop “Pandemimodeller för framtiden”, collecting many persons involved in the national handling of the pandemic including Anders Tegnell, Tom Britton, and others, I gave a seminar entitled “Hur skattar man effekten av lockdown och andra NPI :er?".

A video has been produced presenting the research in medical applications and EEG-based brain computer interfaces at the department. It is available here. The video is aimed for the general public.

13. Academic service activities, including chairing of conferences, editorships and similar

I helped organize the ELLIIT focus period “Data-driven modelling and learning for cancer immunotherapy” held in Lund 2022. During the focus period I arranged, together with Magnus Fontes and Gerard Besson, a course entitled “Statistical Learning and Visualisation – A data driven tour through the cancer immunity state space”.
I was a member of the examination committee for Johan Jönsson’s dissertation at the Linneaus University.

14. Open source software contributions

N/A

Tom Ziemke, Professor in Cognitive Systems (LiU)

1. Main scientific achievements during 2022

My main research focus is on the cognitive and social mechanisms involved in people’s interaction with autonomous technologies, ranging from social robots to (partially) automated vehicles. Main achievements in 2022 include the following:

- Our research on the cognitive mechanisms underlying human interpretation of robot behavior resulted in two journal publications (*ACM Transactions on Human-Robot Interaction*, *Artificial Life*).

This work has also resulted in a new Swedish Research Council (VR-NT) grant on *"Social Cognition in Human-Robot Interaction"* (see details below).

- Our research on social robots in eldercare, carried out in collaboration with care homes in several municipalities in Östergötland, has been continued through empirical studies and resulted in both conference and journal papers.
- Our collaboration with researchers in design and education has resulted in two new externally funded projects on in two new project son using social robots to stimulate school kids to read: one from the Swedish Research Council (VR, HS) and one from Norrköpingsfonden (see details below).
- Research on human interaction with automated vehicles in was continued in ELLIIT project A22 (*Human Interaction with Autonomous Minibuses*) as well as VTI PhD project on remote operation of partially automated vehicles and a RISE PhD project on human interaction with systems-of-systems (in particular drone swarms).

2. Awards and recognitions

I received a 2,8 million SEK project grant from the Swedish Research Council (VR, NT) for a three-year project on *"Social Cognition in Human-Robot Interaction"*. This builds on work in ELLIIT project A22, *Human Interaction with Autonomous Minibuses*, among other projects.

I am a participating researcher in two new project grants starting in 2023, on using social robots to stimulate school kids to read: one from the Swedish Research Council (HS), coordinated by Mattias Arvola (IDA, LiU), and one from Norrköpingsfonden, coordinated by Susanne Severinsson (IBL, LiU).

The European project "SmartWork – Smart age-friendly living and working environment" ended during spring 2022 and received a very positive final review.

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
SmartWork – Smart age-friendly living and working environment	European Commission, Horizon 2020	apx. 1 million SEK/year	January 2019 – March 2022
Human Interaction with Systems-of-Systems	SSF / RISE	Funding for RISE PhD student Oscar Bjurling	2019-2024
Remote operation of partially autonomous vehicles	Vinnova / VTI	Funding for VTI PhD student Christian Jernberg	2020-2025

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Sam Thellman (postdoc)	0000-0003-0098-5391	from January 2022
Franziska Babel (research engineer/ postdoc)	0000-0001-8249-7708	from April 2023
Philipp Hock (postdoc)	0000-0002-9831-9241	from April 2023

5. Inter-university cooperation: summary for 2022

See international collaboration below.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

I actively collaborate with researchers in computer science, cognitive science, design, human factors, traffic psychology, education, and gender studies, among others.

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

I collaborate with both VTI and RISE. This includes the supervision of PhD 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 minbuses*).

Within the European project SmartWork, we collaborated with several European companies (Roessingh, Byte, SparkWorks).

8. International collaboration

Collaboration with a number of European consortium partners in the European project SmartWork (cf. above and https://www.smartworkproject.eu/). Collaboration with Maartje de Graaf at the University of Utrecht, Netherlands.

9. Supervision of master thesis projects in collaboration with industry

N/A

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
Ethics of AI and interactive autonomous systems	graduate/PhD
Critical perspectives on AI	graduate/PhD

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

Tom Ziemke gave popular-scientific lectures on the public perception of AI and its limitations as part LiU's popular-science week in October 2022 (https://liu.se/artikel/popularvetenskapliga-veckan) as well as the Swedish Air Force Museum's theme day on "Tomorrow's Technology" in January 2023.

13. Academic service activities, including chairing of conferences, editorships and similar

Tom Ziemke served as program co-chair for the conference CogSIMA 2022, the *IEEE Conference on Cognitive and Computational Aspects of Situation Management*, held in Sorrento, Italy, in June 2022 (https://edas.info/web/cogsima2022/committees.html).

14. Open source software contributions

N/A

Ingrid Hotz, Professor in Visualization (LiU)

1. Main scientific achievements during 2022

Topological data analysis for comparison of ensemble data and time series

- ***Exploring Cycone Evolution with Hierarchical Features:*** A framework for tracking and visualizing the evolution of cyclones which we organize in hierarchical groups has been developed. Our approach is based on the general concept of critical point tracking and supports the exploration of resulting tracks in a level of detail approach. The problem of tracking and visualizing cyclones is still an active area of climate research, since the nature of cyclones varies depending on geospatial location and temporal

season, resulting in no clear mathematical definition. Consequently, many methods contain multiple parameters used to distinguish cyclones of interest but do not work for general cyclone extraction across the globe. Our pipeline consists of four modular building blocks: (1) a novel critical point tracking method, used in a time-varying scalar field, (2) defining cyclonic features as groups of critical points based on merge-tree crown components, (3) tracking features and creating the hierarchy between them and (4) a hierarchical visualization of features containing a global abstract representation linked to a spatial embedding, allowing exploration on a global and local scale. The modularity of the pipeline allows each independent block to be exchanged with another method conforming to expected input and output. We demonstrate that our method is not limited to the specifics of cyclone tracking and can be used in other application areas.

- ***Towards Benchmark Data Generation for Feature Tracking in Scalar Fields*:** More and more topology-based tracking methods are presented in the visualization community, but the validation and evaluation of the tracking results are currently limited to qualitative visual approaches. To overcome this challenge a benchmark data generator for tracking methods for two- and three-dimensional time-dependent scalar fields has been developed. It is built on a pipeline for creating different ground truth features that support evaluating tracking methods based on quantitative measures. In short, our approach randomly simulates a temporal point cloud with birth, death, split, merge, and continuation events, where the points are then used to derive a scalar field whose topological features correspond to the points. These scalar fields can then be used as the input for different tracking methods, where the computed tracks can be compared against the ground truth feature evolution. This approach makes it also possible to directly compare the results of different tracking methods, independent of the initial feature characterization.
- ***Subject-Specific Brain Activity Analysis in fMRI Data Using Merge Trees:*** A method for detecting patterns in time-varying functional magnetic resonance imaging (fMRI) data based on topological analysis has been developed. The oxygenated blood flow measured by fMRI is widely used as an indicator of brain activity. The signal is, however, prone to noise from various sources. Random brain activity, physiological noise, and noise from the scanner can reach a strength comparable to the signal itself. Thus, extracting the underlying signal is a challenging process typically approached by applying statistical methods. The goal of this work is to investigate the possibilities of recovering information from the signal using topological feature vectors directly based on the raw signal without medical domain priors. We utilize merge trees to define a robust feature vector capturing key features within a time step of fMRI data. We demonstrate how such a concise feature vector representation can be utilized for exploring the temporal development of brain activations, connectivity between these activations, and their relation to cognitive tasks.

Data summarization and abstraction segmentations for visualization applications

- ***Level of detail exploration of transition diagram ensembles.*** We present a pipeline for the interactive visual analysis and exploration of molecular electronic transition ensembles. Each ensemble member

is specified by a molecular configuration, the charge transfer between two molecular states, and a set of physical properties. The pipeline is targeted towards theoretical chemists, supporting them in comparing and characterizing electronic transitions by combining automatic and interactive visual analysis. A quantitative feature vector characterizing the electron charge transfer serves as the basis for hierarchical clustering as well as for the visual representations. The interface for the visual exploration consists of four components. A dendrogram provides an overview of the ensemble. It is augmented with a level of detail glyph for each cluster. A scatterplot using dimensionality reduction provides a second visualization, highlighting ensemble outliers. Parallel coordinates show the correlation with physical parameters. A spatial representation of selected ensemble members supports an in-depth inspection of transitions in a form that is familiar to chemists. All views are linked and can be used to filter and select ensemble members. The usefulness of the pipeline is shown in three different case studies.

- ***Designing Feature Vector Representations: A case study from Chemistry.*** In a case study, different feature descriptors for the analysis of chemical multivariate ensemble data are investigated. The data of each ensemble member consists of three parts: the design parameters for each ensemble member, field data resulting from the numerical simulations, and physical properties of the molecules. Since feature-based methods have the potential to reduce data complexity and facilitate comparison and clustering, the focus is on such methods. Among the many options to design the feature vector representation, a few representations were selected and analyzed. Similarities and differences are explored through characteristics derived from the representations: the distribution of pairwise distances, the clustering tendency, and the rank-order of the pairwise distances. The results of our investigations partially confirmed expected behavior, but also provided some surprising observations that can be used for the future development of feature representations in the chemical domain.

The Scientific visualization group: Currently it consists of 5 PhD students, 2 research engineers and two biträdande lektorer. Besides the ELLIIT funding, the majority of the group is funded by the Swedish e-Science research center (SeRC), WASP and VR. While the SeRC research is targeted towards the development of visualization techniques motivated by specific applications, the ELLIIT funding is used to advance the underlying theoretical framework.

2. Awards and recognitions

- Dr Ram Kumar IISc Distinguished Visiting Chair Professor position at the Indian Institute of Science (two month stay)
- Best paper/honourable mention awards
  - Local bilinear computation of Jacobi sets, second best paper, Journal 'The Visual Computer'.
  - Reduced Connectivity for Local Bilinear Jacobi Sets, second best paper, IEEE Vis collocated Workshop TopoInVis.

- Subject-Specific Brain Activity Analysis in fMRI Data Using Merge Trees, Second best paper, ***IEEE*** Vis collocated Workshop TopoInVis.

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year [kSEK]	Duration of project
Visual Data Analytics in e-Science Applications	Swedish e-Science research center (SeRC)	3500	2018-2022
Topological descriptors for tracking, comparison and visual exploration of complex scientific data	VR grant 2019-05487	850	2020-2023
Robust topological methods for analysis of dynamic large-scale data for modern material design	VR grant 2018-07085	300	2020-2022
A topology-based approach to patterns in dynamic network data for decision support	WASP, academic PhD	1 PhD	2021-2024
ELLIIT Visualization Infrastructure Support	ELLIIT	Research engineer	2022-2027
ELLIIT project, Visual Feature Based Data Reduction	ELLIT	PhD	2021-

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Danhua Lei. Ph.D. for ELLIIT project, Visual Feature Based Data Reduction		From oct 2021
Martin Falk		Part of ELLIIT since 2022

5. Inter-university cooperation: summary for 2022

- Within ELLIIT there has been a cooperation with Michael Doggett and Bo Bernhardsson from Lund University in relation to the ELLIIT project sparse representations for brain imaging data.
- Within the Swedish E-Science Center SeRC there are collaborations with different groups at LiU, KTH and SU.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

– *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. SeRC is one of our major funding sources and it is funding interdisciplinary cooperation by bringing together IT research and scientists from application areas. Under this umbrella we have interdisciplinary cooperation with the center for medical image science and visualization (CMIV) at LiU, the physics department LiU, the fluid mechanics group at KTH and the climate research at SU.

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

– No active industry cooperation during 2022

8. International collaboration

– The most important international collaborations are: Research collaborations with the University of Utah (USA): Two weeks invited Research visit during January 2019. Research collaboration with Vijay Natarajan, professor at the Indian Institute of Science IISc, Bangalore (IN) in the topic of topology-based climate visualization (Joint proposal for VR indo-Swedish network - funded). Research collaboration with Markus Stommel, professor in technical engineering, Technical University Dortmund, Germany. Research collaboration with University of Vienna, Austria in Bio-medical Visualization.

9. Supervision of master thesis projects in collaboration with industry

- Master Thesis at CloudBackend: SQL Interpreter for a Decentralized Edge dbPaaS.

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
Regularly offered courses in scientific visualization in Media and Information Technology program	undergraduate
course visualization for physicists (IFM, LiU)	undergraduate
Mathematical foundations for visualization (new course)	graduate

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

– Invited talk at the digitalization day at the institute for material sciences, Leibniz-Institut für Polymerforschung Dresden
– Ingrid Hotz participated in the ELLIIT tech talks theme 6, “Big data and network science”.

13. Academic service activities, including chairing of conferences, editorships and similar

- Scientific Advisory Board of the Dioscuri Centre in Topological Data Analysis, Poland, supported by the MaxPlanck Society
- Chair of the international workshop series for ‘Topological Methods in Visualization (TopoinVis) since 2015.
- Associated editor for Journals: Computer Graphics Forum, Computer & Graphics
- Eurograpics executive committee
- Steering committee VCBM
- Coordinator of the SeRC Visualization Community, since August 2015.
- Best paper award committee IIIE Vis
- Reviewing activities for multiple international Journals and conferences.
- ICP for multiple international conferences.
- Area Curator VCGT
- Vis Young Researcher Award selection committee
- Scientific Visualization and Data Analytics Showcase (SciViz) jury.
- Organisation Committee BMI@liu day
- SeRC Management group
- SeRC community leader Visualization
- Several PhD and Habilitation commitees

14. Open source software contributions

Open-source software for visual analysis is as the years before still plays an important role in the group. Currently developed softwares are: **Inviwo – An open-source Visualization System with Usage Abstraction Levels,** https://inviwo.org a software framework for rapid prototyping visualizations. 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 year we have been especially focusing on the integration of the open-source software TTK in inviwo. The results have been

presented during diverse tutorials at major visualization conferences. **And the Software VIA-MD for the analysis of molecular dynamics simulation data:** The software VIA-MD, developed in our group, targets the visualization of dynamic molecular data. The SW put specific emphasis on the reliable, interactive, summary aggregations that are visualized based on the multiple linked view paradigm supporting an interactive exploration. The SW includes newly developed techniques for spatial and temporal aggregation of properties e.g., used to analyze the water structure around the cellulose bundle., and intelligent selection methods that support to follow features and properties of interest over time. The software is extensively in the group of Theory and Modelling of the Laboratory of Organic Electronics (LOE, LIU). It is used as a routine tool to analyze their MD trajectories for everyday data analysis.

Jürgen Börstler, Professor in Software Engineering (BTH)

1. Main scientific achievements during 2022

During this period, I have done research on software quality, theories of technology acceptance, and methodological aspects of secondary studies. The research on software quality was mainly carried out in the context of projects A8 and B7; details can be found in the corresponding sections on projects A8 and B7. Besides the collaboration within projects A8 and B7, I also lead an interview study with an international group of researchers on software developers' perceptions of code quality. The results of this study show that developers' perceptions of software quality are not aligned with common quality standards.

Regarding technology acceptance, we have investigated theories of acceptance behavior and their suitability for investigating behavioral aspects of software engineering. We are particularly interested in the reasons for the adoption or rejection of software development practices which would be highly relevant for the research and practice on software process improvement. Traditionally, software process improvement is approached from a rational perspective. However, it has been observed that sufficient evidence for the efficacy of an improvement does not “naturally” lead to its adoption. In an interdisciplinary study with a local colleague with a background in psychology and economics, we identified 30 potentially relevant models and theories. Several of them have been used in researching acceptance behavior in contexts related to software development, but few have been validated in such contexts. They use constructs that capture aspects of (automatic) system 1 and (rational) system 2 oriented processes. However, their operationalizations focus on system 2 oriented processes indicating a rational view of behavior, thus overlooking important psychological processes underpinning behavior. We believe that software engineering research should use established acceptance behavior models and theories more extensively to better understand and predict practice adoption in the industry.

In a follow-up study, we are currently investigating which of those theories have been used in past research and how these theories have been operationalized in software engineering. Initial results show that the theories are used quite liberally which makes it difficult to generalize their results and to compare results between studies.

Regarding methodological aspects of secondary studies, we looked into the threat of double-counting in tertiary studies. Overlooking this issue might lead to biased results. We analyzed 47 tertiary studies in software engineering and found that double-counting might bias the results of 19 of those studies (40%). Our analysis shows that double-counting is an overlooked issue in tertiary studies in software engineering and that existing design and evaluation guidelines do not address it sufficiently. We propose recommendations that may help to identify and mitigate the issue.

One of my Ph.D. students graduated 2022 with a thesis on regression testing practice. Currently, I am co-supervising 3 Ph.D. students who are partially financed by ELLIIT. Of those three, one is co-supervised with colleagues from LU.

Furthermore, I'm a member of ELLIIT's program board, representing BTH.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

N/A

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Ebo Kwabena Bennin (postdoc)	0000-0001-9140-9271	2019-2020
Nasir Mehmood Minhas (student)	0000-0001-8177-4355	2018-2022
Mohsin Irshad (student)		2018-2021

5. Inter-university cooperation: summary for 2022

Within ELLIIT, I work closely together with the Software Engineering group in Lund (SERG), see projects A8 and B7. In these collaborations, we are also co-supervising Ph.D. students.
In 2022, we organized a full-day ELLIIT mini-workshop on software engineering topics at BTH with 19 researchers and Ph.D. students from LU and BTH.

Furthermore, I am working on a study on developers' perceptions of code quality with colleagues from Germany (University of Applied Sciences & Arts Hannover), the Netherlands (Utrecht University and Windesheim University of Applied Sciences), and the USA (St John's University and Virginia Tech).

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

Within BTH, we collaborated with colleagues from industrial economics on research behavioral software engineering.

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

Within most projects, we are collaborating with Ericsson and Axis, see projects A8 and B7 for more information.

8. International collaboration

See item 5. above.

9. Supervision of master thesis projects in collaboration with industry

As the course responsible for BTH's common thesis course for all "civilingenjör" programs at BTH, I have been involved in creating some parts of the framework for such collaborations (processes and templates).

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
TE2502 Examensarbete för civilingenjörer (Degree Project in Master of Science in Engineering): Course responsible, coordinator, teacher	Graduate
PA1461 Ingenjörsarbete inom ICT – Introduktion (Introduction to Engineering Practice in ICT): Teacher	Undergraduate
Guest lecturer in several courses on research methods	Undergraduate, graduate, postgraduate

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

Jürgen Börstler participated in the ELLIIT tech talks theme 10, “Next-generation software technology”.

13. Academic service activities, including chairing of conferences, editorships and similar

Since April 2019, I have been appointed as the chairman of BTH’s recruiting committee.
Furthermore, I’m deputy head of department at the department of software engineering at BTH.
I was a member of the program committee for ICSE-JSEET 2022, the Joint Track on Software Engineering Education and Training of the 44th International Conference on Software Engineering, and the EASE2022 industry experience track (Evaluation and Assessment in Software Engineering).

14. Open source software contributions

N/A

Björn Landfeldt, Professor in Communication networks (LU)

1. Main scientific achievements during 2022

We have for some time worked on derivations of analytical models for estimation of information freshness from a source to a sink using the Age of Information (AoI) metric. Much of the work in this field (including our own previous work) has so far focused on deriving closed form expressions for different kinds of queuing models under the assumption of varying distributions. During 2022 we took this a step further and completed a study of a much more complex system scenario where IoT systems, instead of using direct paths can use multihop communication to forward the data streams from source to sink. We made two separate contributions in the form of 1) closed form analytical expressions for the outage probability in such systems and 2) a numerical study where the results allow designers to make estimations of the outage probability when dimensioning and designing such complex IoT systems.

We have carried out a large collection of datasets on the Telenor production mobile network. The datasets include traffic volumes and patterns in the entire Stockholm region as well as a rural region in Northern Sweden. The datasets are currently being analysed and serve as input to an effort to develop traffic generation tools which will be made publicly available and published. Even though this work is not yet completed as the effort is significant and takes time, it is important to note that such data is all but non-existent in the community and the contributions will be very large once published.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
A5GARD	EU/CELTIC NEXT	1727 kEuro	2020-2023

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
One PhD student was hired in 2022, still waiting for visa processing.		2023-2027

5. Inter-university cooperation: summary for 2022

Ongoing collaboration with Dr. Nikolas papas at LiU in AoI modeling.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

Finished building a research testbed together with the AR/VR lab at LTH, the cancer research center at LU and the high-performance computing center LUNARC. We are now testing cloudification of medical VR applications in the testbed.

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

We finished building a testbed for residential medical care application and are currently rolling out test services in apartments in Northern Sweden. The collaborating partners are Region Västerbotten, Sensative AB and 6 local municipalities.

We have also started a course collaboration with ICANN, the Internet foundation and Netnode and give a workshop in an existing LTH course on the architecture and performance of the global DNS system and distributed root-servers.

8. International collaboration

We have started a new collaboration with a group at Charles Sturt University in Australia on modeling of migration of computational tasks between mobile edge computing platforms.

9. Supervision of master thesis projects in collaboration with industry

One masters student was supervised together with researchers at Ericsson Research.

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
I am vice chair of LG GU, the executive committee for education at LTH. In this capacity, I am jointly responsible for all education programs at LTH, setting rules and protocols for all teaching activities and deciding on all course offerings, new programs allocation of funds to departments etc.	All levels
Coordinator/teacher ETSF10 Internet protocols	undergraduate
Coordinator/teacher ETSF45 Data communication	undergraduate
Coordinator/teacher EITN95 Simulation	graduate

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

N/A

13. Academic service activities, including chairing of conferences, editorships and similar

I was acting as program member of ACM MSWIM, one of the highly regarded conferences on modelling of wireless networks.
I was also an examiner of two Ph D. theses in 2022.

I was acting as the external expert for the Malmö University application to start education in Master of Engineering (civilingenjör) programs.

14. Open source software contributions

N/A

Cristian Sminchisescu, Professor in Computer Vision (LU)

1. Main scientific achievements during 2022

My main scientific activities during 2022 focused on efficient physics-based modeling for of articulated structures like humans. Together with collaborators at LU and Google, we have developed several methods for highly accurate 3d physical simulation. Most existing methods are non-differentiable, and therefore slow and inaccurate. We developed differentiable dynamics methods that can handle complex articulated human structures in the presence of contact with the environment and show how these methods provide superior results both in terms of pure simulation and as regularizers as part of a visual 3d human pose and shape reconstruction process.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
3D Scene Perception, Embeddings and Neural Rendering	WASP NEST	5.000.000	2022-26

4. Recruitments in connection to the project (students, postdocs, faculty)

N/A

5. Inter-university cooperation: summary for 2022

Aachen University (Dr. H Petzka)
Max Planck Institute (Prof. G Pons Moll)
ETH Zurich (Profs. S. Tang and O. Hillliges)

ANU (Prof. Richard Hartley)

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

N/A

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

Google (physics-based simulation of articulated human bodies)

8. International collaboration

N/A

9. Supervision of master thesis projects in collaboration with industry

N/A

10. List of patent applications published during 2022

Patent title	Application Number
Systems and Methods for Refined Object Estimation from Image Data	17200643

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
Machine Learning	Undergraduate

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

N/A

13. Academic service activities, including chairing of conferences, editorships and similar

Area Chair for ICLR 2022.

14. Open source software contributions

PHORHU (Photorealistic Human Reconstruction) https://phorhum.github.io/

Michael Lentmaier, Associate Professor in Communication (LU)

1. Main scientific achievements during 2022

Our research focuses on modern coding theory, graph-based iterative algorithms and the impact of spatial coupling on their performance. Applications include reliable communication, localization, security and group testing.

During the year 2022 we continued our research on spatially coupled iterative receivers. PhD student Muhammad Umar Farooq defended his PhD in November 2022 and is now working at Ericsson Research in Lund. His final contribution was a threshold analysis and optimization of check-irregular GLDPC codes with convolutional code constraints. This novel class of codes on graphs can be seen as a generalization of both turbo codes and LDPC codes. The construction allows for a trade-off between larger variable node degrees and stronger component codes in the code optimization procedure. I presented these results as keynote speaker at a Globecom 2022 workshop.
With the PhD student Mgeni Makambi Mashauri we continued our study of joint iterative detection and decoding of spatially coupled codes for ISI channels. As a new direction, we started to analyze Faster-than-Nyquist (FTN) signaling, with the aim to show that the gap to capacity can be reduced by spatial coupling. This will lead to new design criteria in combination with higher-order modulation. We also made some progress in designing efficient group-testing schemes based on sparse-graph codes. We were able to develop a new scheme for quantitative group-testing based on LDPC code graphs, which outperforms the corresponding GLDPC codes schemes existing in the literature (accepted for ISIT 2023). The fundamental goal is to identify defective items in a large population, where sparse graphs can reduce the number of required tests drastically if the fraction of defective items is small.
With a third PhD student, Neharika Valecha, in collaboration with Fredrik Tufvesson, we continued our work on highly accurate positioning based on mmWave massive MIMO systems, funded within the H2020 training network MINTS. During 2022 we processed the data earlier obtained during a research visit at IMDEA in Spain. The final goal is to develop a novel algorithm for angular-based indoor positioning using received signal strength (RSS) measurements in combination with codebook-based analog beamforming on the Tx and Rx side. With the help of multipath components, a single Rx with known position is sufficient to locate the Tx, without requiring any delay estimation or phase information. During Fall 2022, Neharika had a three-month research visit at KU Leuven.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2022
N/A

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Neharika Valecha, PhD student		from 2020
Mgeni Makambi Mashauri, PhD student		from 2019
Muhammad Umar Farooq, PhD student		2017 - 2022
Wei Zhou, PostDoc		2017 - 2019
Saeedeh Moloudi, PhD student		2013 - 2018

5. Inter-university cooperation: summary for 2022

Mgeni Makambi Mashauri and Muhammad Umar Farooq were co-supervised by Alexandre Graell i Amat from Chalmers University.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

N/A

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

N/A

8. 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.

9. Supervision of master thesis projects in collaboration with industry

- Degree project, “Importance Sampling in Wireless Communication Systems with Ultra-Low Error Rates” by Bharat Maheshwari and Yewen Zhou, collaboration with Dzevdan Kapetanovic (Huawei Lund Research Center)
- I am also acting as degree project examiner at our department, with several degree projects per year in industry

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
Program director of Master's Program in Wireless Communications since July 2013	undergraduate

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

N/A

13. Academic service activities, including chairing of conferences, editorships and similar

- Chair of the IEEE VT/COM/IT Chapter Sweden since October 2021. Board member since Spring 2014. Interface to information theory society since Spring 2017.
- TPC member: IEEE Inf. Theory Symposium (ISIT 2022), IEEE Inf. Theory Workshop (ITW 2022) IEEE Globecom Workshop on Channel Coding (Globecom 2022)
- Ph.D. thesis evaluator: Yihuan Liao, University of New South Wales, Australia, August 2022
- Reviewer for several journal and conference submissions.

14. Open source software contributions
    N/A

Jonas Unger, Professor in Computer Graphics (LiU)

1. Main scientific achievements during 2022

The efforts within ELLIIT during 2022 have been focused in three different research areas. The first area is the development of sparse models and compressed sensing methods for imaging and computer

graphics applications, the second area is medical image analysis, and the third area is novel formulations of deep neural networks as systems of ordinary differential equations.

Our efforts in sparse modelling and efficient sampling for imaging have been directed towards computer graphics applications and simulation in digital product design. The team consists of Dr. Ehsan Miandji (post-doctoral researcher), and three PhD students Wen Cao, and Behnaz Kavoosighafi funded through the EU ITN-project PRIME, and Tanaboon Tongbuasirilai. A fundamental component in computer graphics and visualization is accurate measurement and modelling of light scattering at surfaces, where different materials, e.g., wood, metals, plastics, etc., scatter light differently. Based on our previous sparse models, we have developed novel measurement techniques based on compressed sensing for fast and accurate acquisition of scattering properties at a single point on a surface, described by the so-called bi-directional distribution function (BRDF), and how the scattering properties vary over the extent of the physical material sample, spatially varying BRDF (SVBRDF). This type of digital twins of physical material samples are key building blocks in photo-realistic image synthesis, and product visualization, and for simulation in digital design. Another key result is the formulation of a novel single sensor compressive multi-spectral light field camera. The proposed camera model is based on a main lens and a coded mask located in the optical path between the main lens and the sensor. The main contribution is a novel reconstruction algorithm that recovers the spatial, angular, and spectral image data and forms a 4D view-dependent light field image using only a single "ordinary" image sensor. Light fields are typically captured using an array of cameras (complex system) or a micro-lens arrays placed in front of a single sensor (sacrificing spatial resolution). Dr. Tanaboon Tongbuasirilai defended his PhD in February 2023.

In collaboration with the Center for Medical Imaging and Visualization (CMIV), we have carried out a series of projects in the area of digital pathology. The team consists if Dr. Gabriel Eilertsen and Dr. Karin Stacke (graduated as PhD in December 2022). In this project, we have investigated and developed formulations of deep neural networks for classification of healthy and cancer tissue from digital pathology samples. Within the research, we have focused on issues related to limited data availability, the shortage of labeled data, and the domain shift between different scanners. Key results from 2022 include new methods for how unsupervised learning can be applied in the context of digital pathology.

In the direction of deep learning, we have developed Standalone Neural ODE (sNODE), a continuous-depth neural ODE model capable of describing a full deep neural network. This project is a collaboration with associate professor George Baravdish with a joint PhD student Rym Jaroudi. The project has developed a novel nonlinear conjugate gradient (NCG) descent optimization scheme for training, where the Sobolev gradient can be incorporated to improve smoothness of model weights. We have also developed a formulation of the neural sensitivity problem and show how it is used in the NCG training. The sensitivity analysis provides a reliable measure of uncertainty propagation throughout a network and can be used to study model robustness and to generate adversarial attacks and to improve explainability. Dr. Rym Jaroudi defended her PhD in March 2023.

2. Awards and recognitions

Our efforts in developing methods and algorithms for generation of synthetic data for machine learning and data centric AI was selected for the Royal Swedish Academy of Engineering Sciences IVA-100 list, 2022.

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
Industrial PhD student in medical image analysis together with ContextVision (PI)	WASP	PhD salary and supervision	4 yrs
Post-doc project sparse modelling	KAW / ELLIIT	1 MSek	2 yrs
Post-doc project compressed sensing	KAW / ELLIIT	1 MSek	2 yrs
Wallenberg launchpad (WALP)	WASP	3 MSek	1.5 yrs
Sparseland imaging (PhD project)	WASP	1 MSek	4 yrs
Predictive rendering (2 x PhD project)	EU-ITN	1. 6 MSek	4 yrs
AI in air traffic control	LFV	1 Msek	4 yrs
Neural ODEs	ELLIIT	500 KSek	2 yrs
Synthetic data and data centric AI	WASP/ELLIIT/TFF	2 MSek	5 yrs
AI4C	Vinnova	1 MSek	3 yrs
WASP NEST __main__	WASP	20 Msek	5 yrs

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Dr. Ehsan Miandji		From 2022

5. Inter-university cooperation: summary for 2022

Through ELLIIT and other research programmes, we collaborate with researchers from several universities. Some of the most relevant collaborations include Prof. Amy Loutfi Örebro University, Dr. Johanna

Björklund Umeå University, Prof. Bo Bernhardsson at Lund University, Prof. Rafal Mantiuk Cambridge University, and Dr. Michael Dogget at Lund University.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

Many of our projects are interdisciplinary. One example is our participation in the project B12: Visual Feature Based Data Reduction, led by Prof. Ingrid Hotz and Prof. Bo Bernhardsson, in which we are developing Brain-Computer interfaces (BCIs). Another example is our collaboration with Prof. Michael Felsberg (computer vision), Associate Professor Fredrik Lindsten (statistics and machine learning), and Prof. Amy Loutfi (robotics and human-computer interaction), which recently awarded us a WASP NEST grant that will enable us to work jointly on challenges related to AI alignment and integration.

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

We are active in a number of collaborations with industrial partners, both directly within joint research/development projects, but also through joint M.Sc thesis projects. The collaborations most relevant to ELLIIT include Spheron (DE), Arriver, SMHI, Aurora Innovation, IKEA Marketing and Communications, and Luftfartsverket (LFV), SECTRA, and ContextVision.

8. International collaboration

During 2022 we have collaborated closely with Prof. Rafal Mantiuk at Cambridge University resulting in two papers at ICCV and at SIGGRAPH. PhD student Behnaz Kavoosighafi worked as a visiting student at Denmark Technical University (DTU) together with Dr. Jeppe Frisvad for three months, and PhD student Karin Stacke visited the Personalized Integrative Medicine (PIMed) Laborator at Stanford and worked together with Assistant Professor Mirabella Rusu. Both visits resulted in joint publications currently under review. We are also participating the EU Innovative Training Network (ITN) Predicitive Rendering in Manufacturing and Engineering (PRIME) in which we collaborate closely with universities and companies in Europe.

9. Supervision of master thesis projects in collaboration with industry

Matilda Eriksson, Astrid Johansson. Narrow Pre-training for Deep Neural Networks. Project with SICK-IVP.

Iris Kotsinas, Viktor Tholén. Dynamic Real-Time Simulation of Fire for Networked Multiplayer Games. Project with DICE.

David Karlsson. The World in 3D – Geospatial Segmentation and Reconstruction. Project with Combitech.

10. List of patent applications published during 2022

Patent title	Application Number
System and method for real-time tone-mapping J Unger, G Eilertsen, R Mantiuk	US 11107204
System and Method for Real-Time Tone-Mapping J Unger, G Eilertsen, R Mantiuk	US Patent application 17320689
A method, computer program, computer program product and system for representing visual information J Unger, E Miandji, P Larsson	US Patent application 17413321

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
AI data synthesis and generative models	Graduate

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

We continuously participate in outreach activities. This includes presentations through Visual Sweden, at the Visualization Centre C, and through WASP and ELLIIT. Recent invited presentations include: Goodbye Kansas (Visual effects), Luftfartsverket, and Denmark Technical University at DTU Compute.

13. Academic service activities, including chairing of conferences, editorships and similar

Members of our ELLIIT projects act as reviewers and IPC members for different tracks at venues such as SIGGRAPH, CVPR, SIGGRAPH Asia, HDRi, SIGRAD, and Eurographics. We have recently organized SSDL/SSBA 2023.

14. Open source software contributions

We make code and data available from all our projects. A recent example is a database with carefully captured and curated high dynamic range (HDR) images: https://www.repository.cam.ac.uk/handle/1810/340049

Andreas Kerren, Professor in Information Visualization (LiU)

1. Main scientific achievements during 2022

In the past year of 2022, our research within information visualization and visual analytics focused on four major aspects: multidimensional and temporal data visualization, network visualization, visual text analytics, and explainable ML/AI with the help of visualization. In the following, I briefly summarize our achievements in these areas.

- **Multidimensional and temporal data visualization:** Based on a successful collaboration with colleagues from Canada and Brazil, we developed a novel incremental dimensionality reduction technique, called Xtreaming, for streaming scenarios in which a new re-projection strategy was used to update visual representations without the need to revisit the input data. This work started already in 2021, and the corresponding paper got finally published in the subsequent year. Moreover, in the previous years, we developed an immersive VR environment (head-mounted display, 3D gestural input) and a non-immersive desktop terminal (monitor, keyboard and mouse) centered around spatio-temporal data exploration. Supported through a real-time communication interface, synchronous collaborative features were integrated in both interfaces, facilitating users in their ability to establish a shared context and to make spatio-temporal references. In 2021/22, we conducted an empirical evaluation with five participant pairs to investigate aspects of usability, user engagement, and collaboration during a confirmative analysis task. The VR environment revealed good usability scores, high user engagement, as well as overall close and balanced collaboration of enthusiastic pairs during the task completion independent of their interface type, validating our approach in general. Finally, we kicked off two new projects: one project to develop novel visual analytics approaches for incremental clustering and annotation which will be performed on human transcriptomics data sets from the Human Protein Atlas; and the other one to research the use of immersive environments for the visualization and exploration of the appearance and effect of (extreme) weather events in urban areas with a focus on mapping and understanding the occurrence of urban heat in Norrköping municipality.
- **Network visualization:** The visualization of large and complex multivariate networks (MVNs) continues to be a great challenge as already described in the past report. In this context, we developed an interactive visual analysis interface that facilitates network exploration and comparison at different topological and multivariate attribute scales. When looking into large and complex network data sets based on social media posts, for instance, users of the visualization

approach are able to investigate text- and network-based properties of social network community interactions, identify anomalies of conflict starters, or gain insight into multivariate anomalies behind groups of negative social media posts. Note that our main focus here was on the visual analysis of subnetworks within very large networks. In another project that started already in 2021, we studied the emerging field of multivariate network embeddings and developed a strategy of combining already existing state-of-the-art single scope embedding technologies. For this, we have developed visual analytics approaches that divide an MVN into separately embeddable aspects. We then obtain a flexible vector representation which we can use as input to a novel method of similarity-based clustering, for instance.

- **Visual text analytics:** We applied the above mentioned joint embedding approach to propose a new method for text similarity calculations based on the combination of embedding technology and ensemble methods. By using several embeddings, instead of only one, we could show that it is possible to achieve higher quality, which in turn is a key factor for developing high-performing applications for text similarity exploitation. We also provided a prototype visual analytics tool which helps the analyst to find optimal performing ensembles and gain insights to the inner workings of the similarity calculations. Over the year, we also worked on validation and evaluation aspects in the context of text visualization: in a new user study, we focused on the evaluation of the effectiveness and efficiency of common visual representations for low-level visualization tasks in the context of sentiment visualization. The results provide evidence of strengths and weaknesses of particular representations and visual variables with respect to different tasks, as well as specific user preferences, in the context of sentiment visualization. Furthermore, I would like to highlight that we organized a Dagstuhl Seminar on visual text analytics in 2022 (https://www.dagstuhl.de/22191) that succeeded in bringing together world-renowned researchers from the visualization, natural language processing (NLP), and machine learning communities, with domain experts from several text-related research areas, to identify the most pressing and promising open problems for collaborative research. Discussions in the seminar were comprehensive, focusing on visual text analytics with the goal to provide an application-oriented research agenda. Finally, it is worth to mention that we have kept maintaining our world-renowned and highly cited interactive online surveys, especially those on text visualization (https://textvis.lnu.se/) as well as enhancing trust in ML models with visualization (https://trustmlvis.lnu.se/).
- **Explainable ML/AI with the help of visualization:** Here, we have aimed to develop foundational principles, techniques, and visual analytics tools for analyzing data and machine models with diverse applications in the context of data-intensive sciences. The overall goal has been to make complex machine learning models better understandable and explainable, as well as to provide reliable trust in the models and their results. In 2022, we published two works that both cover this aspect: an evaluation of our previously developed system StackGenVis as well as the FeatureEnVi approach. StackGenVis focuses on the interactive generation of a stack of models which is an ensemble method that combines heterogeneous base models and then employs another

metamodel to summarize the predictions of those models. StackGenVis was designed to monitor and control the entire stacking process visually. We performed a comparative user study for evaluating the StackGenVis system. For this, we divided the study participants into two groups to test the usability and effectiveness of StackGenVis compared to Orange Visual Stacking (OVS) in an exploratory usage scenario using health-care data. The results indicate that StackGenVis is significantly more powerful than OVS based on the qualitative feedback provided by the participants. However, the average completion time for all tasks was comparable between both tools. Our second research focus on feature engineering led to the development of FeatureEnVi, a visual analytics system specifically designed to assist with the feature engineering process. Our system helps users to choose the most important feature, to transform the original features into powerful alternatives, and to experiment with different feature generation combinations. Additionally, data space slicing allows users to explore the impact of features on both local and global scales. The final outcome is the extraction of heavily engineered features, evaluated by multiple validation metrics.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
Visual Analytics for Enhancing Quality and Trust in Genome-wide Expression Clustering and Annotation (WASP-PI)	WASP-DDLS Joint Call	About 1.3 MSEK (WASP partner only)	2 years
Immersive Analytics for Urban Heat (co-PI)	Norrköping Fund	About 1.1 MSEK	2 years
National Research Infrastructure for Data Visualization – InfraVis (co-PI, node coordinator for LNU)	VR	About 1.5 MSEK (LNU node)	5 years
ELLIIT-funded PhD student (PI)	ELLIIT	1 MSEK	5 years

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Zeyang Huang (ELLIIT-funded PhD student)	0000-0003-3945-1274	from 2022

5. Inter-university cooperation: summary for 2022

Within LiU, I established a number of new contacts and cooperations, for instance with Tema M – Environmental Change (collaboration with an ongoing project supported by the Norrköping Fund) or with Tema T – Technology and Social Change (ongoing proposal writing activities).

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

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 research. In 2022, we mainly collaborated with colleagues from the areas of systems biology, social sciences, humanities, and control systems, affiliated to KTH, Linnaeus University, and Lund University.

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

In 2022, we started a WASP/DDLS-funded project together with researchers from the Science for Life Laboratory (SciLifeLab), Stockholm. Moreover, our project “Immersive Analytics for Urban Heat” has been granted funding from the Norrköping Fund and has been performed in collaboration between academia (LiU, LNU), SMHI, and Norrköping Municipality.

8. International collaboration

I regularly collaborate and publish with researchers from various countries and universities. In 2022, I would like to highlight our work with colleagues from Canada and Brazil that resulted in an interesting paper on a novel incremental dimensionality reduction technique for high-dimensional streaming data. The Dagstuhl Seminar on Visual Text Analytics (https://www.dagstuhl.de/22191), that I have co-organized in 2022, also led to many new international contacts. We expect a number of papers based on these collaborations to be published in the coming years.

9. Supervision of master thesis projects in collaboration with industry

No supervision, but I was examiner for a master thesis project in collaboration with Saab, Linköping.

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
TNM048 Information Visualization (course responsible)	undergraduate
TNM098 Advanced Visual Data Analysis (single lectures given)	undergraduate
TNM093 Practical Data Visualization and Virtual Reality (single lectures given)	undergraduate
External advisor (reference group member) for a new Master of Science program proposal at LiU called “Data-Driven Sustainable Development”	undergraduate
Involved in the further development of the LiU/MIT study program “Master of Science in Media Technology and Engineering”	undergraduate

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

I gave the following invited talk:

- BioVis Explorer: A Visual Guide for Biological Data Visualization Techniques. CNS Research Showcase, Indiana University Bloomington, IN, USA, Virtual Seminar.

13. Academic service activities, including chairing of conferences, editorships and similar

- Member of the Editorial Board of Computer Graphics Forum, Wiley
- Member of the Editorial Board of the Language, Data Science and Digital Humanities book
- series, Bloomsbury Academic
- Member of the EuroVis Best PhD Award Committee 2022
- Program Committee Member of many conferences, such as IEEE VIS, EuroVis, Eurographics, VISSOFT, EuroVA, VDA, etc.

14. Open source software contributions

- In 2022, we made the source code for the following published visualization approaches available:
  - FeatureEnVi, see https://leonard.lnu.se/git/ISOVIS/FeatureEnVi
  - HardVis, see https://github.com/angeloschatzimparmpas/HardVis

Fredrik Lindsten, Associate Professor in Machine Learning (LiU)

1. Main scientific achievements during 2022

My research during 2022 has been mostly centered around probabilistic models and inference, uncertainty quantification, and graph-based methods for machine learning.

In one project we investigated the effect of label noise on classification and regression models, both by analyzing the theoretical robustness to such noise (with a specific emphasis on reliable uncertainty quantification of the resulting models), and by developing an active learning method capable of incorporating such label noise/weak supervision.

In another project we analyzed a class of generative models, referred to as Generative Flow Networks (GFlowNet), that has recently received significant attention. Our results showed that these models could in fact, under certain conditions, be reinterpreted as performing a type of variational inference on an extended target construction. Our contribution has helped to shed light on this new and exciting class of generative models and to connect it to existing and more well-established models.

During 2022 we also initiated our work on a probabilistic re-interpretation of clustering-based self-supervised learning based on the popular DINO model. DINO is a state-of-the-art method for self-supervised representation learning from images, one of the leading machine learning paradigms today. By viewing DINO as performing clustering in the latent representation space using a von-Mises Fisher mixture model, we could identify missing terms in the original formulation of the algorithm. By introducing these missing terms to the algorithm we could observe both improved training stability and improved performance on a range of downstream tasks.

Finally, related to graph-based machine learning we continued to develop methods for bridging the gap between probabilistic graphical models and graph neural networks, leading to a generalization of our Deep Gaussian Markov Random Fields model (improved scalability and applicable to general graphs). We also developed a novel graph neural network-based methods for spatio-temporal prediction of irregularly

sampled time series. Finally, we also applied graph neural networks for developing a workflow for efficient computation of phase diagrams for novel material discovery.

2. Awards and recognitions

Notable paper at the International Conference on Learning Representation for the paper: H. Govindarajan, P. Sidén, J. Roll, and F. Lindsten, DINO as a von Mises-Fisher mixture model, in International Conference on Learning Representations, 2023.

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
Handling Uncertainty in Machine Learning	VR	1 MSEK	2021-2024
AI Powered Carbon Border Adjustments	Vinnova	Ca 2.3 MSEK	2021 Oct – 2024 Oct
Probabilistic models and deep learning - bridging the gap	WASP Collaboration Project	Ca 1 MSEK	2019 - 2023
Attentive and Disentangled Representation Learning	WASP Industrial PhD project	Ca 1 MSEK	2020 Aug – 2025 Aug
Novel AI methods for experimentally constrained protein structure prediction	WASP-DDLS Postdoc Twinning	1.25 MSEK	2022-2024
Multidimensional Alignment and Integration of the Physical and Virtual Worlds	WASP NEST	4 MSEK	2022-2027

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Gabriel Ducrocq		2022-2024
Shashi Nagarajan		2022-2027
Oskar Hidén		2022-2024

5. Inter-university cooperation: summary for 2022

I regularly interact and collaborate with researchers from other countries and universities. For international collaboration, see section 8 below. For national collaboration, I have worked together with

Prof Lennart Svensson at Chalmers University of Technology on a joint project involving two PhD students, one at each site. In my WASP-DDLS project I'm collaborating with Prof Sebastian Westenhoff at Uppsala University (DDLS partner) and in our WASP NEST we are working in collaboration between Linköping University and Örebro University (co-PI Prof Amy Loutfi). I have also continued to supervise two PhD students at Uppsala University, one of whom graduated in late 2022 (Anna Wigren).

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

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).

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

Through my research projects I collaborate with several companies:

- WASP Industrial PhD student project with Qualcomm (Hariprasath Govindarajan).
- Per Sidén at Qualcomm is co-supervising one of my academic PhD students (Joel Oskarsson)
- Trafikverket, Qualcomm, 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.

8. International collaboration

I regularly interact and collaborate with researchers from other countries and universities. During 2022, a new international collaboration was initiated by hosting a PhD student from the University of Amsterdam, Heiko Zimmermann, as a visiting student researcher in the spring. This was followed up with a research visit to the University of Amsterdam in fall 2022. This collaboration has already resulted in a joint publication: A Variational Perspective on Generative Flow Networks; Heiko Zimmermann, Fredrik Lindsten, Jan-Willem van de Meent, and Christian A. Naesseth; Transactions of Machine Learning Research (TMLR; accepted), and I'm optimistic that it will lead to further joint research initiatives. Another newly established international collaboration is with Prof Arthur Gretton's group at University College London, where my PhD student David Widmann spent a few weeks during fall 2022 as a visiting student researcher. This visit

has strengthened our international network and has also resulted in a joint publication: Fast and Scalable Score-Based Kernel Calibration Tests; Pierre Glaser, David Widmann, Fredrik Lindsten, and Arthur Gretton (submitted).

9. Supervision of master thesis projects in collaboration with industry

- Oskar Aidantausta and Patrick Asman. Land Use/Land Cover Classication of Remotely-Sensed Satellite Images of Swedish Urban Areas. Värderingsdata. (Examiner)

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
TDDE56 Foundations of AI and machine learning (contributed to development)	Undergraduate

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

N/A

13. Academic service activities, including chairing of conferences, editorships and similar

- Program Chair for ELLIIT Annual Workshop
- Area Chair for AISTATS
- Guest editor for special session on Sequential Monte Carlo Methods in Foundations of Data Science.

14. Open source software contributions

Richard Pates, Associate Professor in Control of Large-Scale Autonomous System (LU)

1. Main scientific achievements during 2022

In 2022 my research has primarily focused on:

- Scalable methods for control systems design.
- Control of electric power systems and district heating networks.
- Optimal control and estimation at scale.

This has culminated in 5 peer reviewed conference contributions, and 3 journal contributions, 2 of which were for invited special issues. The work was conducted with a network of national and international collaborators from industry and academia, spread across 4 continents. In addition, I have developed 2 PhD level courses, joined the editorial board of Control Systems Magazine as an editor to help develop educational content, and produced two educational videos promoting control theoretic content to a wider audience.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
Estimation and Control at Scale (PI)	ELLIIT	1MSEK	5 years
Visual analytics of large and complex multilayer technological networks (co-PI)	ELLIIT	1MSEK	5 years
Scalable Data Processing in Networked Systems (co-PI)	ELLIIT	1MSEK	2 years

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Johan Lindberg	0000-0001-9491-8354	2020
Julia Adlercreutz	N/A	2022

5. Inter-university cooperation: summary for 2022

During 2022 I was involved in three main international collaborations. The first was with MIT, Johns Hopkins, Peking University and Universidad ORT Uruguay, studying control theoretic bounds on the performance of test-trace and isolation schemes for mitigating disease spread. The second was with Saarland University, studying and developing software for the analysis of the impact of weakly-hard constraints on the real time performance of control systems. The third was with CNRS, on the scalable design of control systems for district heating networks.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

During 2022 I have been involved in inter-disciplinary research touching on disease spread, control of district heating networks and electrical power systems, and the analysis of the impact of real time constraints on control system performance and design.

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

I have worked actively with industry in 2022 on projects with Sony Communications AB, and emulate.energy.

8. International collaboration

In 2022 I published papers with the following internationally based collaborators
Andreas Ferragut – Universidad ORT Uruguay
Pauline Kergus – CNRS, Toulouse
Martina Maggio – Saarland University
Enrique Mallada – Johns Hopkins
Fernanado Paganini – Universidad ORT Uruguay
Elijah Pivo – MIT
Pengcheng You – Peking University

9. Supervision of master thesis projects in collaboration with industry

In 2022 I supervised the following 6 masters thesis students who were conducting their projects with Sony Mobile Communcations AB and emulate.energy
Johan Fant, main supervisor, collaboration with emulate.energy
Gustav Warnström, main supervisor, collaboration with emulate.energy
Fredrik Sidh, main supervisor, collaboration with emulate.energy

Gustaf Sundell, main supervisor, collaboration with emulate.energy
Emelie Skoog, main supervisor, collaboration with Sony Mobile Comms. AB
Elin Freberg, main supervisor, collaboration with Sony Mobile Comms. AB

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
Power System Stability and Control (FRT270F) - developed and taught	Graduate
Nonlinear Control Theory (FRT026F) - developed and taught	Graduate

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

Participated in the summer of math exposition 2 (#SoME2), with an educational video on the mathematics underlying peg solitaire. I actively run and maintain a YouTube channel that focuses on educational content for mathematics and control theory.

13. Academic service activities, including chairing of conferences, editorships and similar

I recently took a post on the editorial board of Control Systems Magazine, and am also a member of the Control System Society Technical Committee on Power Generation.

14. Open source software contributions

Coauthor on research on scalable analysis of weakly-hard software constraints, supported by the open source package WeaklyHard.jl:

Zheng Chen, Assistant Professor in Communication Systems (LiU)

1. Main scientific achievements during 2022

Within 2022, my research has been focusing on communication design and signal processing for distributed intelligence over wireless networks, summarized in the following three components:

a) Scheduling and resource allocation for federated edge learning. The research outcome of this topic has resulted in one journal paper published in IEEE Journal on Selected Areas in Communications (JSAC).
b) Low-latency decentralized learning with partial communication. In an initial version of this work, we have studied probabilistic broadcast scheduling for distributed consensus over wireless networks, and our work has been published in IEEE Signal Processing Letters. We are currently working on collision-free broadcast set scheduling for decentralized learning.
c) Communication-efficient data aggregation over wireless networks. In this direction, we have published several articles (magazine and conference papers) on Over-the-Air computation and its applications in federated learning systems.

In addition to scientific publication, I have also been actively engaged in event organization and served as the technical program chair for 2022 IEEE-SPS 6G Summer School and the co-chair of an IEEE GLOBECOM workshop. Both events have greatly helped to promote my own research and establish international collaboration.

2. Awards and recognitions

I have been awarded a starting grant from Swedish Research Council in 2022.

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
Wireless Network Design for Decentralized Machine Learning	CENIIT	450k	2021-now

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Chung-Hsuan Hu		From 2020

5. Inter-university cooperation: summary for 2022

I have worked with Mikael Johansson and Carlo Fischione from KTH (Sweden) in a joint paper accepted in IEEE Network Magazine.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

N/A

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

I have been collaborating with Ericsson Research in Linköping within my CENIIT project.

8. International collaboration

In terms of research collaboration, I have co-authored two papers with Mohammad Hatami and Markus Leinonen from University of Oulu (Finland). Through the organization of a workshop and a summer school, I have also established collaboration with Osvaldo Simeone (King's College London, UK), Vincent H. Poor (Princeton University, USA), and Petar Popovski (Aalborg University, Denmark).

9. Supervision of master thesis projects in collaboration with industry

N/A

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

N/A

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

N/A

13. Academic service activities, including chairing of conferences, editorships and similar

- Technical Program Chair for 2022 IEEE-SPS and EURASIP summer school on **Defining 6G: Theory, Applications, and Enabling Technologies**.
- Workshop co-chair for IEEE GLOBECOM workshop on "Wireless Communications for Distributed Intelligence", 2022.

- Program co-chair for ELLIIT annual workshop at Linköping University.
- Editor at IEEE Transactions on Green Communications and Networking.

14. Open source software contributions

N/A

Farnaz Adib Yaghmaie, Assistant Professor in Automatic Control with focus on Reinforcement Learning (LiU)

1. Main scientific achievements during 2022

I have been on parental leave from 2022 and I have started working one day per week for a couple of months now. Before going on parental leave and while working part-time, my research focuses on addressing safety and uncertainty issue in online learning algorithms applicable to control systems:

a. Observation and process noises affect the performance of controllers. In a series of works, we have studied this effect extensively and proposed approaches to tackle this issue to some degree.
b. A major issue in the application of online learning algorithms on control systems is to ensure that the generated control input is safe. We have developed a data-driven safety certifier to intervene with the actions of the reinforcement learning algorithm to ensure safety.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
Reinforcement Learning for partially observable dynamical systems with continuous state and action spaces	Zenith	480 SEK	6 years

4. Recruitments in connection to the project (students, postdocs, faculty)

N/A

5. Inter-university cooperation: summary for 2022

I have been collaborating with Hamidreza Modares from Michigan State University, USA in 2022. It resulted in one accepted publication, two under revision and one under preparation. I have collaborated with Johannes Andreas Stork from Örebro University in initiating, developing and teaching a 6 credits Ph.D. level course “Reinforcement Learning”, for WASP.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

I have collaborated with Fredrik Heintz from IDA in initiating, developing and teaching a 6 credits Ph.D. level course “Reinforcement Learning”, for WASP.

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

I have been collaborating with ABB AB research corporate, SAAB AB, and Nira Dynamics within my CENIIT project but there are no collaborations in 2022 as I was mostly on parental leave.

8. International collaboration

I have been collaborating with Hamidreza Modares from Michigan State University, USA in 2022. It resulted in one accepted publication, two under revision and one under preparation.

9. Supervision of master thesis projects in collaboration with industry

- Master thesis examiner: “Labyrinth navigation using reinforcement learning with a high fidelity simulation environment.” Combine.
- Master thesis supervisor: “An Adaptive Strategy For Short Term Stock Trading Using Reinforcement Learning.” Celerus Capital.

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
Reinforcement Learning	Ph.D. course for WASP

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

N/A

13. Academic service activities, including chairing of conferences, editorships and similar

N/A

14. Open source software contributions

N/A

Viktor Larsson, Assistant Professor in Mathematics (LU)

1. Main scientific achievements during 2022

In 2022 many of the projects started before I joined Lund University came to fruition. We published the paper NICE-SLAM (https://arxiv.org/abs/2112.12130) at CVPR'22 which was one of the first RGB-D SLAM algorithms using a neural scene representation for tracking and mapping. We also published the LAMAR dataset (https://lamar.ethz.ch) for benchmarking localization and mappgin for augmented reality at ECCV'22. To advertise the dataset we also organized a tutorial at the same conference which was well received.

During 2022 my research was focused on exploring line-based sparse reconstruction. This has resulted in three papers; DeepLSD (https://arxiv.org/abs/2212.07766), GlueStick (https://arxiv.org/abs/2304.02008) and LIMAP (https://arxiv.org/abs/2303.17504) which are currently accepted for publication at CVPR or in submission. These three papers tackle the three components necessary for line mapping; detection, matching and triangulation.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
Revisiting Data-associations for Large-Scale Mapping (Call D)	ELLIIT	1 MSEK	5

4. Recruitments in connection to the project (students, postdocs, faculty)

N/A

5. Inter-university cooperation: summary for 2022

N/A

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

N/A

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

N/A

8. International collaboration

- Ongoing collaboration with Marc Pollefeys' group at ETH Zurich and the Microsoft Mixed Reality and AI Lab in Zurich on several projects related to visual localization and mapping.
- One project with Benjamin Kimia at Brown University on using GPU accelerated homotopy continuation solvers for camera pose estimation.
- Ongoing collaboration with Tomas Pajdla (CIIRC Prague, Czechia), Anton Leykin (Georgia Tech, US), Tim Duff (Uni. of Washington, US), Luke Oeding (Auburn Uni., US) regarding camera calibration and pose estimation.
- Ongoing collaboration with Martin Oswald (University of Amsterdam, Netherlands), Zhaopeng Cui (Zhejiang University, China) on neural scene representations for SLAM.
- Ongoing collaboration with Torsten Sattler (CIIRC Prague, Czechia) and Zuzana Kukelova (CTU Prague, Czechia) on semi-generalized and hybrid pose estimation.

9. Supervision of master thesis projects in collaboration with industry

During 2022 I have supervised one master thesis at Volvo Cars regarding multi-camera 3D reconstruction and one with Axis Communications regarding semantic segmentation from fisheye images.

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
Computer Vision (lecturer)	Graduate
Advanced Topics in Computer Vision (in development, first edition expected to run in fall 2023)	Graduate (PhD)

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

Talk on benchmarking localization and mapping for augmented reality at the Learning Machines seminar series organized by RI.SE (https://www.ri.se/en/learningmachinesseminars)

13. Academic service activities, including chairing of conferences, editorships and similar

- Area chair for *International Conference of 3D Vision (3DV)* 2022
- Started work as Local chair for the upcoming *European Conference of Computer Vision (ECCV)* which will be held in Malmö/Copenhagen in 2026
- Reviewer for all major computer vision conferences (CVPR/ICCV/ECCV)

14. Open source software contributions

In addition to releasing open-source code for all of my papers, I am also driving the open-source project PoseLib (https://github.com/vlarsson/PoseLib) which provides state-of-the-art robust estimators for camera poses.

Susanna F. de Rezende, Assistant Professor in Theoretical Computer Science (LU)

1. Main scientific achievements during 2022

In 2022, my VR project “Efficient proofs and circuits: a unified approach” started and I also obtained a WASP PhD student grant for the same project. I published an invited survey article titled “Proofs, Circuits

and Communication" for the SIGACT News Complexity Theory Column together with Robert Robere (University of Toronto) and Mika Göös (EPFL).

I was invited to participate in the Communication Complexity and Applications workshop at BIRS, Canada; and was invited to give talks in the following workshops:

- Theory and Practice of SAT and Combinatorial Solving, Dagstuhl, Germany
- Mathematical Approaches to Lower Bounds, ICMS, Edinburgh, UK
- Logic Colloquium, Reykjavik, Iceland
- Satisfiability: Theory, Practice, and Beyond Reunion, Simons Institute for the Theory of Computing, UC Berkeley

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
Efficient proofs and computations: a unifying approach	VR	1MSEK	2022-2025
WASP (Academic PhD student) Noel Arteche	WASP (KAW)	1MSEK	2022-2026

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Noel Arteche		From 2022

5. Inter-university cooperation: summary for 2022

I have started to collaborate with Elina Rönnberg from the Department of Mathematics at LiU. We also submitted a joint application for ELLIIT funding for a PhD position.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

N/A

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

N/A

8. International collaboration

- Ongoing collaboration with Kilian Risse (EPFL) and Aaron Potechin (University of Chicago).
- Ongoing collaboration with Marc Vinyals (University of Auckland) and Lukáš Folwarczný (Charles University and Institute of Mathematics of the Czech Academy of Sciences).
- Collaborated with Robert Robere (University of Toronto) and Mika Göös (EPFL) on a survey article.
- Worked on a project with Allan Sapucaia (Unicamp, now at UCLouvain); Andre Cire (University of Toronto); Pedro de Rezende (Unicamp); and Cid de Souza (Unicamp) which resulted in a paper which is under submission.

9. Supervision of master thesis projects in collaboration with industry

N/A

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
Discrete Structures in Computer Science (lecturer)	undergraduate

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

N/A

13. Academic service activities, including chairing of conferences, editorships and similar

Guest editor for Special Issue of Theory of Computing Systems on selected papers from CSR ‘21;
Program committee of FLoC proof complexity workshop 2022;
Program committee for STOC '23;
Co-organizer of the Proof Complexity Workshop at FOCS ’21 held in February 2022;
Co-organizer of the Proof Complexity Beyond Propositional Logic Special Session at ASL 2023.

14. Open source software contributions

N/A

Daniel Jung, Associate Professor in Fault Diagnostics and Prognostics (LiU)

1. Main scientific achievements during 2022

I became ELLIIT-affiliated as an Associate Professor in June 2022. During 2022, my research has centered around two areas:
The first research area is data-driven fault isolation of unknown faults which is progressing in a new Vinnova-funded project (DELPHI) in collaboration with Scania. In this project I'm both involved as a researcher but also as the main supervisor for a PhD student. Our research in this area started in 2019 with a CENIIT/faculty-funded project where we are investigating how to design data-driven models from physical insights to reason about the cause of abnormal behaviour in dynamic systems and improve model interpretability. Our research has attracted attention and we have initiated discussions around collaboration with other universities and industrial partners.
The second research area is electrification of transportation where I'm involved as a researcher in one project. The project is funded by Energimyndigheten as is conducted in collaboration with Rise, Östgötatrafiken and Nobina where we are investigating optimization of charging infrastructure and batteries for public transportation. We are developing methods to decide where to put charging infrastructure and evaluate the cost when changing to electric buses. My activities in this research area have been increasing during the last three years which will continue in 2023, for example as a main supervisor for a new PhD student project and as a co-supervisor for a PhD student at the Mathematical department in a joint research project in collaboration with Scania.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
Rotfelanalys med maskininlärning	Vinnova/FFI	781 kSEK	2019-2022
DELPHI Diagnos genom att nyttja fysikaliska insikter i neurala nätverk	Vinnova/FFI	1 585 kSEK	2022-2024
Optimerad laddinfrastruktur för elektrifierad kollektivtrafik	Energimyndigheten	414 kSEK	2021-2023
Hybrid Methods for Fault Diagnosis and Prognostics	CENIIT Faculty funding	450 kSEK	2020-2025

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Arman Mohammadi		From 2021

5. Inter-university cooperation: summary for 2022

N/A

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

We have started to collaborate with Elina Rönnberg at the Mathematical Department at LiU around Optimization and Integer Programming which is also continuing in other projects that has started in 2023.

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

As mentioned in the scientific achievements, I'm involved in research collaborations with different industrial partners. I have ongoing projects with Scania but we also have discussions around collaborations in new projects with Volvo Cars.

8. International collaboration

I'm collaborating with researchers at the Center for Automotive Research at The Ohio State University, USA. We are working with cybersecurity in automotive applications.

9. Supervision of master thesis projects in collaboration with industry

I have been on parental leave during the spring 2022 and have not been active as a supervisor for industrial MSc projects during 2022.

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
Electric Machinery TSFS04	undergraduate

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

During the fall 2022, I was one of the main responsible in arranging an information evening for MSc students about what it is like being a PhD student. We invited alumni and active PhD students to share their experiences. The goal is to attract more students to PhD studies. This was the first time we arranged this event and around 15 students attended. The feedback from the students was positive so we are planning to arrange this event again this year also.

13. Academic service activities, including chairing of conferences, editorships and similar

N/A

14. Open source software contributions

N/A

Soheil Samii, Associate Professor in Cyber-Physical Systems (LiU)

1. Main scientific achievements during 2022

Our research focused on the scheduling of time-critical data communications considering cyber-physical systems that are closed over a cellular communication network. We consider configured-grant scheduling and proposed both an exact method and several efficient heuristics to schedule messages with hard deadlines.

The work focused on uplink transmission scheduling considering multiple endpoints and one base station. The work has been accepted for publication at the Design, Automation and Test in Europe Conference (DATE). The work has been extended towards a journal paper to be submitted. Future work will joint uplink and downlink scheduling, as well as extensions towards multiple base stations. Another research direction is to consider mobile applications (e.g., automotive systems) where base station that an endpoint communicates with is not fixed at design time. This calls for more adaptive methods to proactively schedule data communications.

My role has been a co-advisor of the PhD student carrying out the abovementioned research.

Note: My activity was limited to 10-20% throughout 2022.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

N/A

4. Recruitments in connection to the project (students, postdocs, faculty)

N/A

5. Inter-university cooperation: summary for 2022

Collaborated with Prof. Samarjit Chakraborty, University of North Carolina at Chapel Hill, and served as Guest Editor on a special issue on Automotive Systems in the ACM Transactions on Cyber-Physical Systems.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

N/A

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

N/A

8. International collaboration

N/A

9. Supervision of master thesis projects in collaboration with industry

N/A

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

N/A

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

N/A

13. Academic service activities, including chairing of conferences, editorships and similar

Co-Chair of the Program Committee of IEEE-SA Ethernet & IP @ Automotive Technology Days, Yokohama, Japan (November 9-10, 2022).

14. Open source software contributions

N/A

Maria De Lauretis, Associate Senior Lecturer in Electromagnetic Compatibility (HH)

1. Main scientific achievements during 2022

I joined Halmstad in August 2022. During 2022, I performed literature research on side-channel attacks based on electromagnetic leakages (EM SCAs). I submitted a paper for the IEEE EMC conference in 2023. The paper was not accepted, but we got insightful feedback that will help us sharpen our focus. I am currently supervising a Master's thesis on SCAs with a focus on microstrip design.

I started investigating Dual-Function Radar Communication (DFRC) systems due to the interest in radar applications for automotive at Halmstad.

2. Awards and recognitions

N/A

3. External funding attracted

N/A

Itemized list of external projects that were active at some point during 2022

N/A

4. Recruitments in connection to the project (students, postdocs, faculty)

N/A

5. Inter-university cooperation: summary for 2022

- Collaboration with the University of Siena, Dept. of Information Engineering and Mathematics, for the Erasmus teaching program.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

N/A

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

- Started to collaborate with Nibe that asked for educational material about crosstalk.

8. International collaboration

N/A

9. Supervision of master thesis projects in collaboration with industry

N/A

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
Electronics design (2022)	graduate
EMC and Advanced Measurement Technology (2023)	graduate
Supervisor of 2 Master's thesis students	
Supervisor of an Erasmus student	

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

- I presented at the Elektronikmässa in Gotheborg in April 2023 about crosstalk.

13. Academic service activities, including chairing of conferences, editorships and similar

N/A

14. Open source software contributions

N/A

Henry Edison, Associate Senior Lecturer in Software Engineering (BTH)

1. Main scientific achievements during 2022

While I joined BTH in Aug 2022, I came to Karlskrona in Nov 2022. During this year, I published two conference papers in ICSOB 2022, where I was the most senior researcher in the author list. My next steps include continuing my efforts to establish collaboration with industry partners to work on data-driven software engineering and analytics, mainly in the context of unstructured and dynamic software development projects. I will continue the recruitment of a PhD student before summer to join this project.

2. Awards and recognitions

   N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

N/A

4. Recruitments in connection to the project (students, postdocs, faculty)

N/A

5. Inter-university cooperation: summary for 2022

On going collaboration with researchers at:

- Free University of Bozen-Bolzano (Italy) and Sintef (Norway). We are working on data analytics and product development.
- University of Indonesia (Indonesia). We are working on agile maturity in global software development. We have submitted a paper to the Journal of Software: Evolution and Process.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

N/A

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

N/A

8. International collaboration

N/A

9. Supervision of master thesis projects in collaboration with industry

N/A

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

N/A

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

N/A

13. Academic service activities, including chairing of conferences, editorships and similar

- Poster chairs, the 13th International Conference on Software Business (ICSOB) 2022, Bolzano, Italy

14. Open source software contributions
    N/A

Yiannis Karayiannidis, Associate Professor in Automatic Control with focus on Robotics (LU)

1. Main scientific achievements during 2022

I became ELLIIT-affiliated as an Associate Professor in Automatic Control with focus on Robotics in August 2022. Before I was Senior Researcher equivalent to Associate Professor in Research Track with the

Mechatronics Group at Chalmers University of Technology. As an Associate professor with Lund University I have kept my duties as a main supervisor of students at Chalmers.

During 2022, I have contributed to deformable object manipulation, an area where I am both involved as a researcher but also as the main supervisor for one PhD student. My research in this area has been initiated by the DARMA (DAta-driven foundations for Robust deformable object MAnipulation) WASP collaborative project and its spin-off DARMA Bridge with industrial focus. My work on deformable object manipulation have attracted the interest of several international academic partners and I have hosted three Phd students that requested collaboration in relevant topics. During 2022 I and my team published two conference papers on cable routing. The first one published in the International Conference on Robotics and Automation – ICRA 2022 and studies planning and hierarchical closed-loop inverse kinematic aspects of the problem of cable routing while the second published in International Conference on Intelligent Robots and Systems -- IROS 2022 incorporates haptic information obtained by force/torque sensors at the robot wrist to achieve a variety of interaction primitives for cable routing. I have presented my research on deformable object manipulation as invited speaker in the workshop ROMADO-SI@IROS22 and for the Robotics cluster and Industry Days of WASP.

Force-based control and estimation is a field that I have a long-term connection. In 2022, I have also co-authored survey paper summarizing research for manipulation in contact where I contributed in reviewing articulated motions, dual arm manipulation in contact, and control for manipulation in contact. The article was published in the journal Robotics and Autonomous Systems. Another research area, I worked during 2022 was online motion planning under constraints. In this area I have co-authored papers on trajectory scaling for addressing constraints using dynamical systems, published in ICRA 2022, and also probabilistic prediction of obstacle motion for obstacle avoidance, published in International Conference on Automation Science and Engineering – CASE 2022. Both works can be used as components of a general navigation scenario where the obstacles are moving and the robots needs to adapt its motion online to avoid them, thus ensuring safety in dynamically changing environments...

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2022

Project title	Funding source	Granted amount per year	Duration of project
DAta-driven foundations for Robust deformable object MAnipulation - DARMA	WASP	PhD student salary + 30% of my time	2019-2023
Haptic-based Object Tracking	WASP	PhD student salary + 15% of supervision time	2021-2026

AIMCoR: AI-enhanced Mobile Manipulation Robot for Core Industrial Applications	CHAIR AI	900 kSEK	2021-2022

4. Recruitments in connection to the project (students, postdocs, faculty)

Name	ORCID	Period (ex. 2020-2022; 2021-2022, from 2021, etc)
Marko Guberina		2022-2027

5. Inter-university cooperation: summary for 2022

I am main supervisor of three Phd students affiliated with Chalmers University of Technology. Albin Dahlin is funded by CHAIR, AI Chalmers, Rita Laezza and Gabriel Waltersson are funded by WASP. I have been co-supervisor of two Phd students affiliated at KTH, Royal Institute of Technology. Ioanna Mitsioni with main supervisor Danica Kragic presented her Thesis in February 2022. Shuangshuang Chen has as main supervisor Mårten Björkman and she is expected to present her Thesis in the beginning of 2023.

6. Inter-disciplinary cooperation: summary, when relevant, for 2022

N/A

7. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

I am member of the Core Team of Wallenberg Research Arena (WARA) Robotics coordinated by ABB.

8. International collaboration

I have hosted the following international Phd students:
Monica Sileo, University of Basilicata, Italy
Andrea Monguzzi, Polytechnic University of Milan, Italy
Ignacio Cuiral-Zueco, University of Zaragoza, Spain
Mohammadreza Shetab-Bushehri, University Clermont Auvergne, France

9. Supervision of master thesis projects in collaboration with industry

Classifying the motion patterns of bikes using machine learning by Filip Larsson and Pontus Hallqvist with Robert Bosch AB
Design of an Industrial Bin Picking Station by Jonathan Ramb with Odigo Consulting (co-supervisor)

10. List of patent applications published during 2022

N/A

11. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

Course name	Level (undergraduate/ graduate)
FRTN05 - Nonlinear Control and Servo Systems	Graduate

12. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

Introductory seminars to groups of students visiting the Robotics week organized as part of the European robotics week by the departments of automatic control, cognitive science and computer science at Lund University.

13. Academic service activities, including chairing of conferences, editorships and similar

Chairman for the session Compliance and Impedance Control 2, IROS 22
Associate Editor for Robotics and Autonomous Letters, European Control Conference (ECC), International Conference on Robotics and Automation (ICRA), International Conference on Intelligent Robots and Systems (IROS)

14. Open source software contributions

N/A

Onur Günlü, Assistant Professor of Information-Theoretic Privacy and Security (LiU)

1. Main scientific achievements during 2022

During October-December 2022, I have published a journal paper in IEEE Transactions on Information Theory on function computations with hidden function inputs under privacy and security constraints. The results are highly information-theoretic and illustrate the effects of having hidden random variables whose noisy/distorted versions can be observed. I have also worked on and published about an old information theoretic security problem, namely, secure source coding problem. We have established that having private keys allow to achieve strong privacy in source coding problems, which is an insight that was missing

in the literature. Furthermore, an extension of our previously proposed private federated learning method is presented at IEEE GlobeCom 2022, which applies a low-complexity compression method.
Next steps for me include continuing my individual efforts to establish a strong information security group via various funding sources to significantly strengthen LiU's position in the information security and privacy area worldwide.

2. Awards and recognitions

N/A

3. External funding attracted

4. Itemized list of external projects that were active at some point during 2022

N/A

5. Recruitments in connection to the project (students, postdocs, faculty)

N/A

6. Inter-university cooperation: summary for 2022

N/A

7. Inter-disciplinary cooperation: summary, when relevant, for 2022

N/A

8. Industry and institute cooperation, inclusive research projects and courses devoted to industrial sectors

Zenith Research and Career Development Fund in collaboration with Sectra Communications AB in Linköping.

9. International collaboration

H. Vincent Poor (Princeton University, USA), Holger Boche (TU Munich, Germany), Rafael F. Schaefer (TU Dresden), Matthieu Bloch (Georgia Institute of Technology, USA)

10. Supervision of master thesis projects in collaboration with industry

N/A

11. List of patent applications published during 2022

N/A

12. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses (including e-courses MOOC), use of research results, and education program leadership

N/A

13. Highlights from outreach activities, including popular science presentations, influence on standards, and similar

I have served for the second year as a member of the IEEE Information Theory Society (ITSoc) Student and Outreach Subcommittee.

14. Academic service activities, including chairing of conferences, editorships and similar

Guest Editor for Entropy Special Issue on "Information Theoretic Methods for Future Communication Systems".
Associate Editor for EURASIP Journal on Wireless Communications and Networking.

15. Open source software contributions

N/A

ELLIIT Gender projects

PIs: Nauman Ali (BTH), Carina Gelhauser (LU), Ingrid Hotz (LiU), Marlena Nowaczyk (HH), Sandra Pott (LU), Sara Maad Sasane (LU)

Report of 2022 activities

This report highlights the efforts made by the members of the ELLIIT gender equality team in promoting gender equality and creating a supportive and inclusive environment for all employees, regardless of gender.
The past year has seen several initiatives aimed at advancing gender equality within our departments. There are the general activities and commitments on the university level (see. e.g., at LiU https://liu.se/en/article/lika-villkor) that are also supported by our divisions and the individual research groups. These commitments from the university are valuable and indispensable, as they provide a precondition for the development of equal opportunities.

All our institutions are too big that we could manage the activities for gender equality alone, and so there are many ongoing activities without us. The focus is always local on what the community needs. E.g. at

LU electrical engineering, a focus was on diverse cultural backgrounds, and social mentoring. Social mentoring means that colleagues help and support each other when needed and in different situations within organisation. This kind of help can be particularly useful for newly recruited employees.

Let us mention some local activities that we have been conducting:

LiU Division of Media and Information Technology

Our activities were mostly focused on increasing the number of female members on the level of master and PhD, and ensuring a safe and comfortable environment for everybody. In summary, this was

- trying to change our own behavior, observe our own biases, try to compensate for them,
- actively motivate talented students who may be more reserved to consider academic research career,
- bringing the topic of biases actively up in group meetings and discussing situations of non-equal treatment,
- motivate students/employees to speak to a female senior person if they experience uncomfortable situations,
- try to find female lab assistants as role models for the students.

Thanks to these measures, the percentage of females at the PhD level increased a lot over the last years. Unfortunately, we have been less successful on the more advanced level as post-docs.

LTH Mathematics

Mentoring Program: In 2021, with the help of ELLIIT funds, the department 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.

Louise Petren Day: The department celebrated Louise Petren Day on June 2nd, 2022. https://www.lu.se/evenemang/louise-petren-day-2022.

Louise Petren was the first woman to receive a PhD in mathematics in Sweden and this day is dedicated to celebrating her achievements and legacy. The day was marked by various activities and events, including a series of guest lectures and discussions, aimed at raising awareness of gender equality issues and inspiring change within the department. In a video lecture, Inna Emelyanova described the main points of Louise Petren's research, which she had presented also in her article in the SMS bulletin, Nov 2020. The highlight of the morning was a speech given by Louise Petren's grandson, Lars Haikola, who put her life and work into context and shared personal anecdotes about her achievements and impact. In the afternoon, Irina Petterson from Chalmers University, Goteborg, gave an accessible talk on the

mathematics of material science.

EWM General Meeting Helsinki: We were actively involved in the preparation for the European Women in Mathematics (EWM) General Meeting, which was held in Helsinki in August 2022. Members of the department contributed to the event by presenting papers, leading discussions, and participating in panel discussions on topics related to gender equality in mathematics.

Career Talks: Throughout the past year, the department hosted several career talks aimed at inspiring and empowering female staff members to succeed in their careers. The talks were delivered by female leaders from a variety of fields, who shared their experiences, insights, and advice for success. The career talks were well received by attending students of all genders, and women attendees reported feeling motivated and inspired to pursue their careers.

BTH

At BTH, the department is small and there is actually only one female PhD student within ELLIIT. To support underrepresented gender, we have been involved in several programs that aim in getting young people engaged in technology.

- "Teknikdag för tjejer" - November 23, 2022: High school students from year 9 participated in this half-day event at BTH. During the day, they tried out different tech stuff combined in four workshops: app development, building a prototype car, 3D scanning, creating 3D objects, and 3D printing. Based on the evaluation from the students, they enjoyed the day very much. It is the second year BTH has organized this event. Read more at https://bthse.sharepoint.com/lyckad-teknikdag-f%C3%B6r-tjejer-(2)

- Teknikdag för tjejer at Ericsson - January 18, 2022 and January 25, 2023 : This was a half-day event with different workshops for high school students (year 9) at Ericsson. Our students organized a workshop with lego robot programming. Approximately 40 students attended each event. Video from the event in 2022: https://www.linkedin.com/posts/anders-bornstedt-76151a8a_ericssonkarlskrona-girlsinict-ericsson-activity-6544161315374551041-LpxL/?utm_source=share&utm_mediu m=member_desktop

Similarly, Halmstad University's attention was on gender balance in undergraduate education. Moreover, meetings for female students were organized, where they could meet with women working in the companies' boards. The aim of this meeting was to encourage female students to pursue career in leadership. For more information:
https://www.hh.se/4.5a3f038a1683708262e1fb76.html/?url=-1225869449/api_v2/getEvent/2 0644

Report on the additional work of the gender equality team

In 2022, we aimed to isolate effective measures to improve gender equality, having at hand a limited budget, both in terms of time and money. For this, we first isolated the different focus groups:

Focus groups for gender equality actions

Promoting gender equality STEM requires a multi-pronged approach that targets a range of stakeholders, including students, educators, researchers, and institutions. Some key target groups for promoting gender equality in mathematics include:

1. Students: Fostering a supportive and inclusive learning environment for female students in STEM is critical to promoting gender equality in the field. This can be achieved through initiatives such as mentorship programs, female-focused clubs or activities for high schools, and female-led workshops and seminars.
2. Educators: Educators play a critical role in shaping students' attitudes towards mathematics and can have a significant impact on promoting gender equality in the field. This can be achieved through initiatives such as diversity and inclusion training for teachers and increasing the representation of female educators in mathematics.
3. Researchers: Researchers play a key role in shaping the field of mathematics and can help to promote gender equality by advocating for more inclusive policies, increasing the representation of female researchers, and promoting the work of female mathematicians.
4. Institutions: Institutions play a critical role in promoting gender equality in mathematics by providing resources and support for initiatives that target students, educators, and researchers, and by implementing policies and programs that promote diversity and inclusion in the field.

It's important to recognize that promoting gender equality in mathematics will require sustained effort and collaboration across these target groups, as well as continued experimentation and innovation in order to find effective approaches to this complex challenge. Additionally, it's important to recognize that gender equality in mathematics is part of a larger social and cultural issue, and that progress in promoting equality will require efforts across all sectors of society.

Which measures are effective?

It's difficult to determine which gender equality actions are the most effective as different initiatives

may have varying levels of impact depending on a variety of factors, such as the cultural context, the target audience, and the specific goals of the initiative. However, some initiatives that have been shown to be effective in promoting gender equality include:

1. Transparency: Implementing measures that enhance transparency within the department can help to ensure all members of the department that everyone's work is valued, that men and women are treated equally, and therefore to improve the work environment and make the workplace more attractive.
2. Mentorship and sponsorship programs: Providing female employees with access to role models, guidance, and support can help to close the gender gap and promote diversity and inclusion in the workplace.
3. Diversity and inclusion training: Providing training for all employees on topics such as unconscious bias, diversity, and inclusion can help to raise awareness and promote a more inclusive work environment. However, they need to be followed up by concrete action and changes in workplace culture and practices.
4. Flexible work arrangements: Offering flexible work arrangements, such as working from home, flexible schedules, and part-time work options, can help to promote gender equality by supporting women in balancing work and family responsibilities.

However, a threat to all gender equality efforts is deprecating comments from teachers and lack of buy-in from leadership: Gender equality initiatives that lack support from senior leadership can be ineffective.

Plan for 2023

In 2023 we plan one overarching ELLIIT event, to bring everyone together to start building a community. Besides we consider to reserve some action funds for local activities, retaining flexibility in spending.

Overarching activities

- Main event - women's workshop: The main event aims at bringing everyone together, in a relaxed atmosphere, to start a female community.
- The event should not be in competition with the annual ELLIIT meeting where many have multiple obligations and time is tight.
- The target group is PhD and postdocs with keynotes from senior researchers.
- The event will also be used as a barometer for the current situation of female researchers in ELLIIT.

Local activities

Local activities may include

- Research internships for MSc students to give undecided talented female students a chance to experience life in an academic environment.

- Women's lunches that provide a relaxed environment to exchange experiences.
- Other local events.

Improving transparency in all levels where money and power are distributed is considered essential to generate an environment where young researchers can develop independence and take responsibility for their own funding. Making changes of this kind is a difficult task as it often targets established power structures. While no specific activities are planned yet discussions on this topic at the institutional level are consider

APPENDIX

Other recruitments in the broader ELLIIT environment

Title	Name	Site
Wallenberg WASP Professor	Hector Geffner	LiU
Associate Professor in Software Engineering	Nauman Bin Ali	BTH
Professorship in Computer Systems Engineering	Mohammad Reza Mousavi	HH
Assistant Professor in Information Technology	Yousra Alkabani	HH
Professorship in Information Technology	Mark Dougherty	HH
Professorship in Automatic Control	Claudio Altafini	LiU
Assistant Professor in Automatic Control	Isaac Skog	LiU
Professorship in Computer Science	Andrei Gurtov	LiU
Associate Professor Network Dynamics	Giacomo Como	LU
Associate Professor in Automatic Control	Martina Maggio	LU
Associate Professor in Automatic Control	Pontus Giselsson	LU
Associate Professor in Automatic Control	Kristian Soltesz	LU
Associate Professor in Computer Science	Christoph Reichenbach	LU
Associate Professor in Computer Science	Emma Söderberg	LU
Professorship in Computer Science	Volker Kreuger	LU
Assistant Professor in Computer Science	Luigi Nardi	LU
Guest Professor 2016 –	Liesbet Van der Perre	LU
Guest Professor 2018 – 2020	Ulrike Thomas	LU
Assistant professor, Electrical and Information Techn.	Amir Aminifar	LU
Associate professor, Electrical and Information Techn.	Emma Fitzgerald	LU
Associate professor in Automatic Control	Emma Tegling	LU
Assistant Professor in Mathematics	Magnus Oscarsson	LU
Associate Professor in Automatic Control	Björn Olofsson	LU

List of Ph.D. and licentiate defenses

Name	Gender	Industry-based PhD student (yes or no)	Degree (licentiate/doctoral)
Ahrnbom, Martin (LU)	Male	no	PhD
Akbarian, Fatemeh (LU)	Female	no	Licentiate
Becirovic, Ema (LiU)	Female	no	PhD
Berg, Axel (LU)	Male	no	Licentiate
Berner, Tommi (LU)	Male	no	PhD
Couderc, Noric (LU)	Male	no	Licentiate
Ernstsson, August (LiU)	Male	no	PhD
Hrusto, Adha (LU)	Female	yes	Licentiate
Kjellqvist, Olle (LU)	Male	no	Licentiate
Li, Xuhong (LU)	Female	no	PhD
Mandrioli, Claudio (LU)	Male	no	PhD
Minhas, Nasir Mehmood (BTH)	Male	no	PhD
Morales, Oscar (LiU)	Male	no	PhD
Morin, Martin (LU)	Male	no	PhD
Nordlöf, Jonas (LiU)	Male	yes	Licentiate
Rezk, Nesma (HH)	Female	no	PhD
Rodríguez Sánchez, Jesús (LU)	Male	no	PhD
Ros, Rasmus (LU)	Male	no	PhD
Rosdahl, Christian (LU)	Male	no	Licentiate
Ruuskanen, Johan (LU)	Male	no	PhD
Sadeghi, Hamed (LU)	Male	no	PhD
Sidorenko, Galina (HH)	Female	no	Licentiate
Song, Qunying (LU)	Male	no	Licentiate
Tinnerholm, John (LiU)	Male	no	Licentiate
Tran, Vi (BTH)	Female	no	Licentiate
Umar Farooq, Muhammad (LU)	Male	no	PhD
Willhammar, Sara (LU)	Female	no	PhD

Guest researchers and visiting students

Will Woodman, School of Mathematics, Statistics and Physics, Newcastle University (November 2022)
Guojin Zhang, Aalborg University, visiting PhD student, March-June 2022
Alexander Marin

List of invited talks, keynotes, plenaries, tutorials and other significant dissemination events

Name of presenter	**Title of talk/keynote/tutorial**	**Conference name (if applicable)**	**Place (city and country)**
Atila Alvandpour (LiU)	A large series (> 20) tutorials and talks on design of efficient integrated circuits and chip design		Some online and some in LiU/ISY (LiU-Saab-Brazil collaboration)
Lars Nielsen (LiU)	Force-Centric Perspectives on Autonomous Safety Maneuvers	Advances in Automotive Control	Columbus, Ohio
Yiannis Karayiannidis (LU)	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 IROS 2022	Kyoto, Japan
Michael Lentmaier (LU)	Generalized LDPC codes with Convolutional Code Constraints	Keynote, IEEE Globecom Workshop on channel coding beyond 5G, Dec 2022	Rio, Brazil

List of distinguished lectures 2022

[1] 2022-04-01 Dr. Lucy Ellen Lwakatare, Helsinki University, Finland
Development of ML-enabled systems in industrial settings – An overview of practices, infrastructures, and research opportunities

[2] 2022-04-01 Docent Gregory Gay, Chalmers/ Gothemburg University, Sweden
Learning How to Search: Generating Effective Test Cases Through Adaptive Fitness Function Selection

[3] 2022-05-11 Prof. Rui Dinis, Nova university, Lisbon, Portugal
Nonlinear effects in digital communications: analytical evaluation of their effects and how to use them to improve the performance

[4] 2022-05-17 Prof. Martin Shepperd, Gothenburg University/Brunel University London, UK
The Prevalence of Errors in Machine Learning Experiments

[5] 2022-05-19 Prof. Jeannette Wing, Columbia University, New York, USA
Thrustworthy AI

[6] 2022-05-24 Prof. John S. Baras, University of Maryland College Park (UMD), USA
Three lectures: From Copernicus-Brahe-Kepler to Swarms: Learning Composable Laws from Observed Trajectories; Trusted Autonomy: Theory and Applications; Networked Cyber Physical Systems

[7] 2022-06-10 Dr. Chris Rackauckas, Massachusetts Institute of Technology, USA
Scientific Machine Learning: Where We Are and Where We Need to Go

[8] 2022-10-06 Prof. Lars Nielsen, Linköping University, Sweden
Force-Centric Perspectives on Autonomous Safety Maneuvers

[9] 2022-10-12 Prof. Timo Rahkonen, University of Oulo, Finland
RF IC design challenges for future 6G systems

[10] 2022-10-13 Prof. Christoph Studer, ETH Zürich, Switzerland
Wireless Positioning with Channel State Information and Channel Charting

[11] 2022-10-14 Prof. Alexandre Proutiere, KTH, Stockholm, Sweden
Learning Optimal Antenna Tilt Control Policies: A Contextual Linear Bandit Approach

[12] 2022-10-17 Prof. Snorre Aunet from NTNU, Trondheim, Norway
Towards sub-100 mV VDD CMOS

[13] 2022-10-18 Dr. Fabian Fagerholm, Aalto University, Finland
Designing The Right Software: Continuous experimentation and design decision-making in modern software engineering

[14] 2022-10-21 Dr. Hei Victor Cheng, Aarhus University, Denmark
New perspectives on communication environment: creation of smart radio environment and information modulation through the environment via reconfigurable intelligent surface

[15] 2022-12-08 Prof. Karl-Erik Årzén, Lund University, Sweden
Modeling, Control and Learning for Improved Cloud Predictability

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Scientific peer-reviewed publications in refereed journals

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