ELLIIT

Excellence Center at Linköping – Lund in Information Technology

ANNUAL REPORT 2021

Contact:
Chair of the steering group: Per Dannetun (LiU), per.dannetun@liu.se
Chair of the program management group: Ass. Prof. Inger Erlander Klein (LiU), inger.erlander.klein@liu.se
Director: Prof. Erik G. Larsson (LiU), erik.g.larsson@liu.se
Co-director: Prof. Fredrik Tufvesson (LU), fredrik.tufvesson@eit.lth.se
Program coordinator: Angela Sanseverino (LiU), angela.sanseverino@liu.se

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Introduction

ELLIIT is a strategic research environment in information technology and mobile communications, funded by the Swedish government in 2010. With four partners, Linköping University, Lund University, Halmstad University and Blekinge Institute of Technology, ELLIIT constitutes a platform for both fundamental and applied research, and for cross-fertilization between disciplines and between academic researchers and industry experts. ELLIIT stands out by the quality and visibility of its publications, and its ability to attract top talented researchers.

ELLIIT underwent a significant expansion in 2020, with a total annual budget of currently 108 MSEK. The funding is pre-allocated as 45% to each of LiU and LU, and 5% to each of BTH and HH. The forms of management and cooperation are described in an agreement between the parties (Dnr: LiU-2020-01694). The principle for the use of funding is that 30-50% should be used for the support of projects, 30-50% of should be used to fund tenured and tenure-track positions, and 0-20% of the funding should be used for special initiatives.

Management structure

ELLIIT is governed by a Steering Group (SG) and a Program Management Group (PMG). ELLIIT also has a director and a co-director, from Linköping University and Lund, respectively.

The Steering Group (SG) decides about the allocation of the project funding and oversees the appointment processes of the ELLIIT permanent positions. It also monitors the development of the research projects and take strategic decisions for future development of the program.

The Program Management Group (PMG) is appointed by the ELLIIT Steering Group and is composed of ELLIIT senior researchers. The PMG 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 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, co-PI: Johan Thunberg, HH
Participating researchers: 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 2021

Cooperative driving is a promising paradigm to improve traffic efficiency and safety. In congested traffic scenarios, such cooperation allows for safe maneuvering and driving with small inter-vehicle spatial gaps. The vehicles involved coordinate their movements in real-time and continuously update each other about their maneuver execution status by means of Vehicle-to-Everything (V2X) communication. However, unreliable V2X communication increases the Age of Information (AoI) of vehicles' status updates, posing a challenge in situations where emergency braking is required during cooperative maneuvering.

To address the interplay between unreliable V2X communication and the resulting impact on traffic safety, we (with Robert Bosch GmbH) have introduced a so-called safety time function, specifically designed for cooperative driving use-cases in (and beyond) urban environments. The safety time function provides the time available for a vehicle to react to an unexpected event of another vehicle – such as emergency braking to avoid a collision. We provided a computationally efficient algorithm for the computation of safety time functions, which allows for efficient (and scalable) and safe cooperative maneuver planning – even in dense traffic scenarios with many vehicles involved. We show the applicability of our proposed safety time function based on the assessed communication quality for IEEE 802.11p-based V2X communication to meet safety constraints in dense vehicular traffic. With this result,

we provide a new metric for joint characterization of safety and communication quality in complex traffic scenarios.

Further, we (with Volvo Cars) provide a comprehensive performance evaluation of the main state-of-the-art broadcast rate control algorithms from the point of view of channel load, utilization efficiency, and information freshness. We evaluate these algorithms in a realistic simulation environment and describe a centralized approach to define a bound on the performance. We show that controlling the congestion based on either channel load or information freshness only leads to sub-optimal performance.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

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	2019-2024

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

Oscar Molina and Taqua Saeed were hired at HH as postdoctoral researchers.

5. Inter-university cooperation: summary for 2021

LiU (Asplund) and HH (Vinel). A collaboration on emerging surveillance applications of UAV teams that rely on secure communication to exchange information, coordinate their movements, and fulfil mission objectives.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

N/A

7. Industry and institute cooperation

Volvo Cars (joint paper, IEEE MedComNet 2021) and Robert Bosch GmbH (joint paper, IEEE Access).

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

N/A

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

N/A

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

Alexey Vinel is an associate editor of IEEE Transactions on Information Forensics and Security.

12. Open source software contributions

N/A

A2: Scalable Data Processing in Networked Systems

PI: Anders Rantzer, LU
Participating researchers: Richard Pates, LU, Claudio Altafini, LiU, Anders Hansson, LiU

Summary
This project aims to develop scalable algorithms to monitor, predict, and analyze data from large scale dynamic networks. In line with ELLIIT focus theme Big Data and Network Science, the objectives are:
1. Exploit structural properties (such as graph properties, symmetries and conservation laws) in large dynamic networks for scalable estimation and filtering with noisy and unreliable data.
2. Develop tools to support network operators monitoring the behaviour of networked systems, through scalable algorithms with provable performance guarantees.

1. Main scientific achievements during 2021

The year saw progress 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, and accepted for publication in 2022.
Secondly, work on large scale techniques control and estimation in electrical power systems was initiated. Specialised algorithms and tools for systems with so called *lossless* dynamics were developed. This work will continue in 2022, with a focus on evaluating the approaches on detailed models.

2. Awards and recognitions

PI Anders Rantzer was invited to give virtual (due to the pandemic) oral presentations to

- Conference of Learning for Decision and Control (L4DC) at ETH Zürich, June-21
- MIT LIDS virtual seminar series Changing Electric Energy Systems, Cambridge USA, Nov-21
- Invited seminar at Data Science & Systems Complexity Centre at Univ. of Groningen, Dec-21

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amount per year	Duration of project
SoPhy: Societal-Scale Cyber-Physical Transport Systems	SSF: Foundation for Strategic Research	1 MSEK	2016-2022
Scalable Control of Interconnected Systems	ERC: European Research Council	0.5 MEUR	2019-2024
Throughput Control in Autonomous Networks	WASP PhD project	0.9 SEK	2019-2024
Statistical and Adversarial Learning in Continuous System Control	WASP collaboration project	1.1 MSEK	2019-2024

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

A student Johan Lindberg was hired to work on the project.

5. Inter-university cooperation: summary for 2021

Collaborations with Johns Hopkins on the control of electrical power systems were maintained.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

N/A

7. Industry and institute cooperation

Discussions with emulate.energy and DNV GL were maintained to keep the research on electrical power systems relevant for the Swedish energy system.
Sub-contractor in project "AI for Guidance Navigation and Control" at European Space Agency

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

The PI developed new masters course starting in Lund January 2022: FRTN75 Learning Based Control.

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

A popular science video on control education was submitted to the 'online summer of math exposition' competition. It made the final round, and the video can be found here:
https://www.youtube.com/watch?v=PjwHSDIGsdw&t=1369s

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

Member of examination committe for habilitation by Victor Magron, Toulouse, May 2021.
Member of examination committe for PhD defence by Matías Müller, Stockholm, June 2021.
Member of examination committe for PhD defence by Julio Careaga, Lund, Oct 2021
Member of Steering committee for Int. Symp. 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
Chairman of the IFAC Fellow Search Committee
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 Inform Sciences at Springer Verlag
Member of the IEEE CSS Technical Committee on Nonlinear Systems and Control
Member of the IFAC Technical Committee on Nonlinear Systems
Member of advisory board for excellene center DISMA at Politecnico di Torino
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
Member of organizing committee for IEEE CSS Workshop on Control for Societal Challenges 2021

12. Open source software contributions

N/A

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

PI: Anders Robertsson, LU
Participating researchers: R Johansson, LU, M Greiff, LU, R Tyllström, LU, E Rofors, LU, Boris Godoy, 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.

1. Main scientific achievements during 2021

Existing radiation mapping methods were extended and published at IROS 2021, in a paper titled "Gamma-Ray Imaging with Spatially Continuous Intensity Statistics". This work proposes a novel method involving machine learning techniques related to expectation maximization, and leverages classical numerical integration theory along with Bayesian model selection to estimate intensity of radiation intensity fields. Importantly, the proposed model class is large enough to encompass point sources – in which case both location and intensity are estimated. The method also includes nonlinear estimation models and incorporates known surface geometries. Parts of this work was included in the PhD thesis of Marcus Greiff, which was also published during 2021. Furthermore, field tests were conducted to measure the radiation levels at various sites in the forests around Gävle. This resulted in a technical report and several data sets which will be used in future validation experiments.

Nonlinear Control of Unmanned Aerial Vehicles: Systems with an Attitude
Marcus Greiff, Ph D Thesis, Department of Automatic Control, Lund University, Sweden, Nov 2021
Available for download at https://portal.research.lu.se/en/publications/nonlinear-control-of-unmanned-aerial-vehicles-systems-with-an-att

2. Awards and recognitions

Emil Rofors was awarded a postdoc position at UC Berkeley, in part due to his work and affiliation with the radiation mapping project.

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amount per year	Duration of project
UAS@LU Autonomous Flight	Lund University, Samverkansrådet	1 MSEK	4 years
Semantic Mapping and Visual Navigation for Smart Robots	SSF	6MSEK	2016-2021/22 (prolonged 1 year to 2022 with budget intact)

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

Emil Rofors was hired as a researcher in the project, subsequently moving to UC Berkeley. In addition, Boris Godoy was hired as a full-time researcher in Nov 2021 at the Department of Automatic Control, LU, to replace Emil as he moved to California.

5. Inter-university cooperation: summary for 2021

An expedition was led to Gävle to measure radioactive fallout from the Chernobyl nuclear accident. The group consisted of M Greiff, R Tyllström, E Rofors and R. Mahben, all of whom are affiliated with Lund University. However, the participants are affiliated with different departments, and also include members from Trafikflyghögskolan (TFHS).

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

The project includes expertise from the department of automatic control (concerning control and estimation theory); the department of nuclear physics (concerning the operation of the gamma detector); Trafikflyghögskolan (concerning the operation of the large drones used to carry the equipment).

7. Industry and institute cooperation

During 2021, members affiliated with the project collaborated with Mitsubishi Electric Research Laboratories (MERL) on topics related to estimation and positioning of autonomous systems.

8. List of patent applications published during 2021.

Patent title	Application Number
System and Method for GNSS Ambiguity Resolution	16789455

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

Some of the algorithms and autonomous technologies were showcased during the EU Robotics week at Lund University. This is a yearly event taking place in early November, where students from local schools visit the robotics lab and get to experience concepts related to robotics and control.

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

Presentations and demos were given in the UAV@Lund workshops and during 2021.
The drone activities were demonstrated at the RobotLab, Nov 24-26, 2021 within the yearly arrangement of the euRobotics week, where in total 16 one-hour lab visits were given, most of them for invited school classes and a couple dedicated for visits from faculty, nearby industry and the general public.

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

N/A

12. Open source software contributions

The open-source code AerialVehicleControl.jl was published to facilitate autonomous operations of UAVs for missions such as radiation mapping. While originally published in late 2020, it is affiliated with a publication that was published in 2021, titled “Attitude Control on SU(2): Stability, Robustness, and Similarities”.

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 2021

A Wireless Caching Helper System Serving Heterogeneous Traffic with Secrecy Constraint. We characterized the performance of a wireless caching system with heterogeneous traffic, which we distinguish between cacheable and non-cacheable traffic, and relaying capabilities with secrecy constraints for one of the two receiving users. In the assumed setup, the second user does not have secrecy requirements and receives cacheable content either from the relay helper or the core network through a wireless base station. The wireless relay helper can assist both users since it is equipped with finite storage that can be split between cacheable and non-cacheable storage. At the same time, a passive eavesdropper overhears wireless transmissions originating from the user with secrecy requirements. Thus, we examine how the relay's storage split and the eavesdropper affect the performance in terms of the average throughput and delay of the system as the transmission powers, the relay's transmission probability, and the relay's cache size vary.

KDC Placement in Secure VPLS Networks. Virtual Private LAN Service (VPLS) is a VPN technology that connects remote client sites with provider networks. Session key-based HIPLS (S-HIPLS) is a VPLS architecture based on the Host Identity Protocol (HIP) that provides a secure VPLS architecture using a Key Distribution Center (KDC) to implement security mechanisms such as authentication, encryption, etc. It exhibits limited scalability and a single point of failure, though. Employing multiple distributed KDCs would offer numerous advantages including reduced workload per KDC, distributed key storage, improved scalability, while simultaneously eliminating the single point of failure of SHIPLS. It would also come with the need of optimally placing KDCs in the provider network. We formulate the KDC placement (KDCP) problem for a secure VPLS network as an Integer Linear Programming (ILP) problem. The NP-hardness of the latter suggests a high computational cost for obtaining exact solutions, especially for large deployments. Therefore, we motivate the use of a primal-dual algorithm to efficiently produce nearoptimal solutions. Extensive evaluations on large-scale network topologies, such as the random Internet graph, demonstrate our method's time-efficiency as well as its' improved scalability and usability compared to both HIPLS and S-HIPLS.

A Critical Analysis of the Industrial Device Scanners' Potentials, Risks, and Preventives. Tools such as Nmap, ZMap, Nessus, Shodan, and Censys allow anyone to scan the Internet for potential security vulnerabilities. Even though, they were created as security scanning tools to assist network administrators to assess security risks, they are often used as attack tools as well since scanning an IP address can result in the disclosure of information about a vulnerable device. However, from a defensive perspective, this vulnerability disclosure could be used to secure devices if characteristics such as type, model, manufacturer, and firmware could be identified. This procedure allows the automation of security reports that can facilitate the implementation of security measures before a vulnerability is found by an attacker. To that end, it is necessary to implement a device recognition procedure with the ability to identify a device and its characteristics, such as manufacturer, model, and version of services running on it. A complete device recognition procedure can then be seen as the basis for auditing networks and identifying vulnerabilities in order to mitigate cyberattacks, especially among industrial

devices that are part of critical systems. We considered Supervisory Control and Data Acquisition (SCADA) systems as the essential infrastructure's underlying monitoring and control elements, and focus on analyzing the most recent approaches to device recognition within ICS/SCADA systems. Additionally, we summarized popular scanning tools and studies for ICS/SCADA devices. Moreover, based on the observation that traffic to a host increases after it is discovered by Shodan, we also analyzed proposed methodologies for avoiding Shodan-like scanners. Finally, we presented the results of a parallel related project which highlights how easily hundreds of Internet-connected industrial devices in Sweden could be identified by anyone.

Although the fifth-generation (5G) wireless networks are yet to be fully investigated, the visionaries of the 6th generation (6G) systems have already come into the discussion. Therefore, to consolidate and solidify the security and privacy in 6G networks, we survey how security may impact the envisioned 6G wireless systems, possible challenges with different 6G technologies, and the potential solutions. We provide our vision on 6G security and security key performance indicators (KPIs) with the tentative threat landscape based on the foreseen 6G network architecture.

2. Awards and recognitions

Prof. Andrei Gurtov (PI) has been enlisted as one of the top 2% of World Scientists in the Scopus Database by Stanford University.

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

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

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

Postdoc Ioannis Avgouleas left the LiU ELLIIT project for Ericsson Research. The recruitment process for hiring a new post doc, Gurjot Singh, started in 2021.

5. Inter-university cooperation: summary for 2021

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

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

N/A

7. Industry and institute cooperation

We invited technology experts from Ericsson for delivering lectures to our bachelors' and masters' students at LiU. We conducted cyber security research in cooperation with Ericsson, Linköping, and Knowit, Linköping.

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

PI proposed and discussed the possibility to launch a new MSc program in Cyber security at Linköping University.

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

Our article "The roadmap to 6G security and privacy," published in IEEE Open Journal of the Communications Society, 2021, was the most downloaded LiU publication on ResearchGate in May 2021.

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

1. Prof. Andrei Gurtov (PI) served as an Associate Editor for the MDPI Sensors journal (Q1).
2. Prof. Andrei Gurtov (PI) has served and serving currently as Chair, IEEE Sweden section.

12. Open source software contributions

PI along with his team contributed to an open-source protocol, OpenHIP.

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 2021

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

Laplacian pseudoinversion: For Laplacian matrices, we showed that the commonly used notion of pseudoinverse must be taken with care: the pseudoinverse of a Laplacian is not itself a Laplacian but rather a signed Laplacian, i.e., a matrix having off-diagonal entries that can assume both positive and negative signs. Starting from this observation we have analyzed in detail the structure of the Laplacians and Laplacians pseudoinverses for signed graphs, and developed a nearly exhaustive classification of all possibilities.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amount per year	Duration of project
Control of network systems with signed dynamical interconnections	Australian Research Council	150 K AUS $	4 years
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	6 M SEK	5 years

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

N/A

5. Inter-university cooperation: summary for 2021

Various collaborators including Francesco Ticozzi from University of Padova, Francesca Ceragioli from Politecnico di Torino, Italy, and Francesco Vasca from University of Sannio, Benevento, Italy.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

The PI collaborated with various group at Dept of Physics, Chemistry and Biology (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

N/A

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

The PI delivered a new PhD course entitled "Opinion Dynamics on Social Networks" arranged in cooperation with the University of Sannio, Italy.

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

Our research on political networks was highlighted in a LiU news article entitled "Forming a government – how long will it take?", see https://liu.se/en/news-item/hur-lang-tid-tar-det-att-bilda-regering-efter-ett-val.

11. 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 10th Int. Conference on Complex Networks and Their Applications, and of the 19th International Conference on Computational Methods in Systems Biology.

12. 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. The proposed research aims at, in different ways, to incorporate more precise and up-to-date information about disturbances and to decrease uncertainties in the plan that often traditionally are handled by introducing conservativeness. The proposed research presents 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 2021

The main researcher Abhishek Dhar in this project started in September 2021. During the fall 2021, research was performed about the robust motion planning problem to be studied in this project and the first result from that work was reported in a conference paper submitted to CDC 2022. During 2021, the PI published 4 journal articles (one more accepted) and 4 conference articles, within the areas of motion planning, real-time optimization, and uncertainty estimation in deep neural networks. Furthermore, he was the main supervisor for one defended PhD thesis and one defended licentiate's thesis. Additionally, he was the co-supervisor of one PhD thesis and one licentiate's thesis.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amount per year	Duration of project
iDecide	FFI, Vinnova	1,11MSEK	4 years (including teaching)
Unified task planning and optimal-control-based motion planning	WASP	Ca 1MSEK	5 years (including teaching)
Real-time certification and self-optimization of interior-point and branch-and-bound software for predictive control	WASP	Ca 1MSEK	5 years (including teaching)
iQDeep	FFI, Vinnova	1,45 MSEK	4,5 years (including teaching)
Real-time certification and reinforcement learning code generation for model predictive control	VR	Ca 1MSEK	5 years (including teaching)
Advanced real-time planning and decision making for autonomous systems	WASP Industrial PhD	Ca 1MSEK	5 years (including time in industry)

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

A post-doc Abhishek Dhar working in the A6 project was recruited and started at LiU on September 13, 2021.

5. Inter-university cooperation: summary for 2021

The PI has continued his collaboration with Professor Alberto Bemporad at IMT Lucca, Italy. A collaboration that has resulted in several publications at top conferences and journals. Furthermore, the PI collaborates regularly with other Swedish universities within WASP graduate school management group.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

N/A

7. Industry and institute cooperation

The PI has regular cooperation with Scania CV in motion planning under uncertainty and collaboration with Saab Dynamics within integrated motion planning and task planning. Beyond that, he is collaborating with industry within both the Automatic control project course at LiU (undergraduate level) and the WASP project course (graduate level).

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

Research problems and results are continuously being used in the Automatic control project course at LiU, where the students can use and learn the results and test them in new applications. The PI is a member of the WASP graduate school management group, which manages the WASP graduate school. Furthermore, the PI is the examiner of the WASP Project Course at graduate level, given biannually last time fall 2021 involving PhD students and industry from all over Sweden.

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

The PI participated in the recording of a video presentation to communicate the research within ELLIIT to a broader audience. The presentation was followed by a recorded cross-disciplinary panel discussion.

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

Participation in the Swedish Research Council (VR) international post-doc review panel.

12. Open source software contributions

The PI has been leading the research resulting in the open-source software contributions https://github.com/darnstrom/ASCertain.jl and https://github.com/darnstrom/daqp . The co-PI is the developer of the very well-spread open-source software package YALMIP https://yalmip.github.io/ .

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.

1. Main scientific achievements during 2021

Initial results were published based on a systematic literature study and on a multi-case study of startups (11 companies, 13 interviews). The results consist of a model of the practice of prototyping and empirically-based insights into how prototyping is used by software startups. Both publications were presented with good feedback from the community (at ESEM 2021 and RESET 2021).

2. Awards and recognitions

- Nominated for Best Paper award at ESEM 2021 for article: *A Model of Software Prototyping based on a Systematic Map*. Invited to submit an extended version of the paper to a special issue in Empirical Software Engineering Journal.
- Awarded Most Influential Paper Award at RE 2021 for article: *Requirements Are Slipping Through the Gaps — A Case Study on Causes & Effects of Communication Gaps in Large-Scale Software Development*, published at RE 2011

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.
N/A

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

N/A

5. Inter-university cooperation: summary for 2021

Collaborated with Dr Varun Gupta, University of Alcala, Spain, during Nov-21 to Feb-22, on the topic of technology-adoption factors for prototyping tools.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

N/A

7. Industry and institute cooperation

Cooperation with 11 startups companies in a multi-case study of prototyping practices.

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

Included material on prototyping in the course ETSF25 (Business of Software), mandatory for 3rd year C (Infocomm) and D (Datateknik) programmes.

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

Presented at workshop on requirements for Software startups (RESET 2021) and at conference on Empirical Software Engineering and Measurement (ESEM 2021).

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

Participated in programme committees for
- International Conference on Software Engineering (ICSE)
- International Conference on Requirements Engineering (RE): Industry track, Workshops
- International Conference on Agile Software Development (XP)
- International Conference on Evaluation and Assessment in Software Engineering (EASE)

Reviewed for scientific journals:
1. Springer Empirical Software Engineering
2. ACM Transactions on Embedded Computing Systems
3. Elsevier Information and Software Technology

12. 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 2021

The project was carried out in two parallel activities; one development part focused on the construction of a code review prototype incorporating eye-tracking, and one empirical part focused on a deepened understanding of the developer experience during code review and to what extent existing tools support the activity.

The prototype development work has been driven by two engineering students hired as research assistants (amanuenser) and supervised by Söderberg (PI) and Church (co-PI). At the end of the year the prototype had reach a point where it was a fully functioning micro-service architecture with a web-based code review client with an integrated eye-tracking sensor ready for the first round of pilot studies to inform next development phase. The prototype was presented as a poster at the ELLIIT workshop in Lund in October 2021.

The empirical study of the project was carried during 2021, with interviews in the Spring and a follow up survey in the Fall. The main result coming out of the study was a list of mismatches between the code review tool and the task, and also the code review process and the task. We saw that reviewer in code review would typically implicitly take on different roles/perspectives and with those roles they would have different questions. However, all reviewers are given the same presentation of a code change, leading some developers to regularly pay the extra cost (in terms of effort) of moving their review task to a different environment. The results from the study have been accepted for publication and are presented in two venues for empirical software engineering research during 2022 (ICSE-SEIP, EASE).

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.
N/A

4. Recruitment highlights: new hires (students, postdocs, faculty) to the project 2021

Olivia Mattsson, engineering student hired as a research assistant (amanuens)
Hedda Klintskog, engineering student hired as a research assistant (amanuens)

5. Inter-university cooperation: summary for 2021

Collaboration with BTH via Prof. Jürgen Börstler who is one of the co-PIs. This collaboration has been continuous during 2021 via regular project meetings and working meetings connected to the empirical study in the project.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

The project is structured around an inter-disciplinary core with co-PIs from several different disciplines: software technology, software engineering, human-computer interaction, and psychology. The inter-disciplinary cooperation in the project has especially strong in the empirical study which has been carried out during 2021.

7. Industry and institute cooperation

Collaboration agreement for the project with Axis communications.

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

Luke Church (co-PI) of the project, gave the first instance of a PhD course on the topic of “Programmer eXperience Centric Methods for Designing Languages and Tools” together with Emma Söderberg (PI) at Lund University.

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

Emma Söderberg (PI) talked about the project in the ELLIIT outreach activity recorded during the Fall of 2021, which included presentations and panels.

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

Emma Söderberg (PI) was the associate editor of the Programming Journal Vol 6. and the PC chair of the connected conference <Programming> 2022. She was also PC co-chair for the International Conference on Software Language Engineering (SLE) 2021 and joined both the <Programming> and the SLE steering committees.

12. Open source software contributions

N/A

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 2021

Introduction

In addition to the PI and co-PIs, Victor Fors, Theodor Westny, and Jian Zhou have been active in this ELLIIT project. Focus has been on safety and resilience in different multi-vehicle traffic situations, and the main achievements are well captured by the following three publications.

Model predictive control in multi-vehicle scenarios with inherent uncertainties

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 was submitted for publication in 2021 and has during 2022 been accepted for publication in IEEE Transactions on Intelligent Vehicles:

1. V. Fors, B. Olofsson and E. Frisk, "Resilient Branching MPC for Multi-Vehicle Traffic Scenarios Using Adversarial Disturbance Sequences," in IEEE Transactions on Intelligent Vehicles, 2022, doi: 10.1109/TIV.2022.3168772 .

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 strengths and effectiveness of the approach have been verified in highway lane-change simulation scenarios. The research has been accepted for publication at the European Control Conference 2022:

1. J. Zhou, B. Olofsson, and E. Frisk. “Interaction-Aware Moving Target Model Predictive Control for Autonomous Vehicles Motion Planning”. In: European Control Conference (ECC). Accepted for Publication. London, UK, 2022.

Learning-based intent prediction for surrounding vehicles in complex multi-vehicle scenarios

The use of learning-based methods for vehicle behavior prediction is a promising research topic. However, many publicly available data sets suffer from skews in class distribution which limit learning performance if not addressed. This research has developed an interaction-aware prediction model consisting of a Long Short-Term Memory (LSTM) autoencoder and a Support Vector Machine (SVM) classifier. Additionally, an imbalanced learning technique, the multiclass balancing ensemble has been developed. Evaluations show that the method enhances model performance, resulting in improved classification accuracy. Good generalization properties of learned models are important and therefore a generalization study has been done, where models are evaluated on unseen traffic data with dissimilar traffic behavior stemming from different road configurations. This was realized by using two distinct highway traffic recordings, the publicly available NGSIM US-101 and I80 data sets. Moreover, methods for encoding structural and static features into the learning process for improved generalization have been evaluated. The resulting methods show substantial improvements in classification as well as generalization performance. The research was presented at IEEE International Intelligent Transportation Systems Conference 2021:

1. T. Westny, E. Frisk and B. Olofsson, "Vehicle Behavior Prediction and Generalization Using Imbalanced Learning Techniques," 2021 IEEE International Intelligent Transportation Systems Conference (ITSC), 2021, pp. 2003-2010, doi: 10.1109/ITSC48978.2021.9564948.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

N/A

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

Ph.D. Victor Fors joined the project in January 2021.

5. Inter-university cooperation: summary for 2021

Significant joint research has been performed between Div. Vehicular Systems, LiU and Dept. Automatic Control, LU. Björn Olofsson (LiU, LU) is a research fellow 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). 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 2021

N/A

7. Industry and institute cooperation

1- VTI (tire models and road geometry characteristics, Dr. Sogol Kharrazi).
2- AB Berntec (efficient and safe motion planning, Dr. Karl Berntorp).
3- AB Volvo (research discussions on heavy-duty vehicle applications).

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

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

The 2nd cycle course at LiU called “Autonomous vehicles – planning, control, and learning systems” developed by Erik Frisk, Björn Olofsson, and Jan Åslund at Div. Vehicular Systems, LiU, was given the third time during the fall semester 2021. Results from this ELLIIT subproject 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. Victor Fors had a guest research lecture in the course, presenting ELLIIT research from this project.

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

N/A

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

1. Erik Frisk is director of CENIIT at LiU.
2. Lars Nielsen is a member of ELLIIT SG.
3. Lars Nielsen is a member of WASP-HS Board.
4. Lars Nielsen is a member of IPC for IFAC Advances in Automotive Control Conference 2022.

12. Open source software contributions

N/A

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 2021

The restrictions to access Electronic Healthcare Records (EHR) ensure the privacy of the patients. But, at the same time, it prevents the use of medical records for research purposes; thereby reducing the utility of the data. Synthetic data generation suggests a way to resolve this issue by preserving the sensitive information, but making it available for downstream tasks. The medical records, often consists of patient's-visits to the hospital at different time, making it a multivariate time-series data, characterized by demographic information such as race, gender, age etc. Models built on such data often include various biases and are thus unfair. To cope with these inequities, we introduce, DeMISe, a fair healthcare data generator, by De-biasing through Mutual Information reduction in a Semi-supervised framework. With DeMISe, we constrain the generator of a Generative Adversarial Network (GAN), to not retain sensitive information from the real noisy data. Additionally, a mutual information estimation module is incorporated to debias the generated distribution. Also, we have developed DeMISe-DF, a distributional subgroup-level fairness enforced model to capture the subgroup-level proportions from the real data using score-based sampling. In our experiments, we show that DeMISe and DeMISe-DF can address label bias, group bias (demographics) and representation bias in an end-to-end framework and control the bias amplification in synthetic healthcare data generation.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amount per year	Duration of project
Foundations of Trustworthy AI – Integrating Learning, Optimisation and Reasoning (TAILOR)	H2020-ICT-48	40M SEK	2020-2023
The 2D-Materials Frontier	KAW	2.4M SEK	2021-2025
Personal grant	KAW	1.2M SEK	2019-2024
WASP-ED	MMW	6,2M SEK	2022-2024
Utilitarian Combinatorial Assignment	WASP	1M SEK	2017-2021
Verification and Validation of Sequential Decision Making in Uncertain and Adversarial Environments	WASP	1M SEK	2021-2025
Multi-agent Reinforcement Learning for Collaborative Missions with Risk Management	WASP	1M SEK	2021-2025
AI transparency and consumer trust	WASP-HS	2,4M SEK	2020-2024

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

A postdoc, Dr. Resmi Ramachandran Pillai, was recruited for this project and she started June 14, 2021. She is the main person working in this project.

5. Inter-university cooperation: summary for 2021

We have been active in the EU-funded TAILOR network including contributing to the Handbook of Trustworthy AI in collaboration with University of Pisa, CNR, TU Delft, and others.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

The collaboration within the TAILOR project is inter-disciplinary. The WASP-HS project on Consumer Trust with Stefan Larsson in Lund is also interdisciplinary (he is a legal scholar).

7. Industry and institute cooperation

N/A

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

The PI, Prof. Heintz is very active at all levels of educational activities, including being the director of the Wallenberg AI and transformative technologies Education Development Program WASP-ED that started on January 1, 2022. Prof. Heintz was the main person writing the grant proposal.

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

The PI, Prof. Heintz is very actively involved in outreach activities including giving keynotes at Skolchefsföreningens conference, Läkarsällskapets etik och ansvarsråd, and the European Academy of Forensic Science Conference.

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

The PI, Prof. Heintz is a board member of the European AI Association (EurAI), the president of the Swedish AI Society (SAIS), a board member of the AI, Data and Robotics Partnership (Adra), an extended core member of CLAIRE, the general chair of the WASP Winter Conference, general chair of the TAILOR Conference, and organizer of the ELLIIT Focus Period on Hybrid AI.

12. 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 the 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 2021

- We have hired a new postdoc Xuesong Cai working on the mmWave and THz radio channel characterization. Together with the postdoc, we have secured a grant from EU Horizon under the MSCA program.
- A low complexity high resolution channel parameter estimation algorithm has been developed for the mmWave channel sounder measurement data in both static and dynamic scenarios. The main difficulty of high computational complexity caused by a large number of antenna pairs was successfully overcome.

- A paper about over-the-air channel emulation for dynamic mmWave and higher frequency bands has been accepted and published by IEEE Transactions on Antennas and Propagation. A paper focusing on power allocation for future wireless systems was submitted to IEEE Transactions on Vehicular Technology.
- By debugging the LabVIEW code, calibrating the antenna arrays, etc., we have successfully made the switched array-based mmWave channel sounder work perfectly. This channel sounder serves as the basic hardware for the development of the mirror-based THz channel sounder.

2. Awards and recognitions

See external funding.

3. External funding attracted

Horizon Europe Framework Programme, Marie Skłodowska-Curie Actions European Postdoctoral Fellowship 2021, "*Lower THz rAdio propagation channeL sounding, parameter Estimation and modeliNg Towards 6G and beyond (TALENT)*", recipient Xuesong Cai, supervisor Fredrik Tufvesson, 222727.68 EUR.

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amount per year	Duration of project
Lower THz rAdio propagation channeL sounding, parameter Estimation and modeliNg Towards 6G and beyond (TALENT)	EU Horizon Europe	55.7 kEUR/year	4 years

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

A post-doc Xuesong Cai was hired in the project formally starting in September 2021. From April to September 2021, the postdoc was also supported by the PI as a visiting researcher at Lund University.

5. Inter-university cooperation: summary for 2021

Aalborg University, Denmark, on mmWave channel characterization, over-the-air testing, as well as wireless system performance evaluation.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021
   N/A

7. Industry and institute cooperation

Technical cooperation with Ericsson AB, Lund, Sweden, on mmWave and THz channels, and scaling laws for (ultra) massive MIMO communications.

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

Contributed to the Ph.D. student training workshop of "EU H2020 MSCA ETN MINTS NWE3" with a tutorial lecture "High-resolution dynamic characterisation and modelling of mmWave and THz channels".

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

N/A

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

Organizing and chairing a special session at the seventeenth International Conference on Wireless and Mobile Communications (ICWMC 2021), Nice, France.

12. 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 2021

We have participated in courses organised by VINNOVA/MedTech4health and SweLife about ethics and laws surrounding the Digital Twins. We then stared a collaboration with the company Z2 which set up a way to store personal data so that the patient themselves request their data, which solves several legal and ethical problems. This has also led to collaborative applications with Z2. Several collaborations with the company incubator LEED have also been identified, and they are helping out with legal and practical aspects of the application, as is Julia Aman who is a assistant professor in ethics and eHealth in Switzerland. We have also received money from VINNOVA to continue developing the digital twin. A review of our hybrid methodology has been published in NeuroImage Clinical, and a first version of the model (finished in 2021) is now submitted to BioRxiv. This article is written with clinical collaborators in Gemany and Spain from our EU network. On the design side of the project, we have hired a new programmer and extended the software development, we have received more money from MeDigit, and we have been running a project where medical students interviewed physicians and other clinical personel to understand the need for digital twins/intelligent assistants. Finally, we have published 5 articles on BioRxiv. One is on the hybrid method, and the other 4 are new models, including a multi-level mouse model in collaboration with Karin Stenkula at Lund University (part of VINNOVA).

2. Awards and recognitions

N/A

3. External funding attracted

VINNOVA, MeDigit. Ongoing from VR-M, VR-NT, Horizon2020, SSF and KAW.

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amount per year	Duration of project
	Swedish Fund for Research without Animal Experiments	Approx 180 000 sek	2015–2021
”Multi-level modelling for improved drug development”	CENIIT	750 000 sek	2015-2020
Post-doc	AstraZeneca	679 000 sek	2018-2021
	SSF	800 000 sek	2018-2022
”PRECISE4Q”	H2020	822 000 sek	2018-2022
"Knowledge-driven drug development”	VR-M	80 000 sek	2019-2022
”M4Health – a foundation for general AI in healthcare”	VR-NT	Approx 1 000 000 sek	2019-2022
20% guest professorship position	Knowledge Foundation, X-HiDE	15 000 000 sek	2020-2028
	SciLifeLab and Wallenberg Foundation (KAW)	400 000 sek	2020-2021
“Usable digital twins in healthcare”	ELLIIT	1000 000 sek	2020-2021
“Digital twins in healthcare”	VINNOVA	1000 000 sek	2021-2023

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

New programmer for the Digital Twin app: Feras Faez Elias, a clinical medical PhD student Valentin Kindesjö, another PhD student to study the blood flow in the brain Gustav Magnusson, and Dr Peter Thompson to formulate analytical proofs for parameter identifiability.

5. Inter-university cooperation: summary for 2021

Lunds universitet, Ki, Örebro universitet, Göteborg/Sahlgrenska, Umeå univeristet, Gävle unversitet, Dublin Institute of Technology, Charite Universitätsmedizin in Berlin, Oxford Univerity, CUNY University of New York, NJIT New Jersey Institute of Technology, University of Auckland.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

Multiple clinics in Region Östergötland, Oxford University, Charite Universitätsmedizin in Berlin, CUNY University of New York.

7. Industry and institute cooperation

AstraZeneca, SUND and Z2.

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

We have developed a new profile within eHealth, a PhD course in systems biology, 6 french internship students to work with clinical app development, bachelor projects for one of the engineering programs (Teknisk Biologi) at Linköping University.

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

Presentation and discussion in Almedalen, contavt with pharmaceutical company in the USA, popular science lecture on eHealth in Kalmar, recording for ELLIIT, organized a workshop on inflammation and systems biology.

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

Organized a workshop on inflammation and systems biology during spring 2021.

12. Open source software contributions

All our models (including source code) are available open source after publication.

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

We focus on the task of embodied visual active learning, where an agent is set to explore a 3d environment with the goal of acquiring visual scene understanding by actively selecting views for which to request annotation. Today's deep visual recognition pipelines, while accurate on some datasets or benchmarks, tend to not generalize well to certain real-world scenarios. In robotic perception there is often a need to refine the recognition capabilities for the conditions under which the robot operates (e.g. cluttered indoor environments, poor illumination). This motivates our proposal (and new task), which can be interpreted as a form of life-long learning, where an agent's visual perception ability continually improves during its lifetime. To study embodied visual active learning in a concrete setup, we plan to develop a set of methods - both learned and pre-specified, and with different levels of knowledge of the environment - which seek to explore and acquire informative annotated views on which to train an underlying segmentation network. The learned methods would use reinforcement learning with a reward function balancing the competing objectives of task accuracy (which requires exploring the environment) and controlling the amount of annotated data requested. We plan to extensively evaluate our proposed models on the photorealistic Matterport3D simulators well as in real scenes. To the best of our knowledge this would be the first work to explores visual active learning for embodied agents navigating in realistic 3d environments. This proposal falls under ELLIIT focus theme 1 (Autonomous Vehicles and Robots) and within the Emerging Research Thrusts, Technologies, and Challenges AI, Large-scale algorithms, machine learning, deep learning, and XAI, in particular Perception-Action Learning.

1. Main scientific achievements during 2021

New methods for active visual learning of depth from single image without supervised depth, presented at International Conference on 3D Vision 2021.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amount per year	Duration of project
WASP (Industrial PhD student)	WASP (KAW) and Zenseact	600+ KSEK	2021-2026
WASP-NTU postdoc	WASP (KAW)	600+ KSEK	2021-2023
WASP (Industrial PhD student)	WASP (KAW) and Sony	600+ KSEK	2020-2022
Semantic Mapping and Visual Navigation for Smart Robots	SSF	6 200 KSEK	2016-2022
ADACORSA - Airborne data collection on resilient system architectures	EU	4 000 KSEK	2020-2023

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

Adam Tonderski (WASP+Zenseact Industrial PhD, 2021 – 2026, Lund).

5. Inter-university cooperation: summary for 2021

New collaboration between Lund University and NTU in Singapore, through WASP-NTU postdoc collaborative projects.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

N/A

7. Industry and institute cooperation

Industrial collaboration with Sony on constrastive and active learning through one WASP funded industrial PhD student projects. Industrial collaboration with Zenseact on deep learning for autonomous driving cars (through a wasp funded industrial PhD student project), collaborative project with KATAM on 3D mapping of forests and localization. Industry cooperation through numerous master's thesis projects, e g with Axis, Sony, Ericsson, Verisure, Umansense, Combain.

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

N/A

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

Popular science presentations during 2021:
Talk on talk on animal navigation "AI Lund lunch seminar: Mimicking insect navigation in a synthetic nanowire bee brain", February 3, 2021.
Kalle Åström gave a popular science presentation at Reijlers, March 19, 2021.
Workshop on Acoustics, EM, Radar and Sonar "Modern Optimization and Machine Learning in Acoustics, EM, Radar, and Sonar", May 19, 2021. https://www.ai.lu.se/2021-05-19.
Popular sciences webinar on AI, Positioning and Forestry, "Nordic AI Popup Live – AI åt skogen", November 11, 2021 with Ida Arvidsson and Kalle Åström, https://www.ai.lu.se/2021-11-11.

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

N/A

12. Open source software contributions

N/A

A15: Relation Extraction with Deep Neural Language Models

PI: Marco Kuhlmann, LiU

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 2021

We focused on understanding the mechanics of neural language models applied for relation extraction. In particular, we studied the internal representations of neural language models and tried to fine-tune them for our target task. However, due to a large number of parameters in these models, fine-tuning is

often a computationally heavy task that requires a significant amount of memory and GPU hours. Hence, instead of fine-tuning the parameters, we are currently focusing on developing methods for adapting the internal representations to our target task using a small-scale adapter network.

Our experimental results on standard data sets show that the internal representation of language models, when processed by our task-specific adapter, can significantly improve the training efficiency of standard information extraction models with no harm to the models' accuracy.

This observation led us to studying the efficient application of large neural language models in various downstream tasks in natural language processing, including question answering, sentiment analysis, semantic similarity, and token classification tasks such as part-of-speech tagging and named entity recognition. Our empirical results show that a neural language model augmented with the task-specific adaptor can be up to 30 times more efficient (in terms of GPU and memory consumption) than fine-tuning a standard neural language model. In the next step, we aim to specify the adaptor mechanism for information extraction further and explore how the general representations of neural language models are adjusted to the target task.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amount per year	Duration of project
Interpreting and Grounding Pre-Trained Representations for NLP	WASP	1,3 MSEK	2021–2024

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

Ali Basirat, started as a postdoc in the project in January 2021

5. Inter-university cooperation: summary for 2021

Within ELLIIT, we have collaborated with Lund University (Christoph Reichenbach) and Halmstad on a joint proposal in response to SSF's call Future Software Systems (not selected for funding). Within WASP, we have collaborated with Chalmers (Richard Johansson) in the project Interpreting and Grounding Pre-Trained Representations for NLP (funding 2021–2024), with Umeå University on a joint proposal for a PhD project A Practical Theory of Computation for Modern Neural Network Architectures (selected for funding, start 2022), and with KTH and Umeå University on a joint proposal for a NEST STING: Synthesis and analysis with Transducers and Invertible Neural Generators (selected for funding, start 2022).

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

As part of the project, our post-doc researcher, Ali Basirat, has contributed to interdisciplinary projects exploring meaning change in historical linguistics. The project has been conducted by Professor Michael

Boyden at the Radboud University, Netherlands, Karl Berglund, a researcher at Uppsala University, and Ali Basirat, the employed post-doc at Linkoping University.

7. Industry and institute cooperation

We are regularly supervising Master's theses at industrial partners. Specifically relevant for this project was a thesis by Lukas Borggren entitled "Automatic Categorization of News Articles with Contextualized Language Models", commissioned by Bonnier News and supervised by Ali Basirat.

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

Our group has developed a distance outreach course "AI for natural language", targeted at a general audience that includes students and professionals. The course had its first installment in Spring 2021 and has so far had almost 900 registered students.

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

(see previous point)

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

N/A

12. Open source software contributions

N/A

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 2021

The research has mainly been focused on cloud-based industrial control systems, so called Cloud Control Systems (CCS). There have been advancements both on using distributed MPC in the cloud as well as on intrusion detection mechanisms for CCS. All proposed solutions have been implemented in the Kubernetes cluster provided by the ELLIIT infrastructure at EIT, LU.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amount per year	Duration of project
IMMINENCE	Vinnova/ Celtic-Next	950 kSEK	2021-06-01—2023-05-31
SEC4FACTORY	SSF	1 MSEK	2018-04-01 – 2024-12-31
Self-driving networked systems	WASP	800 kSEK	2017-11-01 –2022-11-01

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

Emma Cuthbert, starting 2021-01-01

5. Inter-university cooperation: summary for 2021

N/A

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

N/A

7. Industry and institute cooperation

Active collaboration with Ericsson AB.

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

N/A

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

Maria Kihl - Science and Innovation talk at Tetra Pak, 2022-03-08
Maria Kihl - Presentation at IVA Syd, 2022-04-28

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

N/A

12. 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 2021

In 2021 the project focus was THz sensing and building efficient algorithms as described in the project proposal. One such algorithm is the interpolation method that improved the performance of the time-domain backprojection algorithms and another was the developed 3D THz SAR imaging algorithm aiming for short-range applications that initiated the investigation of SAR imaging algorithms for THz FMCW SAR systems. The algorithms provide efficient processing and an opportunity to reduce the sampling rate needed to process SAR data accurately (down to the Nyquist rate) and were successfully tested on real data acquired in the range [0.22, 0.33] THz. Furthermore, in parallel to this research, there has been bistatic SAR imaging research, such as bistatic SAR sidelobe control and the tilt phenomenon in bistatic SAR imaging which is the first step for multi-static setup. All this work has been published in journals or conference papers. In 2021 we also started to work on autofocusing research that is needed for good reliable multi-static sensing at THz frequencies

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amount per year	Duration of project
Radio Occultation Accuracy for Climate, Meterology, and Space Weather	Swedish Space Agency	700 000kr	2021-2023
Target Detection in SAR Imagery	CISB/CNPq/Saab	500 000kr	2021-2022

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021
   N/A

5. Inter-university cooperation: summary for 2021

(1) Intensive collaboration on the development of SAR imaging algorithms for pulse THz SAR systems during 2021 with the Institute of Digital Signal Processing, University Duisburg-Essen, Germany.
(2) In the summer of 2021, we established collaboration with Ruhr University, Bochum, Germany, on the development of SAR imaging algorithms for THz FMCW SAR systems.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

N/A

7. Industry and institute cooperation

In fall 2021, we established collaboration with 2π-Labs GmbH, a radar company in Germany. They provided us with an FMCW radar system operating in the range [0.126; 0.182] THz for the research on monostatic THz SAR. The collaboration is still ongoing and involves all ELLIIT partners Ruhr University, Bochum, Germany. The ongoing collaboration is focused on the following problems:

(1) phase error caused by FMCW radar;
(2) algorithms for FMCW THz SAR in the time and the frequency domain;
(3) experiments with SAR and ISAR;
(4) 1D interpolation for signals in the time domain, 2D and 3D interpolation for signals in the frequency domain.

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

The mm-wave FMCW radar was used in the Master in Marine Engineering to illustrate the performance of small-size radar equipment

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

THz SAR – A New Way to Monitor the World. Keynote talk at the 4th IEEE International Workshop on Mobile THz Systems (IWMTS 2021), Duisburg, Germany

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

Organization and chairing the "THz SAR" session at the 4th IEEE International Workshop on Mobile THz Systems (IWMTS 2021), Duisburg, Germany

12. 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 2021

The focus has so far been on realization of the signal processing in the frequency domain. We have developed systematic ways to shuffle data needed for streaming filters realized in the frequency domain using overlap-save and overlap-add processing. This becomes non-trivial for the general case when considering the high sample rates involved and, somewhat surprisingly, was not covered in the literature earlier.
Furthermore, we have continued our earlier work on chromatic dispersion filter design and proposed new methods, including utilizing the zero-padding usually associated with overlap processing to obtain better filtering results (supporting longer fibres/using shorter FFT lengths). As part of this, we have worked on models for overlap-save and overlap-add processing under finite word length conditions (as these lead to time-invariant impulse responses). Another aspect that has been considered is the numerical stability for the design process where we have proposed a simple method to drastically improve the quality of the solution.
Finally, we have considered word length optimization for implementation of frequency-domain filtering, which shows that there are benefits in selecting heterogenous word lengths for data, FFT twiddle factors and filter coefficient multiplications, respectively.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amount per year	Duration of project
Large Intelligent Surfaces Architecture and Hardware	SSF	6.5 MSEK	2021-2025
Calibration of Time-Interleaved ADCs	Huawei	1 MSEK	2020-2022
Array antennas for SatCom applications on mobile platforms	Vinnova	600 kSEK	2019-2021
Receiver linearization techniques	Huawei	800 kSEK	2021-2023

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

Postdoc Krishna Chaitanya Patchava recruited and started in July 2021. Unfortunately, he announced his exit towards the end of the year for an industry position and left the postdoc position in January 2022. A new recruitment is ongoing.

5. Inter-university cooperation: summary for 2021

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 2021

N/A

7. Industry and institute cooperation

Discussions have been ongoing with Huawei for a project related to optical communication, but it ended up in another subject area.

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

One thesis project related to the project was started, focusing on digital backpropagation.
Results and insights from the area are often used as examples in relevant courses. Especially, the shear computational requirements involved, but also the benefits of realizing complex FIR filters in the frequency domain.

The PI has been involved in the program board of the Applied Physics and Electrical Engineering (Y) program.

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

N/A

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

N/A

12. Open source software contributions

N/A

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 2021

The project did not start until the beginning of June, due to slow handling of work permits at the Swedish Migration Agency. During the first half year of this exploratory project, the work focused on surveying existing literature and exploring the concepts of the project.

"A Literature Survey of Assertions in Software Testing" identified 95 papers related to the project, which were classified into three major themes – assertion problems, solutions, and evaluation. The manuscript was submitted to a conference but unfortunately not accepted, asking for more detail about the work. It will be revised and submitted to a more feasible venue that allows for space for such considerations.

Secondly, the approach to near failure assertions was discussed within the project and with Dr. Christoph Reichenbach at LTH. We explored potential use of language technology tools to identify near failure issues. The work lead to an exploration of existing tools, including Java Path Finder.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.
N/A

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

Dr. Masoumeh Taromirad was hired as a postdoc, beginning June 1, 2021.

5. Inter-university cooperation: summary for 2021

Project members participated in the LTH-BTH collaboration meeting on software, co-organized at the ELLIIT workshop in October.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

N/A

7. Industry and institute cooperation

A master thesis project at Axis was conducted on “Optimizing regression benchmarking for network video products”, by Thomas Rodenberg. This project was more about large scale regression testing in general, rather than the near-failure concepts.
https://lup.lub.lu.se/student-papers/search/publication/9076590

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

N/A

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

N/A

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

N/A

12. Open source software contributions

N/A

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 2021

We have looked at the applied side of things in a master thesis project with supervisors funded in this project and at the theoretical side of things with a postdoc (1 year) and PhD student (1 year) funded by this project.

For the master thesis project available via
https://lup.lub.lu.se/student-papers/search/publication/9064517

we found via numerical examples that SGD and the Adam training algorithm that many use for training of generative adversarial networks are less robust and stable than the alternative training algorithms stochastic optimistic gradient descent and the stochastic extra-gradient method. However, once a setup was found for which all algorithms converged, the best performance between the methods were not distinguishable. Therefore, using different methods than the usual one, stability and robustness can be improved while not sacrificing performance.

These methods do not have a satisfactory theoretical analysis of the nonconvex-nonconcave and nonsmooth setting that GAN training is. We have made significant theoretical contributions to the understanding of these methods in the more restrictive convex-concave but nonsmooth setting in
https://arxiv.org/abs/2112.00481

This is an extension of another recent paper by the proper of this program in https://arxiv.org/abs/1908.07449 (that is published in SIAM Journal on Optimization)

These ideas have later also made its way into analysis of similar algorithms for some nonconvex-nonconcave problems by other authors, but with assumptions still not general enough for the GAN training setting. In summary, we have contributed to the understanding of this training process, but it is not yet fully understood.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amount per year	Duration of project
Joint postdoc program Linköping-Lund, 2 postdocs per group.	WASP	2MSEK	2 years
WASP PhD student	WASP	1MSEK	4 years
VR etableringsbidrag	VR	1MSEK	4 years

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

N/A

5. Inter-university cooperation: summary for 2021

N/A

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

N/A

7. Industry and institute cooperation

N/A

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

Continued development of course on optimization for learning for LTH engineering students.

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

N/A

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

N/A

12. Open source software contributions

N/A

A21: Protecting software against side-channel leakage

PI: Thomas Johansson, LU

Summary

We intend to 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 2021

During the initial part of this project, the work was first directed towards surveying existing literature and learning about useful tools. The postdoc has since been working on a cache-timing attack on the HQC algorithm, an alternate candidate for standardization by NIST. Furthermore, he has also been investigating the implementation of a side-channel protected version of the Grain128AEAD stream cipher, a finalist in the NIST LWC project for future standardization.

We also published results on how to use timing weaknesses in implementations of rejection sampling, a step used in many cryptographic algorithms, to find secret keys etc.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amount per year	Duration of project
Sårbarheter och hotanalys från sidokanaler med maskininlärning i fokus (PI: Dubrova)	MSB	1MSEK	2021-2025

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

Postdoc Senyang Huang started April 2021.

5. Inter-university cooperation: summary for 2021

N/A

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

N/A

7. Industry and institute cooperation

N/A

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

Prepared the course plan for a new course Advanced Cryptology to be given 2022.

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

N/A

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

Thomas Johansson serves as editor for IEEE Trans. On Information Theory.

12. Open source software contributions

N/A

A22: Human Interaction with Autonomous Minibuses (HIAM)

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

Summary

The proposed project is a collaboration between the Cognition & Interaction Lab at IDA/LiU (PI: Tom Ziemke) and human factors researchers at VTI1 (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 is already operating on Campus Valla since late 2019 (with initial funding from LiU and VTI, among others) now 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 will carry out initial empirical studies of how people interact with the minibuses (through behavioral observations, questionnaires, in-depth interviews, etc.), but will in particular focus on the development of a toolbox of suitable 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. It should also be noted that the proposed project is very much in line with LiU and VTI's strategic collaboration (Ziemke and Anund are members of the operative collaboration group), which aims to promote long-term mutual development and competitiveness.

1. Main scientific achievements during 2021

The postdoc recruited to work on the project (Sam Thellman) started 1 January 2022. The work in the project builds on Thellman's PhD thesis "Social Robots and Intentional Agents" which was defended in November 2021. This includes a large systematic review of 155 empirical studies on how people interpret of robot behavior in the context of human-robot interaction (to be published in the ACM Transactions on Human-Robot Interaction in 2022). This work also constitutes the basis for the work on human interaction with autonomous minibuses in this project.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of related external projects that were active at some point during 2021.

Project title	Funding source	Granted amount per year	Duration of project
Human Interaction with Systems-of-Systems SSF	SSF	N/A (funding for RISE PhD student)	2019-2024

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

The postdoc recruited to work on the project (Sam Thellman) started 1 January 2022.

5. Inter-university cooperation: summary for 2021

The work mentioned under heading 1. was carried out in collaboration with Maartje de Graaf at the University of Utrecht, Netherlands.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

The project is a collaboration between researchers in social robotics, cognitive science, automated vehicles, and traffic psychology at LiU and VTI.

7. Industry and institute cooperation

The project is carried out in collaboration between LiU (Ziemke, Thellman) and VTI (Anund, Andersson).

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

The research on human interaction with autonomous vehicles contributed to PhD and masters courses on *"Ethics of AI and Interactive Autonomous Systems"* (autumn 2021).

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

N/A

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

Ziemke guest-edited a special issue on *"Explainable Robot Behavior"* for the journal *ACM Transactions on Human-Robot Interaction*, together with Maartje de Graaf (Utrecht University), Bertram Malle (Brown University) and Anca Dragan (UC Berkeley), which was published in July 2021.

Ziemke was technical 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.

12. 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 2021

At LiU we focused on fundamental algorithmic aspects of ultra-reliable low-latency communications and particularly grant-free multiple access (GFMA). As a main building block of the fifth-generation (5G) and beyond wireless networks, ultra-reliable low-latency communication (URLLC) is expected to enable real-time operations in various critical application scenarios, e.g., remote surgery, industrial automation, and self-driving. An important component towards this end is GFMA -introduced to improve the overall latency performance, by allowing an active device to directly transmit its payload data together with the metadata (pilot/preamble and other signaling) to the BS without waiting for any transmission permission.

Although GFMA can potentially provide much lower latency by reducing the handshake signaling, a failed access attempt costs more radio resources and induces larger delay. Meanwhile, since the devices cannot receive any centralized scheduling during random access, the random access channel capacity, in terms of the number of simultaneous successful accesses, is generally much smaller than the number of available orthogonal pilots. We developed a decentralized control framework, which enables devices to make cooperative decisions with only partial information of the network traffic, by using multi-agent policy optimization (MAPO) from reinforcement learning category. Specifically in a paper published at Asilomar 2021, we considered a dynamic GFMA system, where each device receives data packets associated with some pre-determined deadline randomly in each time slot. We formulated the pilot selection problem as a stochastic network optimization problem for minimizing the average packet drop rate with some fairness/reliability constraints and showed that this stochastic problem can be solved in real-time with global information and proper approximations. A model-aware MAPO algorithm was then developed to learn the decentralized multi-agent pilot selection policy by incorporating the model knowledge.

At LU we worked a lot on channel characterization both at millimeter wave bands and at lover frequencies with the aim to understand critical aspects of beamforming for ultra-reliable communication. We have implemented an upconverter system of our testbed LuMaMi to investigate hybrid millimeter wave beamforming in practice and worked experimentally with beam forming for a reconfigurable intelligent surface. The latter work was presented at Globecom in Spain in December. In the lower bands we have investigated the potential for massive MIMO below 1 GHz in cooperation with KU Leuven in Belgium. To our best knowledge this is the first experimental investigation of the potential of using massive MIMO below 1 GHz for achieving efficient and reliable communication.

A major achievement was also the publication of a joint paper in the prestigious IEEE proceedings "6G Wireless Systems: Vision, Requirements, Challenges, Insights, and Opportunities," by H. Tataria, M. Shafi, A. F. Molisch, M. Dohler, H. Sjöland and F. Tufvesson. It was the most downloaded paper at the whole IEEE Explore for a couple of months when it was released.

1.1. Plans for 2022

At LiU we will continue the track with MAPO algorithms for GFMA. We will also develop new algorithms for activity detection. Much of this work will be in synergy with the efforts in H2020-REINDEER.
At LU we will continue investigating the potential for ultra-reliable communication with sub-6 GHz massive MIMO, but also target reliable communication and understanding of dynamic processes at millimeter wave bands

2. Awards and recognitions

Erik G. Larsson won the "Gyllene Moroten" (golden carrot) best teacher award 2021 by LinTek, the Engineering College student union at LiU.

Erik G. Larsson was elected to the Royal Swedish Academy of Sciences (KVA).

Fredrik Tufvesson got an IEEE Communication Society Best tutorial paper award for the paper “"5G: A Tutorial Overview of Standards, Trials, Challenges, Deployment, and Practice,"

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amount per year	Duration of project
REINDEER	EU/H2020		2021-2024
SURPRISE (cyber security call)	SSF	1.12 MSEK	2018-2022
Wireless Communications and Sensing Wallenberg Technology Beyond 5G	Wallenberg scholar/KAW	3.6 MSEK	2020-2024
Adversarial attacks on the wireless physical layer	VR	1 MSEK	2020-2023
Commissioned research (LiU)	Ericsson	1.2 MSEK	2021-2022
Commissioned research (LU)	Ericsson		2019-2023
Large Intelligent Surfaces Architecture and Hardware	SSF	6.5 MSEK	2021-2025
MINTS, Millimeter-wave NeTworking and Sensing for Beyond 5G	EU H2020	1.5 MSEK	2020-2024
5G-SMART, 5G for smart manufacturing	EU H2020	900 kSEK	2019-2022
Optimizing Radio Access Networks for efficient massive MIMO operation	SSF	500 kSEK	2019-2023

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

New students at LiU: Jianan Bai, working in this project.
New postdocs at LiU: Sarvendranath Rimalapudi.

5. Inter-university cooperation: summary for 2021

An important contribution co-authored by ELLIIT researchers from LiU and LU was

B. R. Manoj, G. Tian, S. Gunnarsson, F. Tufvesson and E. G. Larsson, "Sensing and classification using massive MIMO: A tensor decomposition-based approach," IEEE Wireless Communications Letters, vol. 10, pp. 2649–2653, Dec. 2021.

The paper explored how a massive MIMO antenna array can be used to classify activities in a room based on received radio signals and their time-variation.

Some preliminary results were presented in

B.R.Manoj, G.Tian, S.Gunnarsson, F.Tufvesson and E.G.Larsson,"Moving object classification with a sub-6 GHz massive MIMO array using real data," in Proc. of IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), June 2021.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

We worked in tight cooperation with B2, Baseband Processing for Beyond 5G Wireless; B5, 6G wireless, sub-project: vehicular communications and B11, Local Positioning Systems

7. Industry and institute cooperation

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.
LU has a large bilateral agreement with Ericsson working on Massive MIMO technologies and applications targeting both channel characterization, positioning, machine learning, algorithms and hardware realizations. LU is also working in collaboration with Sony, especially on the aspect of millimeter wave communication and reflective intelligent surfaces. LU has one industrial PhD student working in the area.

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

New specialization in data science on the electrical engineering and applied physics (Y) five-year degree program at LiU started in 2020, the first cohort are now in their final year and most of them started master thesis work in the spring of 2022. This profile also includes the new course TSKS33.

On June 18, 2021, Amin Ghazanfari successfully defended his Ph.D. thesis "Multi-Cell Massive MIMO: Power Control and Channel Estimation".

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

The Wireless Future podcast hosted by Erik G. Larsson and former ELLIIT recruited faculty Emil Björnson proves to be a major success, with many of the episodes having thousands of views, and many high-profile international guests,
https://www.youtube.com/playlist?list=PLTv48TzNRhaKqYJlNucvpaN6Mr8Slkk8Z

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

Erik G. Larsson continued to serve as editorial board member for the IEEE Signal Processing Magazine and on the steering committee of the IEEE Transactions on Wireless communications.

Erik G. Larsson co-edited two journal special issues published in 2021:

L. Liu, E. G. Larsson, P. Popovski, G. Caire, X. Chen and S. R. Khosravirad, “Massive machine-type communications for IoT,” IEEE Wireless Communications Magazine, 2021.

X. Chen, D. W. Kwan Ng, W. Yu, E. G. Larsson, N. Al-Dhahir and R. Schober, “Massive access for 5G and Beyond” (Parts I and II), IEEE Journal on Selected Areas in Communications, 2021.

12. Open source software contributions

LU is a contributor and is maintaining the COST 2100 channel model.

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 2021

Subtopic: Distributed processing algorithms and hardware architectures

* Distributed and scalable uplink detection for active Large Intelligent Surfaces (LIS): LIS consists of a continuous radiating surface located in the proximity of the users. In order to address the challenges of very high interconnection data rate and data storage requirements, hierarchical architectures with distributed processing techniques are investigated, while ensuring scalability. Algorithm-architecture codesign is performed to propose two distributed interference cancellation algorithms, and a tree-based interconnection topology for uplink processing. We also analyzed the performance, hardware requirements, and architecture trade-offs for a discrete LIS, in order to provide concrete case studies and guidelines for efficient implementation of LIS systems.
[Publication: Jesus Rodriguez Sanchez, Fredrik Rusek, Ove Edfors and Liang Liu, "Distributed and Scalable Uplink Processing for LIS: Algorithm, Architecture, and Design Trade-offs", IEEE Transactions on Signal Processing.]

* Positioning for Distributed Large Intelligent Surfaces using Neural Network with Probabilistic Layer: We explored channel state information (CSI)-based fingerprinting via neural networks (NNs) to offer high accuracy positioning service. Moreover, we investigated distributed positioning algorithms and architectures for LIS, that the same infrastructure can be used for both communication and positioning. In the developed method, distributed panels of the LIS provide a parameterized probability density function for the location of each user, which can be shared conveniently and fused in different panels or a central processing unit (CPU), providing high positioning accuracy using very low interconnection bandwidth.
[Publication: Jesus Rodriguez Sanchez, Ove Edfors and Liang Liu, "Positioning for Distributed Large Intelligent Surfaces using Neural Network with Probabilistic Layer," in IEEE Global Communications Conference Workshops (Globecom Workshops), 2021.]

Subtopic: Digital error mitigation of analog circuits

Primarily two contributions:

*We have initiated work on linearization of analog-to-digital converters (ADCs) using convolutional neural networks (CNNs). Preliminary results are promising and show that the use of CNNs for linearization can outperform regular memory-polynomial-based linearizers. The first results will be presented in a conference paper [P1].

[P1] D. Rodriguez Linares and H. Johansson, "Linearization of weakly nonlinear systems using one-layer convolutional neural networks", in preparation for submission to the conference IEEE ICECS, Glasgow, Oct. 24-26, 2022.

*We have shown 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 [P2] has been accepted for publication in IEEE Trans. Signal Processing.

[P2] 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, 15 pages, accepted for publication. doi: 10.1109/TSP.2022.3174407.

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

*We have recruited a new PhD student to work on the project. Since the PhD student is new, it took some time to learn about ongoing research and participate in research activities. The team at Halmstad University is building expertise in the topic as we are all starting the project this year.

* We started a study about enhancing the accuracy and the performance of CSI-based position in Massive MIMO using machine learning. Throughout the process different neural network architectures and model compression techniques were explored. The final results will be published in a paper during the next year.

1.1. Plans for 2022

. Regarding the digital error mitigation, we plan to continue our work on CNNs for linearization, and then to extend it to predistortion, in particular for massive MIMO systems. This is a topic that Lund University and Linköping University will work together.

. Regarding the distributed algorithms and architectures for distributed massive MIMO systems, we plan to continue develop unified architectures for both communication and positioning. Together with other projects, we will also develop a demonstrator for the system based on the Xilinx RFSoC platform.

. Regarding the high-level design methodologies using distributed many-core processor architectures, we plan to continue to explore improving the performance of various algorithms related to distributed massive MIMO using both parallelism and architectural optimization. Halmstad University will work closely with Lund University on this topic.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amount per year	Duration of project
Array antennas for SatCom applications on mobile platforms	Vinnova	2 MSEK (600 kSEK for LiU)	Aug. 2019 - Aug. 2021
Calibration of Time-Interleaved Analog-to-Digital Converters	Huawei	1 MSEK	Jan. 2020 – June 2021
Massive MIMO technology and application	Ericsson	1 post-doc and PhD students in digital baseband processing	2018-2022
BEYOND5	EU ECSEL/Vinnova	~2 MSEK for ULUND	2020-2023
Large Intelligent Surfaces – Architecture and Hardware	SSF	~6 MSEK	2021-2025
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

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

At LiU, Ph.D student Deijany Rodriguez Linares was hired in April 2021.

5. Inter-university cooperation: summary for 2021

Besides the inter-university cooperation within the ELLIIT project, the following inter-university cooperation on digital baseband processing for Beyond 5G are summarized:
Within the EU project REINDEER, Lund University is together with Linköping University, KU LEUVEN, TU Graz working 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 2021

The collaboration between the department of electrical and information technology (EIT) and the department of mathematics at Lund University on vision-based positioning algorithms and hardware is

worthwhile to be mentioned. Now the collaboration has been further developed to explore accurate positioning serves using both vision and radio sensors.

7. Industry and institute cooperation

LiU cooperated with the companies RequTech and Forsway in the Vinnova-project “Array antennas for SatCom applications on mobile platforms” (Aug. 2019 – Aug. 2021) and with Huawei in the project “Calibration of Time-Interleaved Analog-to-Digital Converters” (Jan. 2020 – June 2022).

Lund university: The industry partners in the EU project REINDEER are Ericsson, Technikon, NXP, Telefonica. Within BEYOND5, Lund University is working closely with Ericsson, GlobalFoundries, Leti, MRK-IC.

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

Baseband processing and implementation for massive MIMO is an important case study for courses (LU-EITF35) Introduction to Structured VLSI Design and Computer Architecture, where Liang Liu is the course coordinator. Liang Liu is also giving invited lecture “Digital Signal Processing for Wireless Communication Systems” in the course DSP-Design at LTH. Liang Liu serves as the programme director of the international master programme Embedded Electroncis Engineering at Lund University.

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

N/A

11. 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. Liang Liu organized a special issue on “Circuits, Systems, and Algorithms for Beyond 5G and Toward 6G” for IEEE Open Journal on Circuits and Systems and served a guest editor.

12. 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 2021

-System design platform for sub-THz beamforming receivers

Rikard Gannedahl, Javad Bagheri, Henrik Sjöland, Christer Svensson, Atila Alvandpour

We are developing a sophisticated system model for direct-conversion sub-THz receivers with hybrid beamforming using Simulink and MATLAB. Although there already exist several system models, they typically treat the receiver and converter as a block with a single NF, IP3 etc., giving limited insight to a circuit designer. In this project, we instead use a higher fidelity, modelling the non-idealities of each sub-block, such as LNA, oscillator, sample-and-hold, ADC etc. Using this, we intend to find bottlenecks and performance limits in the receiver system and present an example circuit that could possibly be implemented in the future of the project. So far, we have implemented a Simulink model of a working 4-element antenna array, an ADC, and a simple digital baseband. Non-idealities, such as NF, IIP3, phase noise, phase shifter resolution, ADC resolution etc., can easily be modified in each block. We aim to use the developed 4-element array architecture as a building block to design and study the challenges and limitations for large array systems. We expect to submit a paper on this work in autumn 2022.

-Analog baseband filters for multi-GHz channels

Rikard Gannedahl, Henrik Sjöland

We have been working on analog baseband filters for multi-GHz channels. The idea is to compare several implementations of filters, both active and passive, to find the optimal choice for the receiver described above. An IC was supposed to be taped out now in May, but it got postponed to July. We expect to receive the fabricated chip for measurement in autumn 2022. Furthermore, Rikard Gannedahl will start working on an oscillator system with built-in phase shifter, which will utilize the knowledge and results from the joint system design work described above.

-Wideband energy-efficient data converters (ADCs and DACs)

Javad Bagheri, Atila Alvandpour

We have been working on a pipeline ADC based utilizing a novel parallel amplifier architecture that allows higher sampling rate and linearity in design of a pipeline ADC. A prototype chip was planned to be taped out in July but has been postponed to September (due to changes in fabrication schedule from the CMOS foundry). We are expecting to receive the fabricated chip for measurements in late autumn 2022.

Oscar Morales, Jacob Wikner, Atila Alvandpour
We have done several research work and studies on design of high-speed DACs. This includes: (i) chip design and evaluation of a high speed binary weighted DAC which is currently under measurements, (ii) a detailed analysis of power consumption bound in high speed DACs (publish in Journal of Analog Integrated Circuits and Systems 2022), as well as a comparative analysis of CMOS latch-driver circuits for current-steering digital-to-analog converters (accepted for publication in IEEE Mixed Design of Integrated Circuits and Systems Conference 2022).

Publications

R. Gannedahl and H. Sjöland, "An LO Frequency Tripler with Phase Shifter and Detector in 28nm FD-SOI CMOS for 28-GHz Transceivers," 2021 IEEE Nordic Circuits and Systems Conference (NorCAS), 2021, pp. 1-7, doi: 10.1109/NorCAS53631.2021.9599854.

T. Sundström, J. B. Asli, C. Svensson and A. Alvandpour, "A 10b 1GS/s Inverter-Based Pipeline ADC in 65nm CMOS," 2020 IEEE Nordic Circuits and Systems Conference (NorCAS), 2020, pp. 1-4, doi: 10.1109/NorCAS51424.2020.9264994.

O. Morales, J. Wikner, C. Svensson, A. Alvandpour, Liter Siek, “Analysis of Energy Consumption Bounds in CMOS Current-Steering Digital-to-Analog Converters.” in Journal of Analog Integrated Circuits and Systems 2022.

O. Morales, J. Wikner, A. Alvandpour, Liter Siek, “A comparative analysis of CMOS latch-driver circuits for current-steering digital-to-analog converters”, accepted at IEEE Mixed Design of Integrated Circuits and Systems Conference 2022.

1.1. Plans for 2022

1. Continue the research and development of our system model for direct-conversion sub-THz receivers with hybrid beamforming using Simulink and MATLAB.
2. Research and development of an oscillator system with built-in phase shifter, which will utilize the knowledge and results from the joint system design work.
3. Completing the prototype chip design, chip fabrication, and measurements of the developed wideband ADC.
4. Research, development, and design of a new low-power high-speed ADC based on a highly novel and promising solution.

2. Awards and recognitions

NA

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

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

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

N/A

5. Inter-university cooperation: summary for 2021

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.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

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.

The VINNOVA project between SAAB, Ericsson and LU with the title “DREW – Digital Receivers that are Extremely Wideband”. The project is a close collaboration between SAAB in Järfälla, Ericsson in Lund, and the Integrated Electronic Systems group at Lund University, jointly addressing RFIC design, mixed-signal IC design, building practises for wideband systems, board design, and development of a joint demonstrator.

7. Industry and institute cooperation

There has been continued strong cooperation with industry in SoS, the Industrial Research Center for System Design on Silicon in Lund. There has also been strong cooperation in the 5G power amplifier project (Sändarlösning för 5G Massive MIMO system) in close collaboration between LU and Ericsson.

The VINNOVA project between SAAB and LiU with the title "Next generation distributed processing platform for sensor signal and avionics data processing", made significant progress, including detailed system studies about next generations airborne radars and counter measure systems (Electronic Warfare, EW), including the ongoing development and chip design for our new wideband data converters which is also partially funded by ELLIIT.
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 two industrial PhD students are Imad ud Din and Christian Elgaard.

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

Atila Alvandpour has been responsible for Analog CMOS Integrated Circuits course and the VLSI chip design course at LiU. He has also been the director of LiU international master program in Electronics Engineering. In close cooperation with teachers and LiU education board, the program and course material are continually being evaluated and updated to include latest knowledge as well as some research results generated from projects funded by ELLIIT, particularly in design of energy-efficient radio frequency and mixed analog-digital CMOS integrated circuits.
Henrik Sjöland is responsible for the course Integrated Radio Electronics, which is an advanced course merging the IC design and radio electronics topics. It is close to the research performed in ELLIIT funded projects, and project results are continuously included in different parts of the course.

10. 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/ Formas national SIO program, 'Smartare elektroniksystems'. The competence hub aims to establish strong national network, joint collaboration, and research projects between and within electronics industry and Universities in Sweden.

11. 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.
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).

12. Open source software contributions

N/A

B4: 5G Security

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

Summary

Applications deployed with 5G will be facing several new security challenges. This project will span a variety of research activities in 5G 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 security solutions. We also consider proofs for security of protocols and cross layer analysis of security as well as security mechanisms for 5G 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 2021

We work initially on analysing the security functions in recent 5G technologies such as authentication, confidentiality and integrity. The new 5G system brings high demands on cryptographic algorithms used for air encryption. Together with Ericsson Research we have revised the design of SNOW 3G and updated it to a new faster cipher called SNOW-V, which could be used to secure 5G and the coming mobile systems. 5G brings new challenges that will affect the air encryption algorithms. Most components of 5G will be virtualized, including ciphering layers; 5G is expected to operate at a very high speed, at least 20Gbps; 5G is expected to raise the security to a 256-bit level in order to mitigate future advances in cryptanalysis (quantum attacks, for example).

We also propose and analyse a faster variant of SNOW-V, called SNOW-Vi, that can reach the targeted speeds for 5G in a software implementation on a larger variety of CPU architectures. SNOW-Vi differs in the way how the LFSR is updated and also introduces a new location of one of the LFSR taps for stronger security, while everything else is kept the same as in SNOW-V. The throughput in a software environment is increased by around 50% in average, up to 92 Gbps. This makes the applicability of the cipher much wider and more use cases are covered.

In further work on cryptanalysis, we have investigated and proposed improved guess-and-determine and distinguishing attacks on SNOW-V. These attacks do not threaten SNOW-V, but provide more in-depth details for understanding its security and give new ideas for cryptanalysis of other ciphers.

1.1. Plans for 2022

We will continue to investigate the security algorithms around 5G IoT applications and how the low latency condition in some use cases influences the algorithmic design.
We will investigate the security protocol side of the URLLC use case and how various security solutions match up the required performance.

URLLC devices may be deployed and operated in unattended environments and managed remotely. Due to this, those devices are susceptible to malicious attacks also from side-channel analysis. We investigate how to equip devices with more intrinsic security functionalities for URLLC services.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amount per year	Duration of project
Side-channel attacks in software in autonomous systems	WASP	0.8MSEK	2018-2022
Lightweight Cryptography for Autonomous Vehicles	WASP-NTU	1MSEK	2020-2023
Analysis of emerging cryp-tographic algorithms in a post-quantum setting	VR	1MSEK	2020-2023
Side-Channel Vulnerability and Threat Analysis with Machine Learning Awareness [PI: E. Dubrova]	MSB	1MSEK	2021-2025
SURPRISE: Secure and private connectivity in smart environments [PI: P. Papadimitratos]	SSF	1.1MSEK	2018-2023

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

Phd student Milad Seddigh, LU (have not started since he is still waiting for Migrationsverket, since almost 1 year now)
Phd student Navya Sivaraman, LiU (started September 2021)

5. Inter-university cooperation: summary for 2021

This project includes close collaboration and joint research work between the project partners from Lund and LiU. As the PhD student were not present due to long delays with Migrationsverket, the collaboration has taken place as discussion meetings between PIs.
Collaborative research with other universities is frequent, including the project “Side-Channel Vulnerability and Threat Analysis with Machine Learning” with KTH, resulting in several joint publications in 2021. Also work with researchers from TU Wien on a similar topic has resulted in interesting results.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

N/A

7. Industry and institute cooperation

Collaborative work and joint publications with Ericsson Research.

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

Planning work on a new course Advance Cryptography, to be given next year

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

Thomas Johansson invited speaker on Advenica Insight.
LU is submitter of the Grain-128AEAD stream cipher to the NIST Lighweight Standardization project where it has advance to finalist, https://csrc.nist.gov/Projects/lightweight-cryptography/finalists

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

Thomas Johansson is Associate Editor in IEEE Trans. on Information Theory.

12. Open source software contributions

Some research-related software is publicly available through Github.

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

PI: Alexey Vinel, HH
Co-PIs: Maria Kihl, LU and Johan Thunberg, HH

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 fulfill more global traffic requirements in, for example, a city. We will enhance the vehicular networking concepts of cooperative awareness (when vehicles exchange information about themselves), collective perception (when vehicles exchange information about objects they have observed by their local sensors) and cooperative maneuvering (when vehicles exchange their trajectories and intentions) to achieve the degrees of flexibility required for the designed decision-making algorithms.

1. Main scientific achievements during 2021

A platoon comprises a string of consecutive highly automated vehicles traveling together. Platooning allows for increased road utilization and reduced fuel consumption due to short inter-vehicular distances. Safety in terms of guaranteeing no rear-end collisions is of utmost importance for platooning systems to be deployed in practice.

We (HH and LU, together with Volvo Autonomous Solutions) compared how safely emergency braking can be handled by emerging vehicle-to-vehicle communications on the one hand and by radar-based measurements of existing automatic emergency braking systems (AEBS) on the other. We showed that even under conservative assumptions on the inter-vehicular communications, such an approach significantly outperforms AEBS with an ideal radar sensor in terms of allowed inter-vehicle distances and response times.

Furthermore, we designed two emergency braking strategies for platooning based on inter-vehicular communications. The first braking strategy assumed centralized coordination by the leading vehicle and exploits necessary optimal conditions of a constrained optimization problem, whereas the second – the more conservative solution – assumed only local information and is distributed in nature. Further, we (together with EVAM) outlined the system design of an emergency warning system that makes use of vehicle-to-traffic light communications. The results show that it is highly effective in reducing trip times as well as increasing the overall safety of emergency vehicles.

Also, at LU, there was research on autonomous intersection management (AIM) systems for cooperative vehicles. Here, a hierarchical AIM system was a proposed. The AIM system consists of two control layers, a local and a global. The local control layer in each vehicle is responsible for the movement of the vehicle, and uses sensors in the vehicle to avoid collisions. The global layer placed in the intersection, optimizes the traffic flow in the intersection and gives each vehicle detailed speed instructions. In this way, there is no need for traffic lights in the intersection.

1.1. Plans for 2022

We plan to expand on our previous results in the following directions:

- Analysis on safety and efficiency when using adaptive cruise control and inter-vehicle communication jointly in complex traffic situations. This includes the basic cases of longitudinal and lateral safety for two vehicles, but also involves more complex scenarios such as road intersections and lane merging.
- Further, an analysis is to be done on information redundancy mitigation for collective perception. Such results may then be used as a component to meet objectives on safety and efficiency in cooperative driving scenarios.
- Also, there is a plan for conducting an analysis of age of information in IEEE 802.11p networks with bursty update traffic.
- Further, we will continue our work on cooperative vehicle control systems, where the main focus will be on connectivity and position requirements.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amount per year	Duration of project
Emergency Vehicle Traffic Light Pre-emption in Cities, EPIC	VINNOVA	2.8 MSEK/ 2 years	2020-2022

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

Felipe Valle was hired as a PhD-student at HH (co-supervisors – Maria Kihl, Johan Thunberg, Martin Cooney, Alexey Vinel).

5. Inter-university cooperation: summary for 2021

- HH (Thunberg) and LU (Fedorov) - joint paper, IEEE Transactions in Vehicular Technology: see “Main Scientific Achievements”.

- LU (Tufvesson) and HH (Vinel), WSA 2021: Vehicular networks allow for a variety of applications ranging from platooning to fully automated driving. Most of such applications require the vehicles that constitute the networks to be aware of their relative or absolute position as well as the position of nearby vehicles. To this end, multiple positioning methods can be employed, among

such methods are Global Positioning Systems or methods that employ time delay of arrival. This work presents a localization method that employs a dual polarized antenna at the transmitter and receiver side of wireless communications in vehicular networks. The proposed approach does not increase network load as it does not require extra data packets to be sent for localization purposes, and can be used to mitigate position spoofing inside the network. The accuracy and reliability of the proposed method are measured trough a set of numerical simulations, showing sufficient performance for acting as a secondary positioning mechanism capable of providing improved security and reliability to the network.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

There is significant joint work with B01 when it comes to channel characterization, modelling and simulations for vehicular networks.

7. Industry and institute cooperation

Volvo Autonomous Solutions (joint paper, IEEE Transactions on Vehicular Technology) and EVAM (joint paper, IEEE Access).
Joint FFI project with Volvo cars, AB Volvo, RISE, RanLOS “Simulation and verification of wireless technologies”

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

N/A

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

Alexey Vinel (HH) – keynote speaker at International Workshop on Beyond 5G Support for the Future Vehicular Networks (IEEE PIMRC 2021 conference).

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

Alexey Vinel (HH) - Specialty Chief Editor for Connected Mobility and Automation at Frontiers in Future Transportation.

12. 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 2021

We have studied several issues related to outsourcing a control application to the cloud and the robustness and security challenges implied by such an approach.
Focusing on robust control applications, we have researched how to online design and deploy a timing-robust controller in the cloud. To facilitate fast online LQG controller synthesis via optimization, we have translated the open-source toolbox JitterTime from Matlab to Julia. The main design idea is to collect timing data during runtime (loop latencies and lost packets) and use this data to evaluate the expected control performance as a function of the controller parameters. Utilizing the automatic differentiation capabilities of Julia, numerical optimization is used to derive a robust and well-performance controller. Closed-loop cloud control experiments have been conducted using the Ericsson Research Data Center (ERDC) in Lund.

Focusing on security, we have investigated a mechanism for verifying the control signal received from the outsourced controller (cloud). We have employed a recent cryptographic technique, called verifiable computation, which allows a client to check the correctness of remote execution. We have presented a proof-of-concept implementation to show the applicability of verifiable computation techniques for real-life control applications. We have demonstrated the practicality of verifiable computation schemes with advanced control methods like Model Predictive Control (MPC), where the computationally heavy part of the controller is outsourced to a cloud platform.

We have also been working on developing a cloud-based cyber-physical system platform with a focus on formulating a reliable and resource-efficient communication channel model. The deterministic periodic traffic scheduling problem based on the grant-free uplink transmission scheme in 5G is considered. Detailed problem formulation and a prototype for exact solution based on SMT-solver have been proposed.

1.1. Plans for 2022

The following research issues will be our focus for 2022:

- Implementation and refinement of the SMT-formulation for the deterministic periodic traffic scheduling problem will be carried out.
- Extensive experiments with the SMT-solver and analysis of the results will be performed.
- Heuristics for efficient solutions for the deterministic periodic traffic scheduling problem will be developed.
- Techniques to support different design trade-offs related to control quality, cost, and timing, when the traffic scheduling scheme is deployed in a cloud-based cyber-physical system for control applications will be studied.

2. Awards and recognitions

Nils Vreman, Anton Cervin and Martina Maggio received the Best Paper Award for their paper “Stability and Performance Analysis of Control Systems Subject to Bursts of Deadline Misses” at the 33rd Euromicro Conference on Real-Time Systems (ECRTS 2021).

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amount per year	Duration of project
“Autonomous Clouds and Networks” (PIs: Karl-Erik Årzén, Anton Cervin, Maggio)	WASP/KAW	3400 KSEK	2016–2022
“Event-Based Control of Stochastic Systems with Application to Server Systems” (PI: Anton Cervin)	VR	970 KSEK	2018–2021
“Event-Based Information Fusion for the Self-Adaptive Cloud” (PI: Anton Cervin)	WASP/KAW	850 KSEK	2017–2022
HI2OT: Nordic Hub on Industrial IoT	NordForsk	620 KSEK	2018–2023
“Temperature-Based Design and Optimization of Cyber-Physical Systems” (PIs: Zebo Peng, Soheil Samii)	VR	995 KSEK	2018–2021

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

Two new PhD students were recruited for the project: At LU, Max Nyberg Carlsson joined the project in August 2021, and at LiU, Yungang Pan joined the project in September 2021.

5. Inter-university cooperation: summary for 2021

Besides the strong cooperation between the two partners at LU and LiU, the LiU partner had also cooperation with Dr. Amir Aminifar, who is now with the Department of Electrical and Information Technology at LTH, in developing techniques for control-communication codesign of cyber-physical systems built with Ethernet networks, and using verifiable computation protocols for secure cloud control. The following two joint papers were published in 2021, as a result of this cooperation:

R. Mahfouzi, A. Aminifar, S. Samii, P. Eles, and Z. Peng, “Breaking Silos to Guarantee Control Stability with Communication over Ethernet TSN,” IEEE Design & Test, Vol. 38, Issue 5, Oct. 2021, pp. 48-56.

R. Mahfouzi, A. Aminifar, S. Samii, P. Eles, and Z. Peng, “Secure Cloud Control Using Verifiable Computation,” Proc. IEEE International Conference on Omni-Layer Intelligent Systems (COINS’21), Virtual, Aug. 23-26, 2021.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

The project is by nature and includes both control engineering and computer science.

7. Industry and institute cooperation

We continued the strong industrial collaboration with General Motors, USA, via Dr. Soheil Samii, who is also an adjunct lecturer at LiU. This cooperation led to four joint publications in 2021. Within the Autonomous Cloud research activity at LU, led by Karl-Erik Årzén, there is close collaboration with Ericsson AB and Axis AB in Lund. Cloud researcher Johan Eker at Ericsson is also an adjunct professor at LU. Max Nyberg Carlsson at LU is a WASP-affiliated PhD student.

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

LU continued to participate in the HI2OT Nordic Hub on Industrial IoT, where PhD courses are developed and offered to the academic partners (KTH, DTU, NTNU, Aalto). At LU the new master’s program in Machine Learning, Systems and Control received 16 new students in its second year of existence.

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

Outreach activities were again very few this year, due to the pandemic.

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

Petru Eles is an Associate Editor of the IEEE Design & Test, the ACM Transactions on Embedded Computing Systems, and of Real-Time Systems. Zebo Peng is appointed Board Member of the European Design Automation Association (EDAA), and General Co-Chair for the 5th IEEE International Test Conference in Asia (ITC-Asia), 2021.

12. Open-source software contributions

During the year, the open-source toolbox JitterTime (www.control.lth.se/jittertime) has seen further development and use in the research project. A Julia version of the toolbox has been developed and will be published soon.

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. Advances in technology, 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.
In this project, we 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 the integration of 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 2021

a. **Managing the feedback from operations in DevOps:** (Adha Hrusto, WASP): In collaboration with a Swedish company, responsible for ticket management and sales in public transportation, we have explored challenges in managing feedback from operations in DevOps. One major

challenge is alert flooding, i.e. too much signals from operations create noise in the feedback loop. As a response we have designed and implemented a smart filter optimizing when to raise alerts. Monitoring a microservice system may bring a lot of benefits to development teams such as early detection of run-time errors and various performance anomalies. We explore deep learning (DL) solutions for detection of anomalous behaviors based on collected monitoring data that consists of applications' and systems' performance metrics. Specifically, we address a shortage of approaches for evaluating DL models without any ground truth data. Hence, we propose a solution design for anomaly detection and reporting alerts inspired by state-of-the-art DL solutions.

b. **Facilitating knowledge co-creation between industry and academia:** (Sergio Rico): Empirical software engineering research relies on good communication with industrial partners. Conducting joint research both requires and contributes to bridging the communication gap between industry and academia (IA) in software engineering. We have explored the communication between the two parties in such a setting. To better understand what facilitates good IA communication and what project outcomes such communication promotes, we performed a case study, in the context of a long-term IA joint project, followed by a validating survey among practitioners and researchers with experience of working in similar settings. We identified five facilitators of IA communication and nine project outcomes related to this communication. Our study presents empirically based insights that can provide advice on how to improve communication in IA research projects and thus the co-creation of software engineering knowledge that is anchored in both practice and research. To encourage active researcher-practitioner interaction we previously developed guidelines for performing interactive rapid reviews, a streamlined approach to conduct agile literature reviews in close collaboration between researchers and practitioners in software engineering. These guidelines have now been applied in two cases of emerging industry-academia collaborations. In the first case Four researchers from Lund University and RISE Research Institutes and four practitioners from Axis Communications reviewed a set of 180 primary studies on ML testing. We developed a taxonomy for the communication around ML testing challenges and results and identified a list of 12 open challenges for Axis Communications. The five best research-challenge matches were analyzed with respect to applicability and relevance for Axis Communications. In the other case two researchers from LU and BTH and one practitioner from Ericsson jointly reviewed the literature to find methods for component selection.

c. **Testing autonomous systems:** (Qunying Song, WASP): Testing of autonomous systems is extremely important as many of them are both safety-critical and security-critical. The architecture and mechanism of such systems are fundamentally different from traditional control software, which appears to operate in more structured environments and are explicitly instructed according to the system design and implementation. To gain a better understanding of autonomous systems practice and facilitate research on the testing of such systems, we conducted an exploratory study by synthesizing academic literature with a focus group discussion and interviews with industry practitioners. We provide a conceptualization of autonomous systems, classifications of challenges and current practices as well as of available techniques and approaches for testing autonomous systems. A continuation of this research focuses on the

testing of autonomous vehicles. We present an industrial workbench of tools and workflows to generate efficient and effective test scenarios for active safety and autonomous driving functions. The workbench is based on existing engineering tools and helps smoothly integrate simulated testing, with real vehicle parameters and software. We aim to validate the workbench with real cases and further refine the input model parameters and distributions.

d. Defect management (Muhammad Laiq)**:** Software development companies spend considerable time on resolving defects found in their products. However, defect reports might be invalid, i.e., not pointing to a valid product flaw. Expensive resources and time are expended on invalid defect reports before discovering they are invalid. We have developed tools to assess the prevalence of the issues and used machine learning to help identify if a new defect report is likely to be invalid. We have also used natural language processing to help identify recurring patterns in invalid defect reports that can be exploited to design preventive solutions.

e. Source code quality (Umar Iftikhar): We have extensively reviewed evidence reported in literature to identify internal characteristics of source code that contribute to the overall quality of a software product. This work is essential to design interventions that improve the quality of the software products.

1.1. Plans for 2022

f. We have proposed a plan for in-context implementation and evaluation of the smart filter for anomaly detection in operations, empowered by feedback from the development team. Through continuous feedback from development, labeled data is generated and used for optimization of the DL model. In this way, a microservice system may leverage DL solutions to address rising challenges within its architecture.

g. We plan to evaluate the adoption of automated bug assignment in practice. We have initiated a case study on the broad adoption of a research tool for automated bug assignment at Ericsson. The continuous inflow of bug reports is a considerable challenge in large development projects. A prototype bug assignment solution based on machine learning was developed in academia 2011-2016. The prototype then evolved into an internal Ericsson product (TRR), between 2017-2018. TRR's first bug assignment without human intervention happened in 2019. In this study we want to evaluate the adoption of TRR within its industrial context at Ericsson. We seek to understand 1) how TRR performs in the field, 2) what value TRR provides to Ericsson, and how TRR has influenced the ways of working. Secondly, we aim to provide lessons learned related to productization of a research prototype within a company.

h. Similarly, we plan to investigate the practical adoption of critical scenario identification for testing of autonomous driving, through a multi-case study involving various stakeholders in the autonomous driving domain.

i. The sheer volume of suggestions by static code analysis and refactoring tools makes their use challenging for engineers. We are leveraging actual code commits and reviewers' comments to improve the suggestions made by these tools. Thus, developing a recommendation system that builds on issues that are already considered important by the company.

2. Awards and recognitions

According to a ranking published in the Journal of Systems and Software, Blekinge Institute of Technology (BTH) is ranked seventh worldwide and first in Europe for software engineering research based on the publications in selected venues during the years 2013-2020 and second worldwide. ELLIIT researchers Kai Petersen and Nauman bin Ali are among several researchers from BTH listed in various categories in the rankings. (Further details: https://doi.org/10.1016/j.jss.2021.111029)

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amount per year	Duration of project
WASP (PhD student)	KAW	750 KSEK	2020-2024
WASP (Industrial PhD student)	KAW	150 KSEK	2019-2023
VITS	KK-stiftelsen	0.98 MSEK	2019–2021
SERT	KK-stiftelsen	5.99 MSEK	2018–2026
PLEng 2	KK-stiftelsen	1.68 MSEK	2018–2022
HATCH	Vinnova	1.3 SEK	2018–2021
OSIR	KK-stiftelsen	3.7MSEK	2020-2023
ESS Data Lab	Vinnova	540 kSEK	2020-2021

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

Muhammad Laiq started at BTH in January 2021 as a Ph.D. student in software engineering.

5. Inter-university cooperation: summary for 2021

LTH (Qunying Song) collaborated with KTH on testing of autonomous systems.
LTH (Sergio Rico, Emelie Engström and Martin Höst) collaborated with BTH on interactive rapid reviews.
LTH (Elizabeth Bjarnasson) and BTH (Nauman bin Ali) collaborated on a model for 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 2021

BTH (Kai Petersen, Jürgen Börstler and Nauman bin Ali) collaborated with a colleague from Industrial Economics on investigating the role of theories and models for technology acceptance.

7. Industry and institute cooperation

LTH (Emelie Engström), RISE (Markus Borg) and Ericsson collaborate on adoption of automated bug assignment

LTH (Qunying Song, Emelie Engström, Sergio Rico), RISE (Markus Borg) and Axis Communication collaborate on testing of ML applications

LTH (Adha Hrusto, Per Runeson, Emelie Engström) and Skånetrafiken collaborate on anomaly detection in operations

BTH (Nauman bin Ali), LTH (Emelie Engström) collaborated with Axis, Alstom and TestScouts on the role of visual and data analytics in software testing.

BTH (Muhammad Laiq, Nauman bin Ali) collaborated with Ericsson on software defect management.

BTH (Muhammad Usman and Deepika Badampudi) collaborated with Ericsson, S-GROUP Solutions, and City Network on the topic of software reuse.

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

ELLIIT researchers at BTH have developed a new course covering empirical work for industry professionals in software engineering. In this course, software professionals get research training and are individually coached to conceive, design, and report a scientific study on a real-world problem.

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

Nauman bin Ali (BTH) represents software engineering department in the local collaboration forum (samverkensforum).

11. 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)

Nauman bin Ali (BTH) served as a program committee member for the "1st Workshop on DevOps and Software Engineering: new paradigms of continuous software development, inspection, integration and deployment" - DevOps-SE '21

Nauman bin Ali (BTH) served as a Program committee member for the Experimental Software Engineering track of the 2021 Ibero-American Conference on Software Engineering (CIbSE-ESELAW).

12. 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 2021

We have developed a new attribute-grammar based technique for high-level specification of intraprocedural control-flow graphs, suitable for use in interactive development tools such as cloud-based tooling. The technique includes a language-independent framework, IntraCFG, and an example application of this framework for Java, IntraJ, to illustrate how flow for complex constructs such as exceptions can be handled. We have used IntraJ to implement dataflow-based bug pattern detection such as detection of null-pointer exceptions and dead assignments, and demonstrated that the performance is on par with, and sometimes even faster than commercial bug detection tools.

A prototype framework based on the Julia language supporting variable structure systems in the contest of the Modelica standard was developed. We have developed an automatic translation of the original OpenModelica compiler front-end from MetaModelica to Julia and coupled it with a new backend build on top of the Julia numerical packages to provide simulation support for the new framework. The proof-of-concept prototype can simulate models with switching continuous modes and reconfiguration during runtime.

1.1. Plans for 2022

The newly recruited PhD students are initially focusing on taking graduate courses and coming up to speed with the tools used and developed in our research labs.

For the LU PhD student, the first research study will be to build a prototype cloud-based editor, reusing an existing JavaScript-based text editor in the client, but running JastAdd attribute grammars in the server for semantic computations. For evaluation, we will use several different languages and compilers, including the ExtendJ Java compiler and the IntraJ extension with control-flow analysis and flow-based bug detection.

The LiU PhD student plan is to work on developing a Julia-based computational intelligence library of optimization algorithms to be tried on various hard optimization problems in the OpenModelica compiler (on optimizing the symbolic manipulation of the equation system) or in cloud contexts (such as optimal distribution of simulation parts on nodes). Concurrently an investigation on the use of surrogate models in cloud-based simulation is ongoing.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amount per year	Duration of project
WASP PhD project. Explainable declarative program analysis.	WASP	1 Mkr	2019-2024
LARGEDYN – Modeling and Simulation Tool for Very Large Systems with	SSF	2.3 MSEK	2019-2022
EMBrACE – Environment for model-based rigorous adaptive co-design and	ITEA3	2 MSEK	2019-2022
HUBCAP – Digital Innovation HUBs and Collaborative Platform for Cyber-	H2020-EU	2.5 MSEK	2020-2022

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

Two PhD students have been hired to work in the project: Anton Risberg Alaküla started in August 2021 at LU/CS. Abdelazim Hussein started in November at LiU/IDA.

5. Inter-university cooperation: summary for 2021

A joint LiU/LU paper has been completed and published during 2021 about open source languages and methods for cyber-physical system development. A number of joint meetings have been held, and two concrete topics for new collaboration subprojects have been identified: 1) cloud editor support and 2) library support for RAGs in Julia.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

N/A

7. Industry and institute cooperation

LU has had collaboration with Modelon AB with two MSc projects concerning speedup of compilation and simulation of models.

LiU had collaboration with Saab on further development of the open-source tool OMSimulator to support their test-cases which are based on the open-standards SSP and FMI.

8. List of patent applications published during 2021.

N/a

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

Supervision of several MSc projects closely related to the project, and some in collaboration with industry. Furthermore, the open-source tools developed in the project are used in undergraduate and graduate courses: JastAdd is used in a compilers course and a project course at the graduate level. In particular, two projects were run based on JastAdd and using cloud IDE tooling based on LSP and MagpieBridge.

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

N/A

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

Görel Hedin, LU, Associate Editor, Journal of Object Technology.
Adrian Pop, LiU, organized the 13th OpenModelica Annual Workshop, February 2, 2021
Adrian Pop, LiU, organized the 15th MODPROD Workshop on Model-Based Cyber-Physical Product Development, February 3-4, 2021
Adrian Pop, LiU, organized the 14th International Modelica Conference 2021, 20-24 September, 2021.

12. Open source software contributions

- JastAdd, a meta-compilation system that supports reference attribute grammars. A new release 2.3.5 was issued in 2021. https://jastadd.cs.lth.se/web/
- ExtendJ, an extensible Java compiler constructed using JastAdd. Several improvements were done in 2021. https://extendj.org/index.html
- IntraCFG, a new language-independent framework for building control-flow graphs using reference attribute grammars. https://github.com/lu-cs-sde/IntraCFG
- IntraJ, a new tool that extends IntraCFG and ExtendJ to support control-flow graphs for Java source programs, as well as client dataflow analyses. https://github.com/lu-cs-sde/IntraJ

- OpenModelica is an open-source modeling, simulation, optimization and debugging tool for the object-oriented equation-based open-standard language Modelica. https://www.openmodelica.org
- OMSimulator is a tool that supports co-simulation of composite models made up of several FMI and TLM components. It supports the open-standards FMI and SSP. The tools is distributed as part of the OpenModelica suite but can also be used standalone: https://github.com/OpenModelica/ OMSimulator/.
- OpenModelica.jl is a Julia-based Modelica compiler that supports variable structures systems. https://github.com/JKRT/OM.jl.

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.

The involved groups are referred to as IDA-LiU (Computer Science at Linköping University) and CS-LU/AC-LU (Computer Science / Automatic Control at Lund University respectively).

1. Main scientific achievements during 2021

One of the main scientific accomplishments for the IDA-LiU group was the specification and prototyping of a general distributed system architecture that supports the creation of dynamic data and knowledge networks by teams of robots and humans. The information collected ranges from low-level sensor data to high-level semantic knowledge, the latter represented in part as RDF Graphs. The framework includes a synchronization protocol and associated algorithms that allow for the automatic distribution and sharing of data and knowledge between agents. This is done through the distributed synchronization of RDF Graphs shared between agents. High-level semantic queries specified in SPARQL can be used by robots and humans alike to acquire both knowledge and data content from team members. Limited

empirical experimentation was achieved using teams of UAVs and humans in addition to in-depth simulation experiments. This activity resulted in one accepted journal publication and one submitted journal publication.

Another scientific accomplishment is the development of a system including base functionalities required for UAV-based rapid deployment of an ad hoc communication infrastructure in the initial phases of rescue operations. The main idea is to use heterogeneous teams of UAVs to deploy communication kits that include routers, and are used in the generation of ad hoc Wireless Mesh Networks (WMN). Several fundamental problems are considered and algorithms are proposed to solve these problems. The Router Node Placement problem (RNP) and a generalization of it that takes into account additional constraints arising in actual field usage is considered first. The RNP problem tries to determine how to optimally place routers in a WMN. A new algorithm, the RRT-WMN algorithm, is proposed to solve this problem. It is based in part on a novel use of the Rapidly Exploring Random Trees (RRT) algorithm used in motion planning. A comparative empirical evaluation between the RRT-WMN algorithm and existing techniques such as the Covariance Matrix Adaptation Evolution Strategy (CMA-ES) and Particle Swarm Optimization (PSO), shows that the RRT-WMN algorithm has far better performance both in amount of time taken and regional coverage as the generalized RNP problem scales to realistic scenarios. The Gateway Node Placement Problem (GNP) tries to determine how to locate a minimal number of gateway nodes in a WMN backbone network while satisfying a number of Quality of Service (QoS) constraints. Two alternatives are proposed for solving the combined RNP-GNP problem. The first approach combines the RRT-WMN algorithm with a preexisting graph clustering algorithm. The second approach, WMNbyAreaDecomposition, proposes a novel divide-and-conquer algorithm that recursively partitions a target deployment area into a set of disjoint regions, thus creating a number of simpler RNP problems that are then solved concurrently. Both algorithms are evaluated on real-world GIS models of different size and complexity. WMNbyAreaDecomposition is shown to outperform existing algorithms using 73% to 92% fewer router nodes while at the same time satisfying all QoS requirements. This activity has resulted in on accepted journal publication and an arXiV publication on area decomposition that will be submitted as a journal article.

Due to a delay in the recruiting process for the PhD student working on this project in the CS-LU group, the achievements for 2021 could only be based on MSc projects that are related to the project topics and were carried out with involvement of the co-PI or other researchers directly tied to the project. One of these projects at AC-LU was the development of an inspection tool using dense reconstruction of visual / range data produced with a Boston Dynamics SPOT for construction sites, which can give insights into how to make use of this particular robot's abilities to move in unstructured environments and produce a suitable (dense) representation of its environment to be conveyed to other robots or a human operator. In another project started in 2021, also this at AC-LU, the distributed framework for robot control developed at LiU (see above) was explored as a tool for interactive drone control, which can give direct support to the planned work at CS-LU regarding mixed-initiative interaction between humans and robots, but was also aimed at investigating the coordination of the drone with the Boston Dynamics SPOT. In the CS-LU group one MSc project concerned the implementation of a gaze tracker only relying on data from an RGB-D camera mounted on a robot, i.e., the human user does not need to wear any

equipment. This gaze tracker is anticipated to be evaluated further as a potential modality for robot control in interactive scenarios. Another MSc project carried out at CS-LU in collaboration with a former PhD student of the co-PI at Saab Kockums investigated the automatic annotation of relevant markers (sea marks, landmarks) at sea. Results from this project were reported as part of a journal publication (see paragraph on industry collaborations below).

1.1. Plans for 2022

Plans for 2022 are to focus on mixed-initiative interaction and human-robot interaction. This aspect of the proposal has been delayed due to difficulties in the CS-LU group recruiting a PhD student. This issue has now been resolved (see paragraph on recruiting below) and the CS-LU group will now be able to focus their main efforts on working towards aspects of support for mixed-initiative interaction and more general human-robot interaction (HRI). Specifically, our plans include to further investigate the suitability of the gaze tracker developed in 2021 (see above) for robot control and / or interpretation of a human user's attention and focus as well as to conduct a virtual experiment to understand likely behaviour of humans in complex scenarios involving the coordination of (several) robots and humans. This entails to combine suitable tools for visualisation and system control in virtual reality with the simulation provided through the IDA-LiU framework. In a side line of these efforts, (cognitive) architectures established in the intersection of AI and HRI over the recent years as well as the recently published ROS package ROS4HRI will be investigated for their compatibility with the framework developed in the IDA-LiU group and their applicability for the interaction support we are striving to provide.

As mentioned above, in 2021, we initiated joint activities between LU and IDA-LiU to study collaboration between a Boston Dynamics SPOT robot and smaller UAV systems. This work is ongoing and additional effort will be spent on this in 2022.

Additionally, there is still a lot of work to do with the systems described under main scientific accomplishments. This work will be more empirical in nature and focusing on field-robotic experimentation.

2. Awards and recognitions

P. Doherty served as a Distinguished Guest Professor Jinan University (Zhuhai campus), China (Fall 2018-Fall 2021) in addition to being appointed as an Honorable Dean of the School of Intelligent Systems and Engineering, Jinan University (Zhuhai campus), China for the same period.

P. Doherty was appointed in July 2021 as the Public Safety Cluster Manager, Autonomous Systems and Software Program (WASP), funded by the Knut and Alice Wallenberg Foundation.

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amount per year	Duration of project
Robot-assisted Hastily Formed Knowledge Networks	SSF	5MSEK	2016-2021
Robotic Skill Learning with Interactively Acquired Knowledge Based Models	WASP / KAW	1MSEK	2019-2024 (5yrs)
SelectiCa	EuroStars	1MSEK	2021-2023 (2yrs)
Semantic Mapping and Visual Navigation for Smart Robots	SSF	6MSEK	2016-2021/2022

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

At CS-LU, one recruitment exclusively dedicated to this project was made, however, the recruit Ayesha Jena started her PhD project employment only on April 13, 2022. A recruitment process for this PhD position was initiated already in the fall of 2020, but had to be re-initiated in the summer of 2021. While the actual recruitment process was concluded during 2021, it took then an additional period of roughly five months to start the employment due to the lengthy immigration procedures.

5. Inter-university cooperation: summary for 2021

IDA-LiU has cooperated in this project with LU in the areas of human-robot interaction and robotics. AC-LU has cooperated with IDA-LiU specifically on exploration of the IDA-LiU software framework for drone control.

CS-LU (co-PI E.A. Topp and PhD student A. Dürr) collaborated in a WASP collaboration project on Robot Skill Learning with Örebro University.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

CS-LU (Elin A. Topp, project co-PI) has been involved in an interdisciplinary Study Group at the Pufendorf Institute for Advanced Studies at Lund University, the topic was Political Polarization on the Internet.

7. Industry and institute cooperation

IDA-LiU has had extensive collaboration with Saab, Saab-Combitech, and Saab Kockums in the context of the WASP WARA-Public Safety arena, where several software systems developed by IDA-LiU and

related to this ELLIIT project have been integrated and used by these companies. Also CS-LU and AC-LU have had (and still have) direct collaborations with Saab Kockums through WASP-funded industrial PhD projects (one concluded in 2021 and one ongoing) and related MSc projects (see above). These activities have in fact resulted in a joint journal publication that includes both the PI and co-PI in this project as well as employees for the mentioned companies as co-authors.

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

CS-LU proposed a new course on Advanced Applied Machine Learning in 2021, with the first course occasion in the academic year 2022/23, for which the co-PI in this project is responsible.

CS-LU is running a rather new course on Intelligent Autonomous Systems (started 2020) in which the co-PI is involved and contributed in 2021 with significant updates to incorporate aspects of interaction with autonomous systems to a larger extent than in the first course occasion.

Application examples and project tasks for both these courses are or will be in many cases drawn from the research topics (robotics, knowledge representation, machine learning) that are pursued in the group.

The LU co-PI in this project joined the WASP Graduate School Management Group from January 2021 and has the coordination responsibility for a new course on Interaction, Collaboration and Visualisation to be given the first time in spring 2023.

The LU co-PI in this project joined the COMPUTE Graduate School steering group at Lund University from July 2021 (https://compute.lu.se).

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

Both groups at LU have been involved in the annually conducted Robotics Week (calendar week 47), which offers lab tours to school classes as a contribution to the European Robotics Week initiated by the EuRobotics network.

Several researchers from CS-LU and AC-LU including the co-PI have contributed with short portrait videos to the standing AI exhibition at LU's Science Center "Vattenhallen".

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

P. Doherty continued in 2021 as Editor-in-Chief of the Artificial Intelligence Journal, one of the most prestigious journals in the area of AI.

E.A. Topp was appointed Associate Editor for the ACM Transactions on Human Robot Interaction (THRI), the flagship journal of the HRI community.
E.A. Topp joined the organisation committee for the IEEE/ACM Conference on Human Robot Interaction (HRI) 2023, to be held in Stockholm.

12. 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 2021

A paper with Johan Edstedt as main author (see recruitments under 4) has been submitted to ICPR 2022. The paper covers a multi-modal end-to-end learning task and the main purpose of the submission was to train the PhD candidate to go through the full process of scientific publications. The paper was accepted. Johan Edstedt started also the implementation and evaluation of a dense correspondence learning approach for geometric matching.

A paper with Marcus Valtonen Örnhag (PhD 2021 from Lund University) as first author was submitted to CVPR 2022 and was subsequently accepted to the WAD workshop held in

conjunction with CVPR. The paper concerns minimal solvers for epipolar geometry with radial distortion. The solvers use IMU pre-integration to eliminate the relative rotation, which simplifies the governing equations and allow the inclusion of intrinsics and distortion parameters instead.

1.1. Plans for 2022

Johan Edstedt - Presentation of the ICPR paper. Submission of a manuscript of the dense matching method to a major machine learning conference. Submission of a manuscript (as coauthor) to a major computer vision conference.

Anders Heyden – Recruitment of a new PhD-student.

2. Awards and recognitions

M. Felsberg – best paper at VISAPP, honourable mention at DAGM-GCPR

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amount per year	Duration of project
Constrained Deep Spatio-Temporal Networks (M. Felsberg)	WASP	1 mkr	2021-2025
Alignment and Integration of Physical and Virtual Worlds (NEST, M. Felsberg co-PI)	WASP	1.2 mkr	2022-2026

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

Johan Edstedt joined the project as a PhD student at the Computer Vision Laboratory (Department of Electrical Engineering, Linköping university).

5. Inter-university cooperation: summary for 2021

Due to the pandemic situation, project meetings were held via Zoom during 2021. A physical meeting in Linköping during Spring 2022 was planned in 2021.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

N/A

7. Industry and institute cooperation

It will be relevant in the near future.

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

It will be relevant in the near future.

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

M. Felsberg presented at the MAIN (Mathematics, AI, and Neuroscience) Meeting

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

M. Felsberg act as AE for PLOS ONE, AC for BMVC.

12. 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

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 2021

During 2021 we have continued collaboration with the Max Planck Institute for Ornithology and with navigation research at Aalto University and the University of Vaasa. Applications to simple setup and calibration of multi-microphone installations. Such local positioning systems have been applied to bat tracking in caves for ornothology research. Co-supervision of PhD student Thejasvi Ravindra Beleyur.
During 2021 we have continued collaboration with the Aalto University and the University of Vaasa concerning basic reconstruction algorithms for time difference of arrival data. This has resulted in joint publications at EUSIPCO 2021 and ICASSP 2021.
New results on robust calibration methods for sensor node calibration and for robust trilateration through industrial collaboration with Combain and financed by WASP through industrial PhD student programme. This has resulted in joint publications at EUSIPCO 2021, ICASSP 2021 and IPIN 2021.
Joint work using mapping and positioning research at the centre for mathematical sciences and autonomous control at the automatic control department in Lund, Arxiv publication in 2021, also accepted for publication in CCTA, 2022.
New PhD dissertation: Gabrielle Flood "Mapping and Merging Using Sound and Vision Automatic Calibration and Map Fusion with Statistical Deformations", Lund University, Doctoral Thesis in Mathematical Sciences 2021:10. After the dissertation Dr Flood continued at the Centre for Mathematical Sciences at Lund University.

1.1. Plans for 2022

The vision for the research is two-fold: Further theoretical developments and development of application-centric systems. Examples of theoretical areas includes research on (i) algebraic geometry and its connection to mapping and localisation, (ii) optimization techniques, (iii) estimation theory, (iv) sensor fusion and (v) combinations of data-driven and model-based techniques. We will continue to work on a wide range of sensing modalities e g vision, RGB-D, lidar, radar, sound, radio (in terms of UWB time of arrivals, WIFI signal strength, WIFI round-trip-time, 5G/B5G directional information and time of arrival), IMU and magnetometers. Each of these modalities provide research challenges on their own (how to make maps, how to estimate position, how to track), but also taken together in different combinations, e g using sensor fusion. An interesting theme going forward is to provide not only geometric understanding using these sensors, but also start analysing maps and motions in terms of semantic meaning. A few more concrete lines of research are the following:

- audio - We have now several algorithmic building blocks for determining sender and receiver positions from audio. Using such algorithms, we can generate data that can be used in a machine learning context to improve on current state of the art for audio signal processing for positioning.
- vision + radar - This sensor combination is particularly interesting in order to be able to localise and track during both day and night and for different weather conditions.
- vision + radar + radio - High-precision positioning in cellular systems is topical for upcoming releases of 5G. Going forward, we envision a more integrated communication and positioning solution, where positioning is not only a service, but is integrated in the system to increase

communication performance and reliability. Both pure radio-based and sensor fusion approaches are interesting here.

- vision + IMU - This sensor combination makes it possible to make 3D reconstructions with the correct scale and down-direction. Establishing both geometry and scene semantics is of interest. Here there are lots of opportunities for basic research, but also for applications for autonomous drones.
- WIFI signal strength + RTT + IMU - These sensor modalities are appropriate for establishing indoor mapping and positioning for personal use. Again, both geometry and semantic understanding is of interest.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amountper year	Duration of project
Semantic Mapping and Visual Navigation for Smart Robots	SSF	6 200 KSEK	2016-2021
WASP (AcademicPhD student)	WASP (KAW)	700 KSEK	2016-2020
WASP (Industrial PhD student)	Wasp (KAW) and Combain	600+ KSEK	2017-2021
WASP (Industrial PhD student)	WASP (KAW) and ARM	600+ KSEK	2018-2022
WASP (Industrial PhD student)	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)	WASP (KAW) and Saab	600+ KSEK	2016-2020
WASP (Industrial PhD student)	WASP (KAW) and Epiroc	600+ KSEK	2018-2022
WASP (Industrial PhD student)	WASP (KAW) and Ericsson	600+ KSEK	2016-2020
WASP (AcademicPhD student)	WASP (KAW)	700 KSEK	2016-2020
Link-Sic (Industrial PhD student)	Link-Sic	600+ KSEK	2018-2023
WASP (Industrial PhD student)	WASP (KAW) and Zenseact	600+ KSEK	2021-2026

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

New PhD recruitments: Erik Tegler (ELLIIT academic PhD, 2021 - 2026, Lund), NN (ELLIIT academic PhD, 2021 - 2026, Linköping), Adam Tonderski (WASP+Zenseact Industrial PhD, 2021 – 2026, Lund)

5. Inter-university cooperation: summary for 2021

We have yearly workshops on localisation and navigation. These are co-organized by this ELLIIT project and with WASP cluster Smart Localization Systems. Participants from all over Sweden – academia, industry and organizations such as FOI. For 2021, we cancelled our physical workshop due to the pandemic.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

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

- Farming - Work on interdisciplinary cooperation within precision agriculture. Partners here are Hushållningssällskapet I Skåne och Östergötland, T-kartor, Agtech 2030, Region Östergötland.
- Forestry - Collaborations on precision forestry, with KATAM. During 2020 worked with
- Biology – ongoing collaborations with the biology department in Lund and with the Max Planck Institute for Ornithology,
- Wildlife protection – ongoing collaboration with Kålmården zoo and with the Ngulia Rhino Sanctuary in Kenya.

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

7. Industry and institute cooperation

Industrial collaboration with Sony on indoor positioning (through Lund Positioning Laboratory and the competence center Systems on Silicon) and on 3D modelling (in separate Sony-financed project) and through two WASP funded industrial PhD student projects. Industrial collaboration with Combain on indoor positioning (through Vinnova funded project and through a wasp funded industrial PhD student project), industrial collaboration with ARM on learning and positioning (through a wasp funded industrial PhD student project), industrial collaboration with Zenseact on deep learning for autonomous driving cars (through a wasp funded industrial PhD student project), collaborative project with KATAM on 3D mapping of forests and localization. There is also joint radio-based positioning work with Ericsson in the newly established cooperation between LU and Ericsson AB. Industry cooperation through numerous master's thesis projects, e g with Axis, Sony, Ericsson, Verisure, Umansense, Combain.

8. List of patent applications published during 2021.

Patent title	Application Number
Method for generating an indoor environment model and a method for determining position data for a location in an indoor environment	U.S. Patent No. 10,955,518

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

Development of new course material for WASP course on Autonomous Systems. New PhD-course in multi-target tracking.

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

Popular science presentations during 2021:

- Talk on talk on animal navigation "AI Lund lunch seminar: Mimicking insect navigation in a synthetic nanowire bee brain", February 3, 2021.
- Kalle Åström talked about DeepFakes in SvT, March 3, 2021.
- Kalle Åström gave a popular science presentation at Reijlers, March 19, 2021.
- Popular sciences webinar on AI, Positioning and Agriculture, "Nordic AI Popup Live om smart mat och klimat", May 5, 2021 with Mikael Nilsson and Kalle Åström, https://www.ai.lu.se/2021-05-05.
- Kalle Åström gave a popular science presentation on sound based mapping and positioning: "AI Lund lunch seminar: Geometry and sound - mapping and positioning using sound", May 12, 2021, https://www.ai.lu.se/2021-05-12.
- Workshop on Acoustics, EM, Radar and Sonar "Modern Optimization and Machine Learning in Acoustics, EM, Radar, and Sonar", May 19, 2021. https://www.ai.lu.se/2021-05-19.
- Alexandros Sopasakis gave a popular science presentation on AI and agriculture, "AI Lund lunch seminar: Machine Learning in the service of Agriculture", November 10, 2021.
- Popular sciences webinar on AI, Positioning and Forestry, "Nordic AI Popup Live – AI åt skogen", November 11, 2021 with Ida Arvidsson and Kalle Åström, https://www.ai.lu.se/2021-11-11.
- Workshop on Acoustics, EM, Radar and Sonar "Modern Optimization and Machine Learning in Acoustics, EM, Radar, and Sonar II", November 23, 2021. https://www.ai.lu.se/2021-11-23.

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

Gustaf Hendeby is associate editor för tracking i IEEE Transactions on Aerospace and Electroncis Systems

12. Open source software contributions

N/A.

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 2021

During the last year the project has been in a start-up phase as new people are hired and founding research continues, while new directions are explored. We have hired new PhD students. Continuing research has led to major contributions in all work packages of the project.

Sparse signal modeling has been shown to be a powerful tool for representation of high dimensional discrete signals. Of particular importance for sparse modeling is the ability to reconstruct signals from a few samples, often much lower than what is required by the Shannon-Nyquist theorem. The field of compressed sensing \cite{Donoho:CS} addresses the problem of optimal discrete signal sampling. In most applications, we are interested in point sampling of discrete signals in high dimensional spaces to facilitate the design of imaging systems. An example of such discrete high dimensional signals is volumetric medical imaging data. Finding the optimal location of samples in a discrete signal is challenging since this is a combinatorial problem. To this end, we have derived a new sampling and reconstruction technique, named A Fast and Robust Optimal Sampling Technique (FROST), for computing a minimal set of optimal sample locations for a discrete signal such that the signal is faithfully reconstructed \cite{FROST-BRDF}. FROST casts the problem of designing an optimal sampling operator for compressed sensing into a sparse representation formulation under the Multiple Measurement Vector (MMV) signal model \cite{Tropp:SOMP}. Unlike previous methods, FROST is accompanied with theoretical guarantees, which bound the required number of samples for exact recovery, as well as error bounds conditioned on the number of samples. We have applied FROST on a number of data sets obtained from material reflectance properties, also known as Bidirectional Reflectance Distribution Function (BRDF). A BRDF is a 1,458,000-dimensional signal. Our experimental results show significant advantages compared to the state-of-the-art with respect to the reconstruction quality. Our results show that with as low as 20 optimally placed samples (out of 1,458,000), we can recover a full BRDF

with negligible visual and numerical error. Moreover, the proposed method is more than two orders of magnitude faster that the state-of-the-art.

Real-time rendering: Generating Billions of pixels for XR. Ensuring synthetic 3D objects look realistic when displayed on augmented reality headsets and layered over the physical world is a challenging task. Over the last year we have investigated a system to capture the lighting in a scene using a separate camera and raspberry Pi, that communicates data to a Microsoft HoloLens 2 headset. The camera and raspberry Pi are mounted on the HoloLens allowing accurate direction capture. The lighting is processed using white balancing and stored in an adaptive two-dimensional quad tree that is progressively updated as new data is captured. Once an object is placed in the scene this data is accessed and interpolated to light objects in the scene making them blend more naturally into their surroundings, particularly when complex lighting situations are encountered.
Other research results have improved the ability to reconstruct scenes, which is an essential component of any Augmented Reality system that requires an understanding of the objects in the physical world that are being interacted with. This research has advanced differentible rendering, which aims to use highly realistic path tracing to estimate the objects in a scene. If the scene contains highly glossy surfaces, it can be difficult to reconstruct the underlying geometry of the surface. By using a technique called antithetic sampling, we are able to reduce the variance when reconstructing glossy surfaces. This research was presented at the highly prestigious SIGGRAPH conference.
During 2021 research continued on using Real-Time Ray Tracing hardware in modern GPUs to produce advanced lighting effects, in particular caustics. Caustics occur when light is concentrated via transparent objects. Our approach combines bi-directional tracing of light and view paths with the BVH hardware acceleration to store and access the light as it travels through the scene. By using hardware acceleration, we are able to achieve real-time frame rates for complex reflections and refractions.
We have also created a new method for modelling plasma in order to use plasma as a light source in 3D rendering. This new method is based on traditional Computational Fluid Dynamics techniques, but instead of working with fluid, considers the movement of charged particles inside the forces of a magnetic field. This research was begun in 2021 and will continue into 2022.

1.1. Plans for 2022

Real-Time rendering research will focus on Neural Rendering techniques that can enhance the capabilities of AR/VR. Also we will ramp up the activities for the captured and procedural data part of the project at Linköping.

2. Awards and recognitions

N/A

3. External funding attracted

See individual PI's

Itemized list of external projects that were active at some point during 2021.
N/A

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

Martin Gemborn-Nilsson was hired as PhD student in Automatic Control in Lund. He started January 1, 2021. Danhua Lei has been hired as PhD student in Sparse Data Analysis in Linköping. She started in October 2021.

5. Inter-university cooperation: summary for 2021

Project meetings were held in May, June and October.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

N/A

7. Industry and institute cooperation

N/A

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

N/A

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

N/A

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

N/A

12. Open source software contributions

N/A

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 2021

In 2021 the PI and Co-PI collaborated with Daniel Cederberg, who is a Master's student at LiU, and currently spending a year at Stanford University. The work involved efficient computations for minimax adaptive controllers, and it has been submitted for the IEEE Conference on Decision and Control in 2022. On October 27th the people involved in the project met in Lund, where preliminary results were presented and discussed. Also, plans for future collaboration were discussed.

1.1. Plans for 2022

On May 23rd the PI and Co-PI will meet in Lund to discuss collaboration regarding distributed system identification. Lund has collaborations with CNRS Toulouse regarding an application to district heating systems.

The PI is together with Fredrik Heinz and Elina Rönnberg organizing the ELLIIT Focus period "Hybrid AI – Where data-driven and model-based methods meet" in October-November of 2022. There he will also give a short course on Reinforcement Learning based on a future book to be published by Wiley in 2023.

2. Awards and recognitions

Co-PI: Anders Rantzer was invited to give virtual (due to the pandemic) oral presentations to

- Conference of Learning for Decision and Control (L4DC) at ETH Zürich.
- MIT LIDS virtual seminar series on Changing Electric Energy Systems, Cambridge, USA
- Invited seminar at the Data Science & Systems Complexity Centre at University of Groningen

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

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
SoPhy: Societal-Scale Cyber-Physical Transport Systems	SSF: Foundation for Strategic Research	1 MSEK	2016-2022
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

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

Recruitment highlights: At LiU a new PhD student, Yannick Strocka, was recruited in October 2021. He is currently working on distributed system identification. Fethi Bencherki was hired by LU as a PhD student to the project in 2021.

5. Inter-university cooperation: summary for 2021

See Item 1.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

N/A

7. Industry and institute cooperation

Sub-contractor in project "AI for Guidance Navigation and Control" at European Space Agency

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

The PI co-authored a new edition of the book Modelling and Identification of Dynamic Systems together with Lennart Ljung and Torkel Glad published by Studentlitteratur.
The CoPI developed new masters course starting Lund January 2022: FRTN75 Learning Based Control.

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

N/A

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

PI:
Swedish representative in the European Control Association General Assembly.
Member of the IEEE Control Systems Societie's Technical Committee on Robust and Complex Systems.
Member of the IFAC Technical Committee on Robust Control.

Co-PI:
Member of examination committe for habilitation by Victor Magron, Toulouse, May 2021.
Member of examination committe for PhD defence by Matías Müller, Stockholm, June 2021.
Member of examination committe for PhD defence by Julio Careaga, Lund, Oct 2021.
Member of Steering committee for Int. 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.
Chairman of the IFAC Fellow Search Committee.
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 Inform Sciences at Springer Verlag..
Member of the IEEE CSS Technical Committee on Nonlinear Systems and Control
Member of the IFAC Technical Committee on Nonlinear Systems.
Member of advisory board for excellene center DISMA at Politecnico di Torino.
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
Member of organizing committee for IEEE CSS Workshop on Control for Societal Challenges 2021.

12. 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 2021

In addition to the PI and co-PI, Erik Frisk, Björn Olofsson, Theodor Westny, and Zheng Jia have been active in the project. Two major articles based on research started in previous ELLIIT projects have been published in high-profile journals during the year. During 2021, the first year of this project, there was also a start-up of research by Ph.D. student Theodor Westny encompassing modeling of trucks to enable extensions of previous research on force-centric methods targeting passenger cars to heavy vehicles. Moreover, start-up of research aiming at planning and control for force-interaction with mobile manipulators by Ph.D. student Zheng Jia has been made.

Wary Control to Handle Unknown Friction

Research initiated in 2019 by Victor Fors, Björn Olofsson, and Lars Nielsen leveraging on the previous results from optimization of vehicle maneuvers, led to new interesting research results regarding how to actually control the vehicle online with real-time constraints and inherent uncertainty on the tire friction. Handling of critical situations is an important part in the architecture of an autonomous vehicle. Based on a w*ary strategy to perform the maneuver t*hat is feasible with the least tire–road friction, a c*ontroller for autonomous collision avoidance h*as been developed. The controller uses an acceleration reference obtained from optimal control of a friction-limited particle, whose applicability is verified by using numerical optimization on a full vehicle model. By employing an analytical tire model of the tire–road friction limit to determine references for steering and body-slip control, this results in a controller where the computation of its output is explicit and independent of the actual tire–road friction. When evaluated in real-time on a high-fidelity simulation model, the developed controller performs close to that achieved by offline numerical optimization. The results were published in IEEE Transactions on Intelligent Vehicles during 2021:

- Victor Fors, Björn Olofsson, & Lars Nielsen (2021), "Autonomous Wary Collision Avoidance". I*EEE Transactions on Intelligent Vehicles, 6*(2), pp. 353-365.

Extension of Research to Moving Obstacles in Safety-Critical At-The-Limit Situations

Research on how to extend the force-centric control design to the cases of at-the-limit maneuvers with *moving obstacles* was performed during 2020 and 2021. A solution was developed that leverages on previous ELLIIT research in terms of planning based on a friction-limited particle model and a subsequent acceleration-following controller, and it employs a *receding-horizon control strategy*. The results have been published during 2021 in an article in ASME Journal of Dynamic Systems, Measurements and Control:

1. Victor Fors, Pavel Anistratov, Björn Olofsson, & Lars Nielsen (2021). "Predictive Force-Centric Emergency Collision Avoidance". *ASME Journal of Dynamic Systems, Measurement, and Control*, 143(8), 081005.

New line of research targeting truck-and-trailer combinations

Research by Theodor Westny, Björn Olofsson, and Erik Frisk has been performed during 2021 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 deriving necessary vehicle-dynamics models and subsequent analysis and parameter-uncertainty prediction in aggressive slalom maneuvers, resulting in at-the-limit motion of the truck-and-trailer system.

New line of research for force-centric path tracking for mobile manipulators

Research by Zheng Jia, Björn Olofsson, Lars Nielsen, and Anders Robertsson has been initiated during the year 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. Initial research results have been obtained, analyzing force-centric path-tracking control for a simplified robot manipulator in a scenario where a robot tool interacts with a wall under both path-tracking and force constraints.

1.1. Plans for 2022

The research by Theodor Westny, Björn Olofsson, and Erik Frisk regarding force-centric prediction, planning and control for autonomous trucks will continue, utilizing the results obtained during the first project year to adapt and extend the methods for at-the-limit maneuvering previously developed in ELLIIT projects. In particular, using the developed models and uncertainty predictions will enable autonomous velocity adaptation for avoiding both collisions with surrounding vehicles and objects and entering hazardous situations such as roll-over. The results are planned for submission to conference during 2022.

The research by Jian Zhou, Björn Olofsson, and Erik Frisk regarding traffic environment modeling and prediction in multi-vehicle scenarios, will be further investigated using real traffic data recorded at highways and stored in open-source databases. Moreover, aspects particularly related to dynamics and involved force interactions in the scenarios will be investigated. The overall goal of such investigations is to validate the feasibility of the methods for autonomous vehicles in real traffic. A manuscript extending the accepted paper for the European Control Conference 2022 is planned for submission during 2022.

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 initial results to the case where the mobile platform is included and there are interaction forces also between the platform and the ground. The results are planned for submission to conference during 2022.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

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	2016-2021/22

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

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.

5. Inter-university cooperation: summary for 2021

Significant joint research has been performed between Div. Vehicular Systems, LiU and Dept. Automatic Control, LU. Björn Olofsson (LiU, LU) is a research fellow 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 2021

N/A

7. Industry and institute cooperation

- Autoliv (vehicle accident databases, Dr. Nils Lübbe and Dr. Erik Rosén).
- 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)
- Toyota Material Handling (Master's thesis project)
- OMotion AB (Master's thesis project)

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

Anders Robertsson is responsible for the Applied Robotics course, given within the undergraduate education at LU.

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

The 2nd cycle course at LiU called “Autonomous vehicles – planning, control, and learning systems” developed by Erik Frisk, Björn Olofsson, and Jan Åslund at Div. Vehicular Systems, LiU, was given the third time during the fall semester 2021. Results from this ELLIIT subproject 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. Victor Fors had a guest research lecture in the course, presenting ELLIIT research.

Björn Olofsson has been a main contact at Dept. Automatic Control for the “autonomous driving team” of the “Formula student project” at Lund University, and initiated related thesis projects.

10. 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 2021, several school classes visited the lab and experienced demos of ongoing research. In these presentations, parts of the research results demonstrated were obtained within this ELLIIT subproject. There were also additional activities co-organized by DIGIT@LTH & AI Lund aimed for industry, the public sector and colleagues at Lund University.

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

- Anders Robertsson is Director of Robotics 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.

12. 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 2021

At LiU side, the recruitment was concluded in July 2021. The position was offered to Mehrdad Salimnejad. He applied for the VISA and residence permit and in the meantime we managed to finalize one paper that is now published. The student officially started at LiU in January 2022.

In the meantime, the PI was conducting research in the area, and we managed to have several related publications accepted and submitted, where the semantics of information show clear benefits in scenarios such as source coding, autonomous maintenance, real-time remote tracking, and fault detection in IoT systems. Indicative (not exhaustive) publications are listed below:

1. G. Stamatakis, N. Pappas, A. Fragkiadakis, A. Traganitis, ''Autonomous Maintenance in IoT Networks via AoI-driven Deep Reinforcement Learning", IEEE INFOCOM - 4th Age of Information Workshop, May 2021.
2. N. Pappas, M. Kountouris, ''Goal-Oriented Communication for Real-Time Tracking in Autonomous Systems", IEEE International Conference on Autonomous Systems (ICAS), Aug. 2021.
3. P. Agheli, N. Pappas, M. Kountouris, ''Semantics-Aware Source Coding in Status Update Systems", IEEE ICC Workshop on Semantic Communications, May 2022.

At LU, activity in this project has been limited due to the severely delayed recruitment of the PhD student who will work in the project (the LU recruitment process was concluded in June 2021, but a residence permit was not approved by the Migration Board until the end of 2021), as well as approximately six months of parental taken by the co-PI. Nonetheless, some scientific results were obtained, in particular in terms of building up our testbed capability (in collaboration with other projects) and papers published in the area of industrial control systems. Our lab is now equipped to experiment with a full industrial control environment, including real-time processes and other end devices, a 5G base station and accompanying core network, a PLC, and a cloud backend.

Now that both students are recruited, we have started the joint meetings for the joint activities to further strengthen the collaboration.

1.1. Plans for 2022

Mehrdad Salimnejad, LiU PhD student is currently working on a stream of papers related to semantics of information, we expect two submissions/publications before the end of 2022.
Suleyman Sadikhov, the LU PhD student, has since February started working in the project and is currently designing experiments to be carried out in our lab. He has investigated industrial IoT gateways to include in the lab environment and selected one suitable for his experiments. He has conducted a literature review on Age of Information in real industrial environments, including its interaction with industrial communications protocols such as ProfiNET. During 2022, our plan is for him to carry out experiments investigating how AoI can be used together with ProfiNET, and what gains can be made in terms of network performance and efficiency from using this metric instead of more traditional ones such as end-to-end delay. The initial experiments will be based on the existing theoretical work conducted by the team at LiU, employing the same scenario such that we can compare the testbed results with the analytical ones.

2. Awards and recognitions
   N. Pappas

- 2022 Journal of Communications and Networks (JCN) Best Paper Award
- 2021 Best Student Journal Paper Award in Swedish Communication Technologies Workshop (Swe-CTW 2021)
- 2021 Top 2% scientists list, single year impact, in the area of Networking and Telecommunications

3. External funding attracted

N.Pappas “Semantics-Empowered Communication for Networked Intelligent Systems”, Swedish Research Council (VR), (3 800 000 SEK) (2022-2025)

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amount per year	Duration of project
Low Latency Communications for Wireless Networks: Exploiting Traffic Characteristics	CENIIT	450kSEK	6 years
Physical Layer Secrecy for IoT Networks with Heterogeneous Traffic	Swedish Research Council (VR)	350kSEK	2 years

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

Mehrdad Salimnejad (PhD student, LiU, recruted during 2021 but started 2022-01-17). Suleyman Sadikhov (PhD student, LU, recruited during 2021 but started 2022-02-01)

5. Inter-university cooperation: summary for 2021

Several online meetings between the PIs as well as a physical meeting in connection with the ELLIIT workshop in Lund. Furthermore, we have planned several visits to both sites for the further in-site collaboration.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

N/A

7. Industry and institute cooperation

Collaboration with ERICSSON is expected within this project.

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

N. Pappas is currently developing two new courses that will take place in 2023, namely the Wireless Connectivity and the Performance Analysis and Evaluation of Communication Networks. In addition, he is developing a PhD course on Age of Information.

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

N. Pappas is a member of the IEEE Tactile Internet standardization group. Furthermore, he is member of One6G and he gave a talk on “Age and Semantics of Information” at One6G in March. Other relevant activities are:

- Secretary for the IEEE Tactile Internet TC
- Co-chair for the Special Interest Group on IoT in Tactile Internet (IEEE Technical Committees)

Tutorials

- 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
- IEEE SPAWC 2021: Goal-Oriented Communication for Networked Intelligent Systems

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

N. Pappas - Symposium/workshop/special session chair

- IEEE International Conference on Communications (ICC) 2022
- IEEE Wireless Communications and Networking Conference (WCNC) 2022

- IEEE SPAWC 2021 Special session on Information Freshness in Real-Time Communication Networks
- 17th International Symposium on Wireless Communication Systems (ISWCS) 2021 - Special Session on Age of Information
- The 4th Age of Information Workshop (AoI'21) in conjunction with IEEE INFOCOM 2021

N. Pappas - Editorial

- Expert Editor for Invited Papers, IEEE Communications Letters
- IEEE Transactions on Communications
- IEEE/KICS Journal of Communications and Networks
- IEEE Open Journal of Communications Society
- Guest-editorial IEEE Internet of Things Journal Special Issue on ''Age of Information and Data Semantics for Sensing, Communication and Control Co-Design in IoT"

12. Open source software contributions

N/A

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 Ph.D. projects were funded. These projects will run 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 2021

Models for opinion dynamics. We have developed several models for opinion dynamics. A first one has to do with the so-called biased-assimilation problem, in which an agent tends to evaluate in different way its own opinion as compared to those of the other agents. The particular extension we studied in the paper is associated to signed graphs, i.e., to the case in which information on e.g., trust/mistrust among agents is available and can be encoded in the interaction graph.

Another model in which self-opinions are valued differently from the opinion of the other agents is the so-called Friedkin-Johnsen (FJ) model. We developed an extension of the FJ model, in order to deal with concatenations of opinion dynamics processes, like when successive discussion meetings have to occur in order for a group of agents to achieve a common decision (here a consensus).
The concatenated FJ model was used to investigate a concrete example: how the climate negotiations that led to the 2015 Paris agreement unfolded over the 10+ years that preceded this accord. We showed that the model we developed has predictive power for describing which countries had a more influential role in this negotiation process.

Control-inspired network centrality measures. Another axis of research involved the development of centrality measures on networks inspired by system & control thinking. We showed that the notion of non-normality (i.e., the deviation from normality of the adjacency matrix, concept related to the "directedness" of a graph) is helpful in understanding the control energy required to steer a network. In particular, significantly non-normal networks are easier to steer than normal ones (the latter are more symmetric, and control is all about "breaking symmetries").

1.1. Plans for 2022

The research on the concatenated FJ model is continuing in 2022 for both PI and co-PI.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amount per year	Duration of project
Control of network systems with signed dynamical interconnections	Australian Research Council	150 K AUS $	4 years
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	6 M SEK	5 years

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

N/A

5. Inter-university cooperation: summary for 2021

ELLIIT collaboration: The PI and co-PI have initiated interacting on this and other topics of the project in the ELLIIT workshop which was held in Lund in October 2021. Discussions have followed up since then and are continuing in 2022.
External collaborations: the PI hosted at LiU 2 visiting PhD students: Lingfei Wang from the Chinese Academy of Science, Beijing and Carmela Bernardo from University of Sannio, Benevento, Italy. Both were involved on research topics related to this project. Other collaborators included Guodong Shi, from University of Sydney, Australia, Yiguang Hong from Tongji University, Shanghai, China and Francesco Vasca, Univ. of Sannio, Italy.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

N/A

7. Industry and institute cooperation

N/A

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

The PI delivered a new PhD course entitled “Opinion Dynamics on Social Networks” arranged in cooperation with the University of Sannio, Italy.

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

Our paper on Paris agreement, published in Science Advances was highlighted on the LiU News (https://liu.se/en/news-item/matematisk-berakningsmodell-kan-ge-mer-effektiva-klimatsamtal) and received attention from several news outlets, like ScienceDaily (https://www.sciencedaily.com/releases/2021/12/211215142050.htm), and PhysOrg (https://phys.org/news/2021-12-mathematical-efficient-climate.html)

11. 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 10th Int. Conference on Complex Networks and Their Applications, and of the 19th International Conference on Computational Methods in Systems Biology.

12. 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 2021

N/A

1.1. Plans for 2022

The two PhD students that form the core of this project have made contact with each other and will have regular online meetings, as well as in person meetings over the year. The PIs will also meet in person 3-4 times per year. The LU student will gather an empirical dataset based on public genomic resources of butterflies and moths, that will form the basis of testing the new methodology developed by the LiU student and collaborators. Both students will continue to take part in online meetings with collaborator Fredrik Ronquist in Stockholm. The first results of the project are expected towards the end of 2022.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

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	700kSEK	2018-2021

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

The PhD student to be based at Lund University was hired starting 03 December 2021. The student is Etka Yapar, who has a background in bioinformatics, and will be applying the new methodology developed as part of this project to empirical data consisting of publicly available genomic resources of butterflies and moths. Since this part of the project only started in December 2021, no results can be reported, other than the project started off well and first results are expected during 2022.
The PhD student to be based at Linköping University was hired starting mid-August 2021. The student is Bayu Beta Brahmantio, who has a background in statistics, and will be developing new methodologies for tree structured data. Since this part of the project only started in August 2021, no results can be reported, other than the project started off well, new collaborations have been established, method development directions have been agreed on.

5. Inter-university cooperation: summary for 2021

Cooperation between LiU and LU in 2021 was mainly done over Zoom due to the pandemic. Joint calls for the PhD positions were coordinated, both PIs took part in evaluating the candidates and interviewing them. Once the students had been chosen, Zoom meetings were held several times over the course of the autumn to discuss how to proceed with the project. We anticipate more in person meetings in 2022.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

Bayu has started a collaboration with Dr. Jesualdo A. Fuentes-González (Dept. Biology, Florida International University) concerning applying the newly developed methods to biological datasets. Bayu and Etka have jointly started a collaboration with Dr. Anastasios Stefanou (Fac. Mathematics/Computer Science, Bremen University) and Paweł Dłotko (Dioscuri Centre in Topological Data Analysis, Polish Academy of Sciences) concerning the development of network based methods.

7. Industry and institute cooperation

N/A

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

Bayu Beta Brahmantio has been a teaching assistant on several master level courses in our programme in Statistics and Machine Learning : Advanced R Programming, Machine Learning, Bayesian Learning and Multivariate Statistics. He also helped in master thesis work.

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

N/A

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

N/A

12. Open source software contributions

Software is being worked on, but as part of Bayu's work we plan on providing open source R packages.

C3: Real-Time Realistic Pixel Synthesis using Deep Learning for Augmented and Virtual Reality

PI: Michael Doggett, LU
Co-PI: Patric Ljung, 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 2021

During the last year the project has been in a start up phase as new people are hired and founding research continues, while new directions are explored. We have hired a new PhD student, and are working to hire a second. Continuing research has lead to major breakthroughs in the area of differentiable rendering.

This project aims to use the latest technology and research in Computer Graphics, Augmented and Virtual Reality to enable immersive and realistically localised Augmented Reality experiences. This requires working with the latest hardware and coupling that with the latest technologies.

* Generating Billions of pixels for XR

Ensuring synthetic 3D objects look realistic when displayed on augmented reality headsets and layered over the physical world is a challenging task. Over the last year we have investigated a system to capture the lighting in a scene using a separate camera and raspberry Pi, that communicates data to the a Microsoft HoloLens 2 head set. The camera and raspberry Pi are mounted on the HoloLens allowing accurate direction capture. The lighting is processed using white balancing and stored in an adaptive two dimensional quad tree that is progressively updated as new data is captured. Once an object is placed in the scene this data is accessed and interpolated to light objects in the scene making them blend more naturally into their surroundings, particularly when complex lighting situations are encountered.

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

During 2021 research continued on using Real-Time Ray Tracing hardware in modern GPUs to produce advanced lighting effects, in particular caustics. Caustics occur when light is concentrated via transparent objects. Our approach combines bi-directional tracing of light and view paths with the BVH hardware acceleration to store and access the light as it travels through the scene. By using hardware acceleration we are able to achieve real-time frame rates for complex reflections and refractions.

We have also created a new method for modelling plasma in order to use plasma as a light source in 3D rendering. This new method is based on traditional Computational Fluid Dynamics techniques, but instead of working with fluid, considers the movement of charged particles inside the forces of a magnetic field. This research was begun in 2021 and will continue into 2022.

1.1. Plans for 2022

In 2022 Real-Time rendering research will focus on Neural Rendering techniques that can enhance the capabilities of AR/VR.
Also, we will ramp up the activities for the captured and procedural data part of the project at Linköping.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amount per year	Duration of project
Efficient GPU Programming for Visual and Autonomous Systems	KWA WASP-AS	1 PhD student	2018-2022

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

New PhD student in the Lund University Graphics Group, Rikard Olajos. September 2021.

5. Inter-university cooperation: summary for 2021

N/A

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

Michael Doggett has continued collaboration with Cheng Zhang and Shuang Zhao at the University of California, Irvine, and Zhou Dong at Facebook Reality Labs on Differentiable Rendering.

7. Industry and institute cooperation

Michael Doggett collaborates with Calle Lejdfors, Director of Production R&D at Tencent, on Real-Time Rendering of Smoke with Masters Student Lukas Mattsson.
Michael Doggett and Gustaf Waldemarson collaborate with ARM in Lund, Sweden.

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

Michael Doggett runs and lectures in the Computer Graphics course at Lund University, while supervising several Master Thesis in Rendering using the latest Ray Tracing hardware.

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

N/A

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

Michael Doggett is working on I3D 2022 as a General Co-Chair and is an Associate Editor for Computers and Graphics.

12. 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 2021

A novel method for robust multi-channel phase difference estimation of oscillating transient signals in high noise levels has been developed (submitted and accepted to EUSIPCO2022). The method is based on reassigned spectrograms and the robust final estimate is given as the median over time-frequency bins.

Furthermore, estimation of temporal response functions and neuro-current response functions from EEG data has been investigated and the two PhD students in the project have studied EEG data preprocessing methods.

1.1. Plans for 2022

The ongoing work involves reliable estimation of low coherence values of EEG and sound as well as of neuro-current response functions using a Lasso algorithm. Dimension reduction approaches will also be investigated.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amount per year	Duration of project
LINK-SIC (2 projects within this center)	Vinnova	1800kSEK (for these 2 projects)	2017-2022 (might be extended)

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

Oskar Keding: PhD student at Lund University, May 2021
Johanna Wilroth: PhD student at Linköping University, August 2021

5. Inter-university cooperation: summary for 2021

Meeting in Lund with Maria Sandsten, Oskar Keding and Johanna Wilroth, September 2021.
Meeting in Lund (in connection to the ELLIIT workshop) with Maria Sandsten, Martin Enqvist, Oskar Keding, Johanna Wilroth, Martin Skoglund and Emina Alickovic, October 2021.
Two online meetings with Maria Sandsten, Martin Enqvist, Oskar Keding, Johanna Wilroth, Martin Skoglund and Emina Alickovic, November and December 2021.
Close collaboration between the two PhD students, Oskar Keding and Johanna Wilroth.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

An established collaboration with Eriksholm Research Centre via Martin Skoglund and Emina Alickovic.

7. Industry and institute cooperation

An established collaboration with Eriksholm Research Centre and Oticon A/S via Martin Skoglund and Emina Alickovic.

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

Martin Enqvist is vice chairman for the committee for electrical engineering, physics and mathematics at Linköping University.

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

N/A

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

Martin Enqvist is associate editor for IEEE Control Systems Letters.

12. 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 2021

A significant part of the work during 2021 was devoted to setup the project and to recruit three PhD students (see below).

Some of the main contributions from CS/BTH in projects related to the GPAI project are (i) the development of new machine learning algorithm for energy-aware very fast decision trees, (ii) a GPU-efficient algorithm for correction of chromatic aberration in images, and (iii) an evolutionary clustering algorithm for streaming data. All of these results provide background and understanding of application behaviour for important application domains for the GPAI project.

A major technical contribution from Christoph Kessler's group is the third generation of the single-source high-level programming framework *SkePU* for heterogeneous parallel systems and clusters, complemented with newly designed high-level programming support for linear algebra computations, image processing and deterministic parallel pseudorandom number generation. The pattern-based programming abstractions of SkePU are planned to become part of a future high-level multi-domain programming model for mixed-domain applications targeting heterogeneous systems with generalized

AI accelerator hardware (GPAI) being developed in this project. Other related research results from Kessler's group include a new application-level technique for temperature-aware energy-optimal scheduling of moldable (parallelizable) streaming tasks onto 2D-mesh-based many-core CPUs with DVFS, and an algorithm for combined design space exploration with task scheduling of moldable streaming tasks on reconfigurable platforms.

1.1. Plans for 2022

During 2022, we will conduct a number of initial studies. A survey of hardware accelerators and their programming interfaces, especially those targeting edge computing, is ongoing. Further, a study on mapping and scheduling of tasks on parallel hardware is also ongoing. One goal is to understand the interaction between the applications' properties and behaviours, the runtime, and the hardware.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amount per year	Duration of project
Enhancing programmability and boosting performance portability for exascale computing systems (EXA2PRO)	EU H2020	1.4 MSEK (LiU)	2018-2021
Directed Air Data Link	VINNOVA	800kSEK	2020-2022
Nordic University Hub on Internet of Things	NordForsk		2018-2023
Tools and Languages for Machine Learning in Radar and Radio Astronomy	STINT		2019-2022

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

Three new PhD students have been recruited for the project:

- Michail Boulasikis, started was recruited in Lund and started in September 2021.
- Christoffer Åleskog, was recruited at BTH in fall 2021 and started in January 2022.
- Sehrish Qummar, was recruited in 2021 and started in Linköping in March 2022.

5. Inter-university cooperation: summary for 2021

We have regular project meetings once per month, where we discuss progress and development of the project.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

N/A

7. Industry and institute cooperation

CS/BTH has ongoing collaborations with, e.g., Ericsson and City Network (submitted project applications), and Saab (ongoing project, “Directed Air Data Link”).

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

The SkePU programming framework has been used for programming labs in a master-level course on multicore and GPU programming at Linköping University in autumn 2021.

A new master course was developed at BTH on multiprocessor programming. The course covers both traditional thread-based programming as well as GPU programming using CUDA.

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

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

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

Håkan Grahn (BTH/CS) served as guest editor of the journal *Big Data Research* (together with Lars Lundberg, BTH, Valeria Cardellini, University of Rome Tor Vergata, Italy, Andreas Polze, Hasso Plattner Institute, Germany, and Sogand Shirinbab, Ericsson AB) for a special issue on "Big Data in Industrial and Commercial Applications".

12. Open source software contributions

SkePU v3.1 (single-source high-level programming framework for heterogeneous parallel systems) was released in August 2021, https://skepu.github.io

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 suggested technique very low power levels corresponding to devices in consumer products can be measured.

1. Main scientific achievements during 2021

N/A

1.1. Plans for 2022

In 2022, we will investigate the pros and cons of two different manufacturing techniques for metasurfaces. The surfaces will be used to image the radiated power of mm-wave devices. We will also develop algorithms for rapid imaging over large surfaces.

During the spring, we manufactured the first metasurface samples using dry phase patterning technique in collaboration with the company DP Patterning in Norrköping. The printed structures are promising, and presently investigating techniques to attach lossy elements to them in a non-destructive way. During the project, we realized that this second step is a bottleneck in manufacturing, and we have developed new designs to eliminate it. We will use screen printing to manufacture the first prototypes.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amount per year	Duration of project
Optimal antenna synthesis	VR	800000	2018-2022

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

People active in the project

- Johan Lundgren, post doc LU
- Marzieh Zabihipour, PhD student LiU

We announced two PhD positions 2021 but did not fill them. They are re-announced 2022.

5. Inter-university cooperation: summary for 2021

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 Lund, October 26-27, 2021. Another physical meeting was arranged in Norrköping Dec 7 2021, 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 2021

N/A

7. Industry and institute cooperation

Collaboration with DP Patterning in Norrköping for manufacturing of metasurfaces. Ongoing discussions with Davide Colombi at Ericsson for validation of EMF performance at 28GHz.

Initial discussions with Torleif Martin at QAMCOM about using the surfaces for array antennas. We hope to joint test next year

8. List of patent applications published during 2021.

Patent title	Application Number
Method, system and components for measuring an electromagnetic radiative near field and performing a radiation characterization using thermal imaging	SE 2051181-2

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

- M. Gustafsson was a teacher in the European School of Antenna and Propagation (ESoA) course 'Antenna Systems for 5G Communication' – 16/2.
- D. Sjöberg lecturing a course on Radar and Remote Sensing, with interactions between students and local radar industry.
- D. Sjöberg Director of PhD studies at EIT.

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

- M. Gustafsson co-organized a workshop with Christer Larsson and Andreas Gällström from SAAB on 'Modern Optimization and Machine Learning in Acoustics, EM, Radar, and Sonar' 19/5.
- M. Gustafsson and Johan Lundgren co-organized a workshop with Christer Larsson and Andreas Gällström from SAAB on 'Modern Optimization and Machine Learning in Acoustics, EM, Radar, and Sonar II' 23/11.
- M. Gustafsson presented a research seminar 'IR and metasurface based power density measurements', Ericsson AB, 3/12.

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

- M. Gustafsson IEEE Antennas and Propagation best paper award committee member.
- M. Gustafsson chair of the Swedish joint IEEE Microwave Theory and Techniques Antennas and Propagation chapter.
- D. Sjöberg Chair of the Swedish National Committe of Radio Science.

12. Open source software contributions

N/A

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.

1. Main scientific achievements during 2021

N/A

1.1. Plans for 2022

N/A

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.
N/A

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

Niloofar Momeni, PhD student at Lund (parental leave).

5. Inter-university cooperation: summary for 2021

N/A

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

N/A

7. Industry and institute cooperation

N/A

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

N/A

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

N/A

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

N/A

12. 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 2021

We investigated different approaches to the problem at hand. One approach was to formalze the problem as an out-of-distribution-detection problem. We took YoLo as the vision application and then were aiming to predict the performance of YoLo. We collected a suitable dataset and explored the use of Variational Autoencoders (VAE) on this.
These results were presented at the ELLIIT conference.
It became clear that VAE are not suitable. As alternative we are now investigating Normalized Flows (NF), an approach that is able to learn a bijective function between probability distribution functions (pdf), in our case a between the pdf on an image space and a Gaussian PDF.

1.1. Plans for 2022

- Continue exploration of NF,
- development of conditional NF: Insight that the out-of-distribution-detection is application-based. I.e, the probability of an image being good depends on the application and the targeted image processing function. We aim to extend the IF towards a conditional IF.
- Intermediate publications at SCIA.
- For final results, we target CVPR.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.
N/A

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

- Hired Simon Kristoffersson Lind at Lund in August 2021
- Hired Zanyu Tuo at LiU, 2021-08-01, He subsequently quit in March 2022.
- Currently hiring a replacement.

5. Inter-university cooperation: summary for 2021

N/A

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

Collaboration with the German Space Agency “Deutsche Luft und Raumfahrt (DLR)”. They have the same problem, i.e., a vision-controlled mars rover should be able to evaluate and assess the reliability of visual perception functions.

7. Industry and institute cooperation

- German Space Agency “Deutsche Luft und Raumfahrt (DLR)”.
- Collaboration with Tetra Pak.

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

- Use of learned insights for the course on Intelligent Autonomous Systems in Lund.
- Per-Erik Forssén has given a lecture on 3D-cameras in the TSBB09 course, based on research on ToF-cameras, and Lidars.

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

N/A

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

- The PI was coordinator of the 2021 ELLIIT conference in Lund.

12. Open source software contributions

- All software is mained as open source following CI-strategies.
  - 12.1. RLL open source package: https://github.com/felja633/RLLReg
  - 12.2. SHIRE open source package: https://github.com/midjji/shire
  - 12.3 IMO dataset: https://www.cvl.isy.liu.se/research/datasets/imo-dataset/
  - 12.4 Git.cs.lth.se

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.

1. Main scientific achievements during 2021

The PhD students started during the third and fourth quarters, respectively, and thus they have focused on getting acquainted to the role as a PhD student, taking introductory courses and discussing the line of research.

1.1. Plans for 2022

The main plans are to conceptualize the topics of the project and to define empirical studies to identify industrial practices and needs.

For the business modelling part, the plans are to:

- Conceptualize the process of data affordance in B2B industries.
- Initiate data collection and collaboration with companies on the topic of data affordance, sharing, and governance for B2B services and solutions.

For the technical solutions part the plans are to:

- Identify practices, needs and gaps in the literature, based on a reading course of related literature on software and data ecosystems.
- Explore industrial needs in an emerging ecosystem of Internet of Things (IoT) companies.
- Study existing IoT and data catalog tools, based on identified needs from data ecosystems.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amount	Duration of project
ESS Data Lab	Vinnova	540 kSEK	2020-2021
RoDL -- Road Data Lab	Vinnova	557 kSE<K	2020-2021

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

Two PhD students were recruited to the project:

1. Tanvir Ahmed, LiU to the business modeling part, beginning in June.
2. Konstantin Malysh, LU to the technical solutions part, beginning in October.

5. Inter-university cooperation: summary for 2021

The two students met at the ELLIIT workshop in October and attended the project's poster session. Konstantyn Malysh was accepted as an affiliated PhD student to the WASP program. WASP affiliation gives access to PhD student courses and academic and industrial networks.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

N/A

7. Industry and institute cooperation

N/A

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

N/A

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

Per Runeson gave four presentations during the fall on the concept of open data ecosystems

- 2021-09-01 Keynote at Graz Symposium Virtual Vehicle, https://www.gsvf.at Open source and open data for automotive – threats or opportunities?
- 2021-11-11 Speaker at STEW'21: Open data ecosystems – caring for innovation by sharing, Lund, Sweden
- 2021-11-23 Internetdagarna 2021: Från betesmarker till källkod och data – allmänningar förr och i framtiden
- 2021-12-03 Keynote SweDS21: Open data ecosystems – wishful thinking or successful business?

Christian Kowalkowski gave three presentations during autumn on service-based business models

- Invited keynote speaker: IRSSM (International Research Symposium in Service Management) India Chapter (2021, online), Servitization: How Product Firms Can Build Competitive Advantage through Services and Customer Solutions

- Invited keynote speaker: DigITS (Digitalization, Innovation, Transformation and Sustainability) Conference, Woxsen University, Hyderabad, India (2021, online), Digitalization and Service-Driven Growth in Business Markets
- Servitization Live (2021, online), An international round-up of servitization trends, 04.10.2022

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

Per Runeson was Co-editor of IEEE Software Special Issue on Collaborative Aspects of Open Data. The special issue was published in February 2022 https://doi.org/10.1109/MS.2021.3118123

12. Open source software contributions

N/A

ELLIIT Infrastructure 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 for enabling the ARS.
Lund University and Linköping University collaborate with the same robot platform to allow easy replication of results for indoor environments. 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.

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.

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.

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.

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.

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.

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 is upgraded to increase the performance and the projection system covers 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)

1. Main scientific achievements during 2021

N/A

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

N/A

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

N/A

5. Inter-university cooperation: summary for 2021

N/A

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

N/A

7. Industry and institute cooperation

N/A

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

N/A

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

N/A

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

N/A

12. Open source software contributions

N/A

Bo Bernhardsson, Professor in Automatic Control (LU)

1. Main scientific achievements during 2021

During 2021 I continued work on statistical learning from EEG signal together with PhD student Frida Heskebeck (WASP), Martin Gemborn Nilsson (ELLIIT), and Pex Tufvesson (financed by Ericsson). Quite some time has also gone in to the international master program "Machine Learning, Systems and Control" at Lund University that I share responsibility for with Mikael Nilsson (LU/math). I have taken on a new role as a member of the WASP-DDLS (data-driven life science) collaboration management group. To support the future cooperation between the data-driven life sciences a suggestion was prepared and handed in for an ELLIIT focus period in "Data-driven Modelling and Learning for Cancer Immunotherapy", to be held in Lund May 2022. During 2021 I was main supervisor for 4 PhD students, and co-supervisor for an additional 6 students, including two at the EIT department. Two students, for which I have been cosupervisor, finished during 2021: Mattias Fält who has worked with optimization algorithms with Pontus Giselsson as main suvervisor, and Marcus Greiff, who has worked with nonlinear control and estimation for UAVs, with Anders Robertsson as main supervisor.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amount per year	Duration of project
Efficient Learning of Dynamical Systems	WASP	1 MSEK	2018-2022
Optimizing the Next Generation Brain Computer Interfaces using Cloud Computing	WASP	0.7MSEK	2019-2024
Realtime Individualization of BCIs	WASP	1MSEK	2019-2021

New funding was secured during the year, through the WASP-DDLS project, for a postdoc working with pharmacometric modelling, to be starting in 2022. This is a collaboration project with the Department of Pharmacy in Uppsala.

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

N/A

5. Inter-university cooperation: summary for 2021

The covid-19 modeling work mentioned below a was based on signficant inter-university cooperation, involving LU, LiU, Uppsala, KTH, Chalmers.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

The covid-19 modeling work that was started in 2020 continued. This was a collaborative effort involving researchers at several universities and people from health sciences and the medical profession. The resulting project "COVID-19: *Dynamic modelling for estimation and prediction",* was included in the Royal Swedish Academy of Engineering Sciences list of 51 promising innovation/research projects 2021. Furthermore, the work on brain computer interfaces builds upon inter-disciplinary cooperation between the three departments of Automatic Control, Mathematical Statistics, and Psychology. As mentioned above, planning work was done for an ELLIIT focus period in "Data-driven Modelling and Learning for Cancer Immunotherapy", to be held in Lund May 2022.

7. Industry and institute cooperation

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. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

The course "Modeling and Learning from Data", which I started in 2020, this year (2021) had around 150 students applying for it. We unfortunately needed to limit the intake, since we could only handle 60 students this year. The ambition is to ramp up to be able to give the course to more students in 2022, if the interest remains high.

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

"Navigering och Radiokanalskattning", lecture recorded for the ELLIIT seminar series on societal challenges from an ICT perspective , Nov 21.
"Reinforcement Learning", lecture in the external LUCE course "AI för civilingenjörer", Nov 9.

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

Member of the WASP-DDLS collaboration management group.

Evaluator of an application to associate professor in Signal Processing in Uppsala. Member of an examination committee (Alireza Javid) in Information Science and Engineering at KTH.

12. Open source software contributions

N/A

Tom Ziemke, Professor in Cognitive Systems (LiU)

1. Main scientific achievements during 2021

My main research focus is on how people interpret and interact with autonomous technologies, ranging from social robots to automated vehicles. Main achievements in 2021 include the following:

- Our research on the psychological mechanisms underlying human interpretation of robot behavior resulted in two journal publications in the *ACM Transactions on Human-Robot Interaction*.
- Our research on social robots in eldercare, in collaboration with care homes in several municipalities in Östergötland, resulted in two publications on (a) participatory design workshops and (b) the pandemic's effects on social robot use in care homes

2. Awards and recognitions

Received the *"Outstanding Paper of the Decade 2006-2016"* award from the *International Society for Artificial Life* (July 2021), for a paper on "Enactive AI", published in the *Artificial Intelligence* journal in 2009.

Our online dataset *"The DREAM Dataset: Behavioural data from robot enhanced therapies for children with autism spectrum disorder"* was listed as number 3 of the *"Top 3 Downloads"* in the *Swedish National Data Service*'s Annual Report 2021.

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amount per year	Duration of project
SmartWork – Smart age-friendly living and working environment	EC, Horizon 2020	Apx. 1 mkr	January 2019 – March 2022
Human Interaction with Systems-of-Systems SSF	SSF	N/A (funding for RISE PhD student)	2019-2024

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

A postdoc was hired for the ELLIIT project A22 in late 2021 (but formally started 1 January 2022).

5. Inter-university cooperation: summary for 2021

I regularly collaborate and publish with a number of researchers at European universities in European projects (cf. above & below). I also guest-edited a journal special, published July 2021, on Explainable Robotic Systems with researchers at Utrecht University, Brown University, and UC Berkeley (cf. details below). Together with colleagues in the US, I am program co-chair for the CogSIMA 2022 conference (cf. below).

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

I'm cognitive scientist working in a computer science department, with a focus on human-technology interaction, so practically all my research is interdisciplinary. I actively collaborate with researchers in, among other areas, robotics and AI (e.g. Umeå, Skövde), transport (VTI, RISE), psychology / behavioral science (Utrecht, VTI, BKV/LiU), social neuroscience (BKV, LiU) and gender studies (TEMA, LiU). We also have long-term collaborations with eldercare homes in several municipalities in Östergötland.

7. Industry and institute cooperation

I collaborate closely with VTI, the Swedish National Road and Transport Research Institute, and was a member of the LiU-VTI operative collaboration group (until spring 2022). The collaboration with VTI includes a PhD project on *remote driving* (Christian Jernberg) and the ELLIIT-funded postdoc project *"Human Interaction with Autonomous Minibuses"* (postdoc: Sam Thellman). I also collaborate with RISE in a joint SSF project on *"Human Interaction with Intelligent Systems-of-Systems*", as part of which I supervise the PhD student Oscar Bjurling, who works on human interaction with drone swarms. This also involves some collaboration with SAAB Aeronautics (co-supervisor: Jens Alfredsson).

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

Taught a new PhD course on *"Ethics of AI and Interactive Autonomous Systems"* (autumn 2021) and developed a new PhD course *"Critical Perspectives on AI"* (for spring 2022).

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

Our online dataset & software package *"The DREAM Dataset: Behavioural data from robot enhanced therapies for children with autism spectrum disorder"* was listed as number 3 of the *"Top 3 Downloads"* in the *Swedish National Data Service*'s Annual Report 2021 (with 764 downloads).

The Swedish magazine *"Funktion i Fokus"* published an article on our research on social robots for kids with autism (*"Robot effektivt hjälpmedel för barn med autism"*).

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

Guest-edited a special issue on *"Explainable Robot Behavior"* for the journal *ACM Transactions on Human-Robot Interaction*, together with Maartje de Graaf (Utrecht University), Bertram Malle (Brown University) and Anca Dragan (UC Berkeley), which was published in July 2021.

Technical program co-chair for the conference *CogSIMA 2022*, the *IEEE Conference on Cognitive and Computational Aspects of Situation Management*, to be held in Sorrento, Italy, in June 2022.

12. Open source software contributions

See 10.

Ingrid Hotz, Professor in Visualization (LiU)

1. Main scientific achievements during 2021

The main theme of my research is developing methods for the reduction of data complexity by extracting characteristic structures with semantic meaning used for visual exploration. In summary the research in the scientific visualization group, led by me, has mainly focused on three topics: The development and use of geometric and topological methods for visual data analysis for complex data types, concepts for the integration of automatic analysis methods in interactive exploration workflows, providing visualization tools in open-source software projects.

During the last year, the focus from a methodological point of view was at first using topological methods for the comparison of data coming from ensemble simulations or time series. And secondly evaluating topological segmentation methods with respect to accuracy. An application focus has been the analysis of electronic structures in physical and chemical applications and the analysis of tensor valued data in engineering. Some of our main achievements will be described in more detail in the following.

Topological data analysis for comparison of ensemble data and time series

- ***Scalar Field Comparison with Topological Descriptors: Properties and Applications for Scientific Visualization*** In topological data analysis and visualization, topological descriptors such as persistence diagrams, merge trees, contour trees, Reeb graphs, and Morse--Smale complexes play an essential role in capturing the shape of scalar field data. We present a state-of-the-art report on scalar field comparison using topological descriptors. We introduce a taxonomy of existing approaches based on visualization tasks associated with three categories of data: single fields, time-varying fields, and ensembles. These tasks include symmetry detection, periodicity detection, key event/feature detection, feature tracking, clustering, and structure statistics. Our main contributions include the formulation of a set of desirable mathematical and computational properties of comparative measures and classification of visualization tasks and applications that are enabled by these measures.
- ***Geometry-Aware Merge Tree Comparisons for Time-Varying Data with Interleaving Distances*****:** Merge trees, a type of topological descriptor, serve to identify and summarize the topological characteristics associated with scalar fields. They present a great potential for the analysis and visualization of time-varying data. First, they give compressed and topology-preserving representations of data instances. Second, their comparisons provide a basis for studying the relations among data instances, such as their distributions, clusters, outliers, and periodicities. Several comparative measures have been developed for merge trees. However, there are oblivious to the geometric embedding of the features which is essential in many visualization applications. We have developed a geometry-aware measure using labelled interleaving distances. We show that our approach is general, computationally efficient, and practically useful. Experiments demonstrate that such geometry-aware merge tree comparisons help to detect transitions, clusters, and periodicities of time-varying datasets, as well as to diagnose and highlight the topological changes between adjacent data instances.

Topological segmentations for visualization applications

- ***Topological analysis of density fields: an evaluation of segmentation methods*****:** Topological and geometric segmentation methods provide powerful concepts for detailed field analysis and visualization. However, when it comes to a quantitative analysis that requires highly accurate geometric segmentation, there is a large discrepancy between the promising theory and the available computational approaches. In this work, we compare and evaluate various segmentation methods with the aim to identify and quantify the extent of these discrepancies. Thereby, we focus on an application from quantum chemistry: the analysis of electron density fields. In the evaluation we consider methods originating from the domain of quantum chemistry and computational topology. We apply the methods to the charge density of a set of crystals and molecules and

compare quantitative measures such as total charge and dipole moments from these regions. As a result, we conclude that an accurate geometry determination can be crucial for correctly segmenting and analysing a scalar field.

- ***Morse theory-based segmentation and fabric quantification of granular materials.*** In this work a robust Morse theory-based framework for segmenting 3D X-ray computed tomography image (CT) has been developed. The result is a fabric, relative arrangement of particles, of granular ensembles. The framework includes an algorithm for computing the segmentation, a data structure for storing the segmentation and representing both individual particles and the connectivity network, and visualizations of topological descriptors of the CT image that enable interactive exploration. The Morse theory-based framework produces superior quality segmentation of a granular ensemble as compared to prior approaches based on the watershed transform. The accuracy of the connectivity network also improves. Further, efficient computation of various distribution statistics on the segmentation and the connectivity network is supported. Such a comprehensive characterization and quantification of the fabric of granular ensembles is the first step towards a multiple length scale understanding of the behaviour.

Visual analysis workflows:

- ***Tracking Internal Frames of Reference for Consistent Molecular Distribution Functions.*** In molecular analysis, Spatial Distribution Functions (SDF) are fundamental instruments in answering questions related to spatial occurrences and relations of atomic structures over time. Given a molecular trajectory, SDFs can, for example, reveal the occurrence of water in relation to particular structures and hence provide clues of hydrophobic and hydrophilic regions. For the computation of meaningful distribution functions, the definition of molecular reference structures is essential. Therefore, we introduce the concept of an internal frame of reference (IFR) for labelled point sets that represent selected molecular structures, and we propose an algorithm for tracking the IFR over time and space. This approach lets us generate a consistent space for the aggregation of the SDF for molecular trajectories and molecular ensembles. We demonstrate the usefulness of the technique by applying it to temporal molecular trajectories as well as ensemble datasets. The examples include different docking scenarios with DNA, insulin, and aspirin.
- ***Visual Analysis of Electronic Densities and Transitions in Molecules.*** The study of electronic transitions within a molecule connected to the absorption or emission of light is a common task in the process of the design of new materials. The transitions are complex quantum mechanical processes, and a detailed analysis requires a breakdown of these processes into components that can be interpreted via characteristic chemical properties. We approach these tasks by providing a detailed analysis of the electron density field. This entails methods to quantify and visualize electron localization and transfer from molecular subgroups combining spatial and abstract representations. The core of our method uses geometric segmentation of the electronic density field coupled with a graph theoretic formulation of charge transfer between molecular subgroups. The design of the methods has been guided by the goal of providing a generic and objective analysis following fundamental concepts. We illustrate the proposed approach using several case studies involving the study of electronic transitions in different molecular systems.

The Scientific visualization group: Currently it consists of 6 PhD students, 5 research engineers and three 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

Dirk Bartz Prize for Visual Computing in Medicine, EuroGraphics, 2021

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

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
In-Situ Big Data Analysis for Flow and Climate Simulations	SSF BD15-0082	900	2016-2021
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	2020-2021
A topology-based approach to patterns in dynamic network data for decision support	WASP, academic PhD	1 PhD	2021-2024

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

New 2 PhD students, 2 new research engineers.

5. Inter-university cooperation: summary for 2021

- 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 KTH and SU.
- 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.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

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

No active industry cooperation during 2021.

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

- Regularly offered courses in scientific visualization in Media and Information Technology program, course visualization for physicists (IFM, LiU)
- Co-organization of an international Spring School on Bio-Medical-Visualization (https://biomedvis.github.io/2021/)
- Organization of an international course on visual Storytelling (https://scivis.github.io/courses/visualstorytelling/)

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

N/A

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

- Chair of the international workshop series for 'Topological Methods in Visualization (TopoinVis) since 2015.
- Eurograpics executive committee
- Steering committee VCBM
- Coordinator of the SeRC Visualization Community, since August 2015.

- Reviewing activities for multiple international Journals and conferences.
- Associated editor for IEEE Transactions on Visualization and Computer Graphics, Computer Graphics

12. 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 2021

During this period, I have researched software quality and human aspects in software engineering.
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.

Beyond this work, I collaborated with a former colleague on cross-project software defect prediction for software projects that lack historical data. Since typical available datasets are skewed towards non-buggy components, resampling techniques are used to mitigate this problem. We showed that data resampling improves recall as well as the g-measure in cross-project defect prediction, however, at the expense of more false positives.

In the context of test-driven development, we developed a semi-automated approach to support the refactoring and reuse of behaviour-driven specifications. In an industry case study, we defined and used two similarity measures for identifying candidate specifications for refactoring and reuse. Compared with manual identification by developers, our approach was about 60 times faster and identified

refactoring candidates with high accuracy; it also outperformed an ML-based text classification approach.

Furthermore, we have started looking into behavioural aspects of software engineering and have started interdisciplinary work with a local colleague with a background in psychology. In particular, we are looking into the adoption of software development practices. In the past, practice adoption was mostly approached from a rational perspective. In practice, however, it has been observed that sufficient evidence for the efficacy of a practice does not "naturally" lead to its adoption. In an initial study, we identified 30 models and theories of acceptance behavior that are potentially relevant for research in software development contexts. We discuss these models from the human information processing perspective of automatic and affect-driven processes ("fast" system 1 thinking) and rational and rule-governed processes ("slow" system 2 thinking). Such theoretical foundations will help to understand and predict practice adoption in the industry and to improve the impact of software engineering research. Since most models and theories have overlapping constructs and have not been validated in software development contexts, further work is necessary to adapt existing data collection instruments to software development contexts.

Currently I'm co-supervising 4 Ph.D. students within the ELLIIT environment. Three of the Ph.D. students are partially financed by ELLIIT, of which 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 2021.
N/A

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

See projects A8 and B7.

5. Inter-university cooperation: summary for 2021

Within ELLIIT, I work closely together with the Software Engineering group in Lund (SERG), see projects A8 and B7. Furthermore, I am working 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 2021

Within BTH, we have started collaborating with colleagues from industrial economics on human aspects of computing.

7. Industry and institute cooperation

Within most projects we are collaborating with Ericsson and Axis.

8. List of patent applications published during 2021.

N/A.

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

Since summer 2017, I am responsible for BTH's common thesis course for all "civilingenjör" programs at BTH.

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

Recorded ELLIIT-video "Att bygga stora mjukvarusystem — snabbare, billigare och bättre?"

11. 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 2021, the Joint Track on Software Engineering Education and Training of the 43rd International Conference on Software Engineering and the EASE2021 PhD Symposium track (Evaluation and Assessment in Software Engineering).

12. Open source software contributions

N/A

Björn Landfeldt, Professor in Communication networks (LU)

1. Main scientific achievements during 2021

During this period, I have been focusing on the collection of background information to combine two research thrusts into a new area of investigation, edge processing for AR/VR applications. In order to tackle this new area, it is necessary to better understand the behaviour of the system and also to devise mechanisms that can learn and predict the system state. In modelling the system behaviour, we have further investigated our previous work in age of information behaviour in computational edge platforms and through a feedback-loop based system shown how it is possible to save on resources (that can be used for other computational tasks) while keeping the timeliness guarantees of a system. We are

currently building an experimental platform withing the LUNARC supercomputing platform to start testing the results in live implementations.

In the work on learning and predicting the system state of edge processing platforms, I have devised novel ways for the edge orchestration function to learn from previous patterns (Q-learning) and from this make predictions on the distributions of loads and types of processes that will arrive at the processing platform. This is an important ability, which can be used to make informed decisions about where to place computation and when to move computation among possible placements. The work was published in IEEE transactions.

In collaboration with Telenor, I have completed a study on the possibility to use statistical methods derived from the seminal work by Bianchi to predict the performance of Wi-Fi networks from access point measurements. This way of attacking the problem operators face with customer dissatisfaction due to poor WLAN performance stands in contrast to less accurate and more generalist approaches such as machine learning. I focused on the potential of collecting information through the Linux kernel as the vast majority of WLAN access points used by operators build on this system. The results show that the Linux kernel in its current architecture cannot be directly used to collect information of enough granularity, or at least, it is a very difficult problem. Therefore, more generalist approaches such as ML to estimate the wireless network state is a more attractive option.

These results will be used in new collaborations that are started between LTH and LiU in the area of VR/AR processing offloading and placement.

2. Awards and recognitions

N/A

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amount per year	Duration of project
A5GARD	EU /Celtic next	1727 kEuro	2020-2023

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

Hiring a new ELLIIT funded PhD student is currently ongoing. The hiring was supposed to happen 2021 but was unfortunately delayed.

5. Inter-university cooperation: summary for 2021

I have collaborated with Nikolaos Pappas at LiU on age of information modelling. This work is ongoing and expanding.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

During 2021 I started a collaboration with the industrial design research group in AR/VR systems at LTH as well as the Cancer research centre at LU. Together we are working on merging our research lab infrastructure to carry out joint research in mobile AR/VR systems and edge processing.

I also started an ongoing collaboration with a local SME, Sensative and region Västerbotten on infrastructure for distributed and remote healthcare. We are currently building a testbed for this ongoing work at EIT.

7. Industry and institute cooperation

I started collaborations with Ericsson research in Lund. Initially we have defined master thesis projects, one has finished in cellular beam management, one will start in August this year.

I also collaborated with Telenor towards the development of operator managed residential gateways to improve predictability of residential wireless performance. This work is currently ongoing.

Finally, as mentioned above in (6) I worked with Sensative and region Västerbooten.

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

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 etc.

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

N/A

11. 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 three Ph D. theses in 2021.

12. Open source software contributions

N/A

Cristian Sminchisescu, Professor in Computer Vision (LU)

1. Main scientific achievements during 2021

- Machine learning methodology including generalisation theory for neural networks
- Statistical 3d human body modelling
- Methods to reconstruct 3d human pose and shape from sensor data
- Human neural rendering
- Large scale 3d human motion datasets for fitness, interaction, self-contact, and human-object interactions
- Differentiable Physics-based 3d human sensing models
- Embodied visual active learning

2. Awards and recognitions

Program Chair for CVPR 2025.

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amount per year	Duration of project
3D Scene Perception, Embeddings and Neural Renderings	WASP-NEST	8,000,000	5 years

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

N/A

5. Inter-university cooperation: summary for 2021

ETHZ, Chalmers, KTH.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

Collaboration on sensing for autistic children (Predictable robots for autistic children, including publication)

7. Industry and institute cooperation

Max-Planck Institute, Google.

8. List of patent applications published during 2021.

Patent title	Application Number
Image processing method, system and device for synthesizing human appearance	US Patent 11,069,150 (granted)

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

N/A

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

N/A

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

Editorial board IJCV, Program Chair ICLR.

12. Open source software contributions

- Github.com/sminchisescu-research
- Statistical 3D human models: GHUM, imGHUM, H-SPACE
- Multiple 3d human motion capture dataset and software (AIFit, HI, Behave), over 7M configurations

Michael Lentmaier, Associate Professor in Communication (LU)

1. Main scientific achievements during 2021

Our research focuses on modern coding theory, graph-based iterative algorithms and the impact of spatial coupling on their performance. Applications range from reliable communication to localization, security and group testing.

During the year 2021 we continued our VR funded research on spatially coupled iterative receivers. The work of the PhD student Muhammad Umar Farooq concentrated on code design, considering a family of generalized LDPC codes with convolutional code constraints, comprising classical turbo-like codes and state-of-the-art LDPC codes as special cases. In particular, we extended the work we published at ISIT 2020 to irregular graphical models, which allows for component codes of different rates and strengths. An optimization was performed to improve the BP/MAP thresholds of the code ensembles, establishing flexible trade-offs between complexity, gap to capacity and error floor. Umar is expected to defend his PhD in fall 2022. With the PhD student Mgeni Makambi Mashauri we studied joint iterative detection and decoding of spatially coupled LDPC codes over ISI channels. We were able to show for a variety of ISI channels with erasures or AWGN that threshold saturation occurs, implying that simple regular codes can achieve capacity/symmetric information rate (ITW 2021). Furthermore, we showed for both optimal and linear detectors that spatial coupling with just a single code yields robust performance over changing ISI channels without the need to know the channel at the transmitter (accepted for ICC 2022).

With a third PhD student, Neharika Valecha, in collaboration with Fredrik Tufvesson, we worked on highly accurate positioning based on mmWave massive MIMO systems, funded within the H2020 training network MINTS. In particular, in an external collaboration with IMDEA in Spain, we carried out measurements in their mmWave testbed, which we use to develop efficient positioning algorithms that can operate with codebook-based beamforming under non-ideal calibration of the antennas.

As a new research direction, we started in 2021 to work on sparse-graph codes for efficient group testing, i.e., solving the fundamental problem of identifying defective items in a large population. In particular, our aim within the coming years is to propose novel iterative soft message passing schemes that can take into account correlations between individual items and to investigate the impact of spatial coupling on their performance. Group testing has a myriad of applications, including screening for diseases such as Covid-19 but also fault detection in computer networks or finding patterns of data in large data sets.

In our collaboration with the security group (Thomas Johannsson and PhD student Jing Yang), where we apply LLR-based message passing for solving sparse systems of equations with non-linear terms, we worked on an improved revised version of our journal submission to IEEE Transaction on Information Theory (meanwhile published February 2022).

In our collaboration with the circuit design group (Liang Li, PhD student Mojtaba Mahdavi) we studied the VLSI design trade-offs for spatially coupled serially concatenated codes, resulting in a journal submission to IEEE Transactions on Circuits and Systems (meanwhile published May 2022).

2. Awards and recognitions

PhD student Mgeni Makambi Mashauri received the Swe-CTW 2021 Best Student Conference Paper Award for his paper presented at GLOBECOM 2020.

3. External funding attracted

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amount per year	Duration of project
Improving iterative receivers with VR spatial coupling	VR	961 KSEK	2018 - 2021

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

N/A

5. Inter-university cooperation: summary for 2021

Mgeni Makambi Mashauri and Muhammad Umar Farooq are co-supervised by Alexandre Graell i Amat from Chalmers University.

Internationally, we have ongoing collaborations on several facets of spatially coupled codes with Prof. Daniel J. Costello, Jr. at University of Notre Dame, IN, USA. Furthermore, we had during 2021 collaborations with the German Aerospace Center (DLR), Munich, Germany, Technical University of Kaiserslautern, Germany, IMT Atlantique, France, New Mexico State University, Las Cruces, NM, USA, and Xidian University, Xi'an, China.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

N/A

7. Industry and institute cooperation

In the MINTS project, with Neharika Valecha we collaborated with at IMDEA Networks Institute in Madrid, Spain, carrying out measurements in their mmWave testbed.

In our research on group testing, with Mgeni Makambi Mashauri we collaborate with the German Aerospace Center (DLR), Munich, Germany.

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

Program director of Master's Program in Wireless Communications since July 2013.

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

N/A

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

Appointed as chair of the IEEE VT/COM/IT Chapter Sweden in October 2021. Board member since Spring 2014. Interface to information theory society since Spring 2017.

General/Program chair of the ELLIIT Workshop at Lund University in October 2021 (together with Volker Krueger). Finally possible as a physical event with around 200 participants!

12. Open source software contributions

N/A

Jonas Unger, Professor in Computer Graphics (LiU)

1. Main scientific achievements during 2021

The efforts within ELLIIT during 2021 has been focused in two main directions. First, we have further developed our framework for sparse representations and compressed sensing for imaging and computer graphics applications. Secondly, we have developed novel methods for modelling deep neural networks using so called Neural ODEs.

The efforts in sparse modelling and efficient sampling for imaging has led to three main highlights. The first highlight is a new design for single sensor compressive HDR light field cameras, in which we combine multi-ISO photography with coded mask acquisition, and image reconstruction using compressive sensing. The proposed camera model is based on a main lens, a multi-ISO sensor and a coded mask located in the optical path between the main lens and the sensor. A key contribution is the

reconstruction algorithm which jointly perform color demosaicing, light field angular information recovery, HDR reconstruction, and denoising from the multi-ISO measurements formed on the sensor. The second highlight is a novel sparse non-parametric model material for reflectance measurements. The scattering of light at a surface is described by the bidirectional reflectance distribution function (BRDF). By training an ensemble of dictionaries under a sparsity constraint, the model guarantees high quality representations with minimal storage requirements and an inherent clustering of the BDRF-space. The model can be trained once and then reused to represent a wide variety of measured BRDFs. Moreover, the proposed method is flexible to incorporate new unobserved data sets, parameterizations, and transformations. In addition, we show that any two, or more, BRDFs can be smoothly interpolated in the coefficient space of the model rather than the significantly higher-dimensional BRDF space. Experimental results show that the proposed approach results in about 9.75dB higher SNR on average for rendered images as compared to current state-of-the-art models. The third highlight is a a novel formulation of the BRDF acquisition problem using compressed sensing. Efficient and accurate BRDF acquisition of real-world materials is a challenging problem that requires sampling millions of incident light and viewing directions. To solve the problem, we propose the Fast and Robust Optimal Sampling Technique (FROST) for computing a minimal set of optimal sampling directions for recovering a full BRDF. casts the problem of designing an optimal sampling operator for compressed sensing into a sparse representation formulation under the Multiple Measurement Vector (MMV) signal model. Unlike previous methods, which rely on a number of heuristics, FROST uses standard sparse representation techniques for finding the optimal sampling locations. As a result, FROST is accompanied with strong theoretical guarantees from the field of compressed sensing. Our experimental results show significant advantages compared to the state-of-the-art with respect to the reconstruction quality. Moreover, unlike previous methods where the computed sampling directions are vastly different at each run, FROST produces consistent results since it is deterministic. In terms of computational complexity, our method is on average 370 times faster than the state-of-the-art.

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 uses 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 also present a general 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. Our evaluations demonstrate that our novel formulations lead to increased robustness and performance as compared to ResNet models, and that it opens up for new opportunities for designing and developing machine learning with improved explainability.

2. Awards and recognitions

Our efforts during 2021 towards 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

We were awarded a 20 MSek NEST project from Wallenberg AI, Autonomous Systems and Software Program (WASP) and a 4.5 MSek Wallenberg Launchpad (WALP) project.

Itemized list of external projects that were active at some point during 2021.

Project title	Funding source	Granted amount per year	Duration of project
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
Digital pathology	AIDA – Vinnova	900 KSek	3 yrs
AI4C	Vinnova	1 MSek	3 yrs

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

Rym Jaroudi PhD student working on neural ODEs, i.e., modelling of deep neural networks using systems of ordinary differential equations.

5. Inter-university cooperation: summary for 2021

In the context of projects related to ELLIIT, we have collaborated with Prof. Amy Loutfi at Örebro 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 2021

N/A

7. Industry and institute cooperation

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, IKEA Marketing and Communications, and Luftfartsverket (LFV).

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

We participate in several courses in the undergraduate education at the Media Technology program at LiU. During 2021 we gave two PhD courses related to the ELLIIT projects, one on sparse modelling and compressed sensing for imaging applications and one on image synthesis.

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

Invited presentations at WASP Winter Conference, WARA Media & Language, and London Imaging Meeting 2021.

11. 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.

12. Open source software contributions

We make code and data available from all our projects.

Andreas Kerren, Professor in Information Visualization (LiU)

1. Main scientific achievements during 2021

Coming from Linnaeus University (LNU), I joined LiU and ELLIIT in December 2020. In general, my own research (including the work of the research groups that I lead at LiU and LNU) focuses on the explorative analysis and visualization of typically large and complex information spaces, for example in environmental research, transportation systems, social sciences, or artificial intelligence. Our vision is to attack the big data challenge by a combination of human-centered data analysis and interactive visualization for deriving meaning from the data and final decision making. We take a human-centered

and problem-oriented visualization approach: human-centered visualization deals with the development of interactive visualization techniques in consideration of user- and task-related information to explore and analyze complex data sets efficiently.
In the past year of 2021, our research within information visualization and visual analytics focused on four major aspects: visual text analytics, multidimensional data visualization, network visualization, and explainable ML/AI with the help of visualization. In the following, I briefly summarize our achievements in these areas.

- **Multidimensional data visualization:** Based on a successful collaboration with colleagues from the Netherlands and Brazil, we contributed by a quantitative survey of dimensionality reduction techniques that helps to answer the question of how to choose the best technique for a given usage context. For this, we characterized the input data space, projection techniques, and the quality of projections, by several quantitative metrics. Based on these findings, we draw several conclusions that help comparing projection techniques, explain their results for different types of data, and help practitioners when choosing a projection for a given context. Another collaboration with researchers from Canada aimed to develop 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. Our tests have shown that in streaming scenarios where data is not fully stored in memory, our approach is competitive in terms of quality compared to other streaming and incremental techniques while being orders of magnitude faster.
- **Network visualization:** The emergence of multilayer networks as a concept from the field of complex systems provides new opportunities for the visualization of network complexity and has also raised many new exciting challenges. The multilayer network model recognizes that the complexity of relationships between entities in real-world systems is better embraced as several interdependent subsystems (or layers) rather than a simple graph approach. In a new textbook, published in 2021, we provide a comprehensive overview and structured analysis of contemporary multilayer network visualization. Here, we also identify research opportunities and examine outstanding challenges for multilayer network visualization along with potential solutions and future research directions for addressing them. Multilayer network visualization will surely become deeper studied by my research group within the coming years. In addition, the visualization of large and complex multivariate networks (MVN) continues to be a great challenge. The field of multivariate network embedding seeks to meet this challenge by providing MVN-specific embedding technologies that targets different properties such as network topology or attribute values for nodes or links. We started to work in this area by focusing on a strategy of combining already existing state-of-the-art single scope embedding technologies. For this, we have developed visual analytics approaches that divide a MVN into separately embeddable aspects. We then can obtain a flexible vector representation which we use as input to a novel method of similarity-based clustering, for instance. As we derived the MVNs from large text corpora, I will continue to describe our preliminary achievements in this area in the following.

- **Visual text analytics:** As a first proof of concept of the joint embedding approach mentioned before, we implemented a visual analytics tool to provide search-and-explore functionality to enable the user to identify items of interest in a large set of text documents by interactive assessment of both high-level similarity patterns and pairwise similarity of chosen texts. This is ongoing work that we plan to continue in 2022. Furthermore, it is worth to mention that we consistently keep maintaining our world-renowned and highly cited interactive online surveys, especially those on text visualization and enhancing trust in ML models with visualization.
- **Explainable ML/AI with the help of visualization:** Here, we aim 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 is to make complex machine learning models better understandable and explainable, as well as to provide reliable trust in the models and their results. In 2021, we published two works that both cover this aspect: VisEvol and StackGenVis. VisEvol supports interactive exploration and configuration of hyperparameters based on evolutionary optimization. It helps the user to generate new models through evolution and eventually explore powerful hyperparameter combinations in diverse regions of the extensive hyperparameter space. The outcome is a voting ensemble that boosts the final predictive performance. StackGenVis focuses on the interactive generation of a stack of models which is an ensemble method that combines heterogeneous base models, arranged in at least one layer, and then employs another metamodel to summarize the predictions of those models. It assists users in dynamically adapting performance metrics, managing data instances, selecting the most important features for a given data set, choosing a set of top-performant and diverse algorithms, and measuring the predictive performance.

Another achievement was the acceptance of a proposal for a new national infrastructure for visualization and analysis of scientific data, entitled **InfraVis,** by the Swedish Research Council (VR). Before my job change to LiU, I have been the local PI for this effort at LNU that is one of nine Swedish higher education institutions participating in this infrastructure project (see https://infravis.se). There at LNU, InfraVis will be coordinated by me and performed by the ISOVIS research group that I am still heading. InfraVis officially started in 2022 for five years and the plan is to be fully operational at the beginning of 2023.

2. Awards and recognitions

N/A

3. External funding attracted

During 2021, we received external grants for an ELLIIT-funded PhD student (formal start in 2022, see below) as well as from the WASP and DDLS Joint Call (funded by the Knut and Alice Wallenberg foundation) for hiring two Postdoc researchers together with the SciLifeLab/KTH (formal start in May 2022).

As mentioned above, we also received a substantial grant from VR to build up a national infrastructure for visualization starting in 2022.

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

The recruitment of an ELLIIT-funded PhD student started in 2021 but could not be finished in the same year due to the lack of qualified applicants. However, we could recruit a qualified PhD student for this open position in early 2022 who will be highlighted in the next year's ELLIIT annual report.

5. Inter-university cooperation: summary for 2021

I regularly collaborate and publish with researchers from various countries and universities. In 2021, I would like to highlight our work with colleagues from the Netherlands and Brazil that resulted in an already highly cited quantitative survey paper on dimensional reduction techniques. Within Sweden, I mainly collaborated with colleagues from Linnaeus University and Lund University in this year.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

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 2021, we collaborated with colleagues from the areas of social sciences, humanities, e-health, and cyber-physical systems from Linnaeus and Lund Universities.

7. Industry and institute cooperation

We have a loose contact with the Institute for Language and Folklore, Uppsala, that we might extend in the future.

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

I regularly offer courses in information visualization in Media and Information Technology program at ITN/LiU. As a highlight in 2021, I would like to mention an educational paper on our experiences in designing and coordinating a project course in visualization and data analysis performed at Linnaeus University. Moreover, I co-authored a book chapter on visualization and image processing in the Swedish standard textbook "Medicinsk Informatik".

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

I gave the following invited talks (mainly online due to the pandemic):

- Visualization Perspectives in Explainable AI. LNUC DISA Seminar, Linnaeus University
- Visualization Perspectives in Explainable AI. Keynote Talk. International Conference on Control Systems and Computer Science (CSCS23)
- Visualization of Multidimensional Data: Possibilities, Pitfalls, and Practices. UEF Data-Driven Lunch Seminar, University of Eastern Finland
- Showcases of Visualization Research for Data Analytics and Explainable AI. Annual ELLIIT Workshop

11. 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
- Short paper co-chair of the 23rd EG/VGTC Conference on Visualization EuroVis, Zürich, Switzerland
- Member of the EuroVis Best PhD Award Committee 2021
- Program Committee Member of many conferences, such as EuroVis, VISSOFT, Graph Drawing, VDA, etc.

12. Open source software contributions

In 2021, we made the source code for the following two published visualization approaches available: StackGenVis and VisEvol, see https://leonard.lnu.se/git/ISOVIS

Fredrik Lindsten, Associate Professor in Machine Learning (LiU)

** I was on parental leave during fall 2021. **

1. Main scientific achievements during 2021

N/A

2. Awards and recognitions

N/A

3. External funding attracted

External projects that have been accepted during 2021 (with starting dates in 2021 or 2022):

- WASP-DDLS Postdoc Twinning grant together with Prof Sebastian Westenhoff (UU) for the project *Novel AI methods for experimentally constrained protein structure prediction (*2022-2024).
- WASP NEST project, *Multidimensional Alignment and Integration of the Physical and Virtual Worlds* (__main__), together with Jonas Unger (main PI; LiU/ITN), Michael Felsberg (LiU/ISY), and Amy Loutfi (ÖRU) (2022-2027). *The aim of the project is to develop new methodology for systematic and symbiotic integration of machine learning with simulation-based model. External partners are: IKEA Communications, Arriver, the Swedish Traffic Administration, AI Sweden, and WASP WARA media and language. Read more at: https://wasp-sweden.org/multi-dimensional-alignment-and-integration/*
- Vinnova-funded cross-disciplinary project *AI Powered Carbon Border Adjustments*. The project is led by 2050 Consulting and involves researchers at the Centre for Climate Science and Policy Research at LiU (Tina-Simone Neset, Anna Ljung, and Björn-Ola Linnér) as well as the industrial partners Alfa Laval and Toyota Material Handling. Read more at: https://2050.se/forskning-och-innovatioN/Ai-powered-carbon-border-adjustments/ (2021-2024)

Itemized list of external projects that were active at some point during 2021.

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 Modeling and Inference for Machine Learning	SSF ICA-7	1 MSEK	2017 Sep – 2021 Aug (extended for parental leave)
Learning of Large-Scale Probabilistic Dynamical Models	VR StG	0.8 MSEK	2017–2021 (extended for parental leave)
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

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

N/A

5. Inter-university cooperation: summary for 2021

N/A

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

N/A

7. Industry and institute cooperation

N/A

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

We introduced a Linköping University version (https://studieinfo.liu.se/en/kurs/ete337/) of the online self-study course Elements of AI, Part 2: Building AI (https://buildingai.elementsofai.com/).

We launched a newly developed online course on the Foundations of Machine Learning (https://foundations-of-ml.ida.liu.se/)

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

N/A

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

N/A

12. Open source software contributions

Julia package CalibrationAnalysis.jl (Python and R wrappers are available) for evaluating the reliability of the predictive uncertainty (calibration evaluation) for probabilistic predictive models. Developed by PhD student David Widmann. https://docs.juliahub.com/CalibrationAnalysis/bzJrU/0.1.1/

Richard Pates, Associate Professor in Control of Large-Scale Autonomous System (LU)

1. Main scientific achievements during 2021

Can simple systems be regulated by simple controllers? Engineering experience indicates that this is often the case. Certainly the overwhelming majority of industrially deployed controllers are PID controllers, many of which are tuned without detailed models. This is often in disappointing contrast with optimal control approaches, where the resulting controllers are often more complex than desired. This is particularly damaging in large-scale applications, such as the control of electrical power systems, where simplicity and scalability are of paramount importance, yet features such as sparsity are notoriously difficult to design for in an optimal fashion.

This year, the main research thrust has been working on bridging this gap between theory and practice. The primary focus has been on identifying classes of optimal control problem where the optimal controller *are* inherently simple and scalable. Important classes of problems that have been identified include the control of lossless systems and relaxations systems. This theoretical work has been supported by application focused research on electric power systems and irrigation networks (which are well modelled by lossless systems), as well as district heating networks (which are well modelled by relaxation systems).

2. Awards and recognitions

N/A

3. External funding attracted

N/A

4. Recruitment highlights: New hires (students, postdocs, faculty) to the project 2021

N/A

5. Inter-university cooperation: summary for 2021

This year has seen publications with 9 international collaborators, from 7 different international institutions: Fernando Pagnini, Universidad ORT Uruguay; Enrique Mallada, Johns Hopkins; Andreas Ferragut, Universidad ORT Uruguay; Eli Pivo, MIT; Pengcheng You, Peking University; Marcus Völp, University of Luxembourg; Gerhard Fohler, University of Kaiserslautern; Martina Maggio, Saarland University; Kristin Kruger, University of Kaiserslautern.

6. Inter-disciplinary cooperation: summary, when relevant, for 2021

Further to work on the control of large-scale systems, 2021 has seen interdisciplinary collaborations resulting in publications on epidemic modelling and real time system analysis.

7. Industry and institute cooperation

This year has seen the start of master's thesis projects involving industrial partners from emulate.energy and Sony.

8. List of patent applications published during 2021.

N/A

9. Highlights from contributions to undergraduate/graduate education, including but not limited to: new courses, use of research results, and education program leadership

Development and teaching of a new Ph.D. level course on Nonlinear Control: https://canvas.education.lu.se/courses/14608
The release of over 80 videos on control theory: https://www.youtube.com/channel/UCVJnlQEfsEYlKrFZVRktAZA/videos

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

Several popular science videos have been produced, including this entry to 'The Summer of Online Math Exposition' (SoME1) competition - https://youtu.be/PjwHSDIGsdw

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

Conference and journal reviewing.

12. Open source software contributions

N/A

Gender Projects

Building a community

PI: Sandra Pott, Sara Maad Sasane, Carina Geldhauser (LU)

This project deals with the empowerment of the women mathematicians working and studying at Lund University.
Already before the pandemic, we had started with women in mathematics evenings, which were quite successful. Due to the pandemic situation, we were not able to have a face-to-face women in mathematics evening before the fall of 2021.

Therefore, we initiated a “women’s coffee” on zoom to keep up the community spirit. There are about 12-15 PhD students and researchers attending the coffee on average.

When the weather became warm, we organized a **half-day hike** close to Lund to bring female students and faculty together. The event was attended by students from both LTH programmes and the mathematics programme at NF, and members of permanent teaching staff.

Women’s career events and virtual career fika

To inform our female students about the many opportunities with a degree in mathematics or engineering mathematics, and to give them the opportunity to ask their questions in a protected environment, we launched a series of career talks, which we complemented by a women’s career fika.

The speakers were

- Gianne Derks, Professor at the University of Surrey and Hedda Anderson Professor at LU,
- Franziska Knauer, KFW Bank Frankfurt
- Fatemeh Mohammadi, Volvo Gothenburg
- Francesca Arici, science communicator and professor at Leiden University
- Salla Franzen, Chief Data Scientist at SEB
- Carolin Trouet, Chief Agility Master at Lufthansa Systems

The talks were very successful with many attendees. In the evaluation after the talk with Carolin Trouet, we also discussed the advantages and disadvantages of an online talk, and concluded that in-person talks are better, but that funding is a constraint.

Supporting and mentoring female students

Motivation and positive environment is crucial to prevent the drop-out of underrepresented groups. We therefore started a mentoring scheme to increase the sense of belonging, the well-being and the motivation of female students.

We also had side-events for this. For example, we supported our female students in their application for fellowship programmes:

In early 2021, still online, we advertised the the Philippa Fawcett fellowship for a summer research internship at Cambridge University. This summer research internship is a highly competitive programme, and many women and non-binary students from all over the world apply for the Philippa Fawcett fellowship. In order to give our students the best possible chances, we supported them in two ways:
First, one of our mentors, Alexia Papalazarou, hosted a coaching session on CV writing, where she gave feedback and improved the write-up of the CVs of the interested students.
Following up on this session, Carina Geldhauser gave individual feedback on the motivation letters and advised in the general application process.

Furthermore, we supported a female student with German nationality in her application for a German government fellowship, which would greatly improve her financial situation as a student in Lund.

Our mentees, Sara Rousta, was awarded the Philippa Fawcett fellowship and spent 10 weeks at Cambridge University under the supervision of Prof. Martin Hyland, a mathematical grandson of Alan Turing. Prof. Hyland is a leading expert in theoretical computer science and higher-dimensional algebra, best known for his work on category theory applied to logic (proof theory, recursion theory), topos theory and on game semantics.

In the winter, Sara Rousta was reporting her experiences from Cambridge in our next fellowship support event. This encouraged other students to apply.

More mentees were thinking about a period of project work or internships abroad in the summer, financed e.g. through ERASMUS+, but it turned out to be quite challenging for them, not only, but also due to funding restrictions, and BREXIT visa requirements.

Mentors reported they spent a lot of time in helping and advising their mentees in their struggles with documents. In order to make our efforts sustainable, we therefore wish to condense useful information, which is not so easily presented on LTH's websites, in an information sheet or website in the rest of the year.
In the future, we would like to more systematically point out fellowship opportunities to our talented students and to provide them with useful information and support.

Kvinnor och matematik

PI: Sara Maad Sasane, Carina Geldhauser (LU)

The goal of this project was to connect women mathematicians working in Sweden. There had been a network, in the 1980s/1990s, called “kvinnor och matematik”. We aim at the revival of the old network, and make it a meeting place for all women mathematicians in Sweden. We started to reach out to all women mathematicians with a PhD degree at other Swedish universities. We emailed them all individually and invited them to join our mailing list. We are proud to report that our mailing list has already 43 members, which means that the majority of women mathematicians at Swedish universities are members of our list.
Furthermore, we created a Linkedin Group, to better connect staff, students and Alumnae: https://www.linkedin.com/groups/12536126/

What remains to be done is to reach out to graduates/employees at högskolan.

In terms of activities, we hosted two get-to-know meetings on zoom, one for everyone, and a smaller one for young researchers (postdoc and BUL).

Furthermore, we hosted one **technical meeting** to exchange ideas about mentoring programmes and the possibility for a national mentoring programme for postdocs or PhD students. We also reached out to similar groups in other countries through the network European Women in Mathematics.

Lastly, there were **two meetings of the newly formed steering committee**, as outlined below.

Steering Committee

A steering committee has been formed to achieve a more sustainable action within the group. The 2021 members of the steering committee were:
From ELLIIT institutions: Zhenxia Liu (Linköping), Sara Maad Sasane (member of nationalkomittén för mathematik), Carina Geldhauser, Rachele Anderson.
From Göteborg: Irina Petterson (ordf.), Julie Rowlett (member of nationalkomittén för mathematik), Laura Fainsilber.
From Stockholm: Sofia Tirabassi (European Women in Mathematics contact person), Martina Scolamiero, Kathlen Kohn.
Furthermore, Sorina Barza (Karlstad) and Kristina Juter (Kristianstad).

Senior advisory group

To connect back to the older generations, who were active in the old network, we formed a senior advisory. Gerd Brandell, Barbro Grevholm and Lars-Erik Persson have agreed to be part of this group.

The senior advisory group has been very helpful and gave important insight, so that we can learn from the past.

Towards establishing a Louise Petrén prize

We were discussing the idea to establish a Louise Petrén prize, intended for younger women mathematicians as a motivation and career boost.
It would be great if such a prize came also with a monetary component, which could e.g. pay an international travel for the laureate to work with a person at another institution, as international collaborations are an important career factor. We are currently understanding different options for a monetary component, and how we could administer such a prize without being too burdened with administration.
We discussed the idea of the prize also with our senior advisory group, who told us that there has been a prize earlier in the honor of Louise Petrén, however given to honor good actions for equality at mathematics departments.

As a start, we planned and organized an annual Louise Petrén lecture at Lund University, which will take place on June 2nd, 2022.

APPENDIX

Summary for all projects/ELLIIT faculty

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
Assistant Professor in Computer Science	Emma Söderberg	LU
Professorship in Computer Science	Volker Krueger	LU
Assistant Professor in Computer Science	Luigi Nardi	LU
Guest Professor 2016 – 2021	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
Assistant professor, Electrical and Information Techn.	Elena Pagnin	LU
Associate professor in Automatic Control	Richard Pates	LU
Associate professor in Automatic Control	Emma Tegling	LU

Assistant Professor in Mathematics	Magnus Oscarsson	LU

Guest researchers and visiting students

Dr Varun Gupta, University of Alcala, Spain, virtual visit during Nov-21 to Feb-22. Topic: technology-adoption factors for prototyping tools.

C. Altafini hosted at LiU two visiting PhD students: Lingfei Wang (Sept. 2021- Sept. 2022) from the Chinese Academy of Science, Beijing, and Carmela Bernardo (March 2020 - February 2021) from University of Sannio, Benevento, Italy. Both were involved on research topics related to an ELLIIT project of C. Altafini.

N. Pappas hosted at LiU a visiting Phd Student: Jing Chen (April 2021-April 2022) form the Beijing Jiaotong University, China sponsored by CSC. Ms. Jing Chen was involved in research topics relevant to the project of N. Pappas.

List of Ph.D. and licentiate defenses

Name	**Gender**	**Industry-based doctoral student (yes or no)**	**Degree (licentiate/doctoral)**
Stefan Andric (LU)	M	No	Doctoral
Daniel Arnström (LiU)	M	No	Licentiate
Ida Arvidsson (LU)	F	No	Doctoral
Kristoffer Bergman (LiU)	M	Yes	Doctoral
Per Boström-Rost (LiU)	M	Yes	Doctoral
Seyedezahra Chamideh (LU)	F	No	Licentiate
Abdelrahman Eldesokey (LiU)	M	No	Doctoral
Gabrielle Flood (LU/math)	F	Yes	Doctoral
Emmanouil Fountoulakis (LiU)	M	No	Doctoral
Amin Ghazanfari (LiU)	M	No	Doctoral
Marcus Greiff (LU)	M	No	Doctoral
Hamed Haghshenas (LiU)	M	No	Licentiate

Name	Gender	Industry-based doctoral student (yes or no)	Degree (licentiate/doctoral)
Daniel Helgesson (LU)	M	No	Doctoral
Mohsin Irshad (BTH)	M	Yes	Doctoral
Felix Järemo-Lawin (LiU)	M	No	Doctoral
Adam Jönsson (LU)	M	No	Doctoral
Anton Kullberg (LiU)	M	No	Licentiate
Zhongguo Li (LU/math)	M	Yes	Doctoral
Johan Lundgren (LU)	M	No	Doctoral
Magnus Malmström (LiU)	M	No	Licentiate
Farnaz Moradi (LU/EIT)	F	No	Doctoral
Gautham Nayak Seetanadi (LU)	M	No	Doctoral
Kristin Nielsen (LiU)	F	Yes	Licentiate
Haorui Peng (LU)	F	No	Licentiate
Aleksis Pirinen (LU/math)	M	Yes	Doctoral
George Smpokos (LiU)	M	Yes	Licentiate
Cristian Tatino (LiU)	M	No	Doctoral
Marcus Valtonen Örnhag (LU/math)	M	Yes	Doctoral
Jing Yang (LU/EIT)	F	No	Doctoral
Alfred Åkesson (LU/CS)	M	No	Doctoral

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)
Patrick Doherty	Collaborative Robotics for Emergency Rescue: A Distributed Task and Information Perspective	Ziejing University 110th Anniversary Global Seminar Series	Via Zoom
Christoph Kessler	Towards future-proof programs for heterogeneous parallel systems	PDP-2021 conference, Valladolid, Spain, March 2021	Via Zoom
Michael Felsberg	Embed Me if You Can: A Geometric Perceptron	MAIN: Maths, AI and Neuroscience	KTH, Stockholm
Michael Felsberg	From Discriminative Object Tracking to Video Object Segmentation	CVPR-WS Robust Video Scene Understanding	Virtual
Nikolaos Pappas	Goal-Oriented Communication for Networked Intelligent Systems	IEEE SPAWC 2021	Virtual
Nikolaos Pappas	Semantics Communications for Future Wireless Communications	Spring School: Emerging and future communication networks: technologies, architectures, and tools	Paris, France
Nikolaos Pappas	Semantics-Empowered Communication for Networked Intelligent Systems	Interdisciplinary Centre for Security, Reliability and Trust, University of Luxembourg	Luxembourg
Tom Ziemke	Who or what is the self in self-supervised learning?	Second International Workshop on Self-Supervised Learning (IWSSL)	Boston, USA (via Zoom)

List of distinguished lectures

2021-11-10 Prof. Chris Rudell, Associate Professor of Electrical and Computer Engineering, University of Washington, Seattle. On-Chip Self-Interference Cancellation for Full Duplex Radios and Other Applications.

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