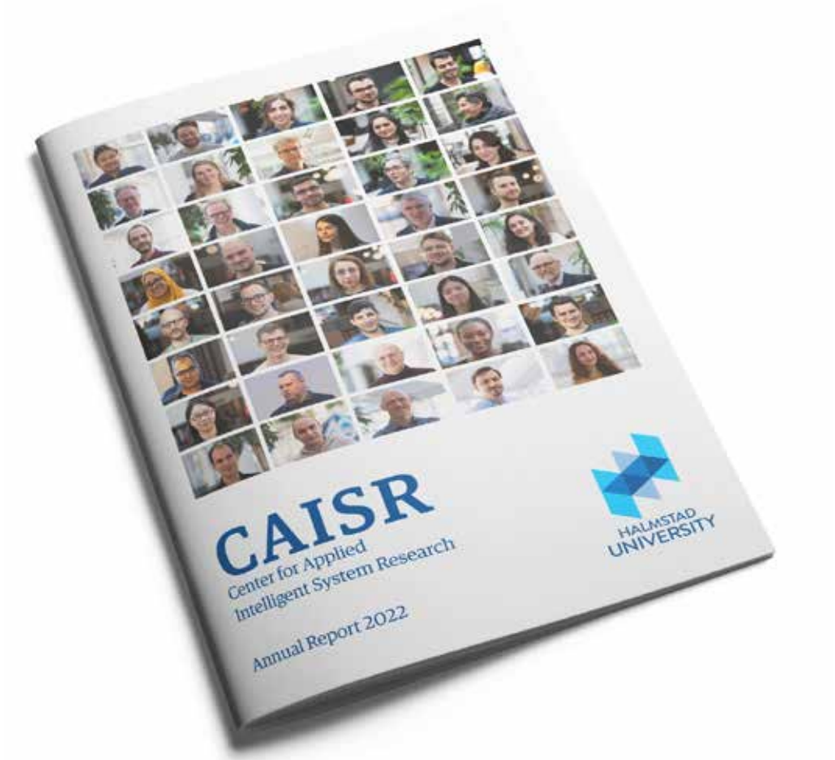
CAISR

Center for Applied Intelligent System Research

Annual Report 2022

HALMSTAD UNIVERSITY



The cover shows 40 of CAISR'S more than 70 employees. You will meet them all in the report.

CAISR

Center for Applied Intelligent Systems Research

Annual Report 2022

Knowledge Foundation

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Director's statement

The year 2022 will for sure be mentioned in future history books. In February Russia invaded Ukraine in a "special military operation", an operation that perhaps Russia expected to be quick but which turned out to be anything but that. At the end of 2022, about a quarter of Ukraine's population had been forced to leave their homes, but the Ukrainian defense had proven strong and the war was not going Russia's way. It is impossible to guess where this will end but we hope that it will turn out to have been a really bad idea to invade a non-hostile neighboring country. Provoked by this invasion, Sweden changed its long-standing foreign policy doctrine of being a neutral country and applied for membership in NATO.

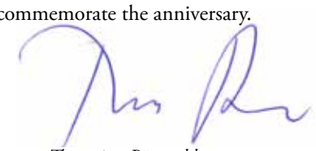
In September, the death of Mahsa Ahmini in Tehran, suspected to be due to police brutality for not wearing a hijab properly, started a wave of protests in Iran and worldwide. Iranian women all over the world reacted and demonstrated their dislike for this. The protests continued well beyond 2022 and perhaps we can look back at this later as the spark that started the fire that led to more equal rights for women in Iran.

In November, ChatGPT was introduced by OpenAI, and it is no understatement to say it took the world by storm. People outside the AI community were shocked over how good ChatGPT was; it could code (which its GPT predecessors could also do), write poetry, write music, write manuscripts, be funny, answer test questions, translate text, summarize notes, and so on. Also people within the AI community were surprised by the quick development and uptake of Large Language Models (LLMs). An intense discussion at universities started, first focusing on how to prevent cheating but later also on how ChatGPT could be used as a tool. In early 2023, the discussion was all over society, with arguments for banning LLMs, pausing their development, or calling for legislation that limited their use. With ChatGPT, the "AI genie" had been let out of the bottle.

In 2022, IT-forensics was the education program at Halmstad University that received the most applicants (out of all programs at the university). Several CAISR members teach in this program and the students who graduate get very good jobs with, e.g., the Swedish police. It was truly a pleasure to see so many applicants to an engineering-oriented program with a strong relation to AI technology.

Also in 2022, Prayag Tiwari started an assistant professorship position with CAISR and shortly after he started in Halmstad he got listed on Professor John Ioannidis' list of "the world's top 2% researchers" (based on subject-normalized citation statistics). Prayag is the sixth CAISR member to make it onto that list but by far the youngest, and the only one who is not a professor (yet). We welcome him to CAISR and present him better in an interview later in this report.

Finally, Halmstad University celebrates 40 years in 2023. We start our annual report with two articles that provide a historical perspective on AI research at Halmstad University, to commemorate the anniversary.



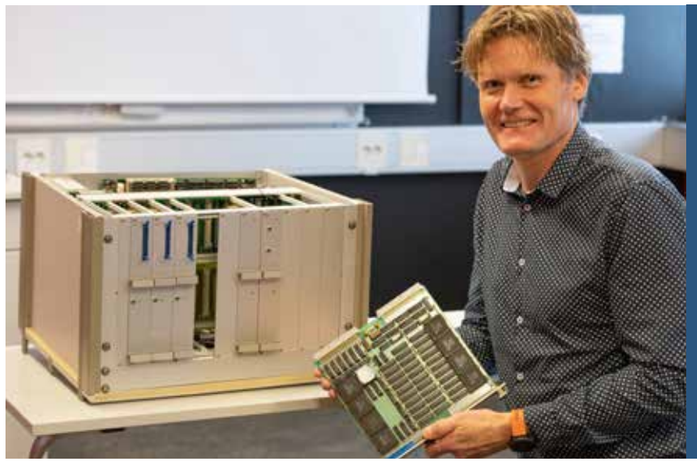
Thorsteinn Rögnvaldsson

In 1981 IBM introduced the PC, and in 1983 Apple released LISA. The early 1980-ies mark the beginning of the digital revolution that over the last 40 years has brought immensely increased communication, the world wide web, smartphones, streaming services, and artificial intelligence (AI). Halmstad University was established in 1983, and its research developed alongside this digital revolution. To celebrate Halmstad University's 40-year anniversary in 2023, we provide two texts in this annual report that look at the development up to this day and illustrate why and how Halmstad University developed a large research group with focus on AI.

40 years of AI Research

The two first research centers established at Halmstad University built on what one would today could call AI and AI enabling technologies: image analysis and embedded parallel computer architectures, respectively. In those days, the research centers included only a handful of people. In the late 1980-ies the REMAP research project started with the ambition to design high speed massively parallel computers for radar signal processing with very low energy consumption. The REMAP project was co-sponsored by the Swedish defense industry and took much inspiration from research on artificial neural network hardware. A strong supporter in Halmstad University's early days was Professor Dan Hammerstrom, then at Intel in Oregon, later at Oregon Graduate Institute, Portland State University, and DARPA.

In the 1990-ies, the two research centers started recruiting PhD students and several international AI researchers; from Kaunas Institute of Technology, ETH, EPFL, and the Oregon Graduate Institute. For example: For example: Antanas Verikas from Kaunas TU, Albert-Jan Baerveldt, winner of the first world championship for ping pong playing robots in Hong-Kong in 1992, and Josef Bigun, a world authority on visual biometrics. Many research projects started during this period built on machine learning and close industrial co-operation, e.g., the self-calibrating engine, the autonomous agricultural robot, and neural networks for print quality estimation (a solution that was later commercialized and sold, e.g., to the Bank of England).



Anders Åhlander showing the REMAP computer that was a part of his PhD exam work at Halmstad University, Anders is currently Specialist, High Speed SW Architecture at Saab AB, Business Area Surveillance.

In 2000, Professor Josef Bigun became IAPR Fellow, and then in 2003 IEEE Fellow. In 2001 Halmstad In 2003 the Swedish Research Council started awarding project grants to the biometrics group in Halmstad, something they have continued to do, and in 2004 Halmstad University was named a European Excellence Center in Image Processing through the Biosecure project. In 2005, Halmstad University was granted the first in a continuous series (up to today) of Vinnova-funded projects focusing on machine learning for predictive maintenance together with the Volvo companies.

Around 2010, several new important international recruitments were done of young researchers: Fernando Alonso-Fernandez (Universidad Autónoma de Madrid), Sławomir Nowaczyk (AGH University of Technology in Poland), Roland Philippsen (Stanford University), and later Eren Erdal Aksoy (Karlsruhe Institute of Technology). In 2012, the Center for Applied Intelligent Systems Research (CAISR) started in close cooperation with Swedish industry with research support from the Knowledge Foundation and Vinnova. Over the next decade, CAISR more than doubled in size (people, research volume and education volume). Today, CAISR includes about 70 people and is a vibrant AI research environment with international staff, high quality research output, close cooperation with industry and public organizations, and awarded education.

In 2023 Halmstad University celebrates 40 years as an independent university. AI, Artificial Intelligence has been a significant part of the university's research throughout the years.

Anita Sant'Anna, first PhD student in AI enrolled at Halmstad University graduated 2012.

Kerstin Malmqvist was recruited to Halmstad University in 1984. She led the Centre for Image Analysis from the start in 1986.

Antanas Verikas and Josef Bigun.

Bertil Svensson - a pioneer

Halmstad University is today one of Sweden's largest research environments in AI and machine learning. Some of Sweden's earliest research in the field was carried out here, and one of those who laid the foundations was the university's first pro-vice chancellor, Bertil Svensson.

The fourth International Joint Conference on Artificial Intelligence was held in Tblisi, Georgia, in 1975. One of the participants was 27-year-old Bertil Svensson, a lecturer and doctoral student at Lund University.

- In the 1970s, work on computers in the field of AI had only just begun. The work centered around theoretical reasoning such as what is computable at all, how knowledge can be represented and what behaviors could be programmed, says Bertil Svensson.

Eight years later, he would become associate professor and pro-vice chancellor at the newly formed Halmstad University, laying the foundations for AI research there. At the time, it was often a matter of building simple but highly parallel structures to mimic how the brain functions. With fellow PhD students in Lund, Bertil Svensson had built parallel computers that were tested in different applications. At the turn of the 1980s and 1990s, he saw that parallel computers would be needed for the development of artificial neural networks.

- At that time, our research focused on showing that our computer architectures were very well suited to execute neural networks.

An international workshop built the identity

Bertil Svensson helped develop the mechatronics program when Halmstad University was founded in the 1983. He was researching parallel computers and how they could be used to analyze data from sensors in real time. In this work, he had a lot of contact with Anders Lansner, who was doing research in computer science at the Royal Institute of Technology (KTH) in Stockholm. The two built up Sweden's very first research in artificial neural networks, and in 1993 they together organized an international workshop in Halmstad. The title was Mechatronic computer systems for perception and action. It discussed how mechanics, electronics and computer control could be combined to enable, for example, a robot to orient itself and act in a room.

In the 1970s, work on computers in the field of AI had only just begun. The work centered around theoretical reasoning such as what is computable at all, how knowledge can be represented and what behaviors could be programmed

- In retrospect, I'm surprised we managed to attract so many people. Eighty participants from twenty countries came, many of them very prominent scientists, says Bertil Svensson.

Although the topic of the workshop was described as robotics rather than AI, it contributed to the growth of the AI field in Halmstad. Bertil saw that the meeting gave the university an identity and increased its attractiveness. It made

Bertil Svensson and Thorsteinn Rögnvaldsson at the KK-environment inauguration 2012.

new contacts with other universities and opened up for recruiting a lot of people at the same time. This was possible thanks to the establishment of the Knowledge Foundation, which at the time was making major investments in collaboration between industry and academia.

- The establishment of the Knowledge Foundation, the fact that we knew where we wanted to go and that we had good industrial contacts gave the university strong growth in the 1990s. Among other things, a project called PARAD was carried out together with the part of the Ericsson Group that was then called Ericsson Microwave Systems (now part of SAAB). It involved drawing up guidelines for a massively parallel computer capable of signal processing in airborne radars and in the mobile phone systems that were then being developed. The computer needed to be able to quickly process very large amounts of data on the spot in the aircraft or in the mobile phone base station.

The breakthrough came with more computing power

It was also possible to apply to the Knowledge Foundation for funding for so-called profile areas. Halmstad University made two proposals and received support for one of them. It developed into CERES, Center for research on embedded systems, which Bertil led throughout the profile period until 2013. The other proposal was CAISR, Center for applied intelligent systems research.

- Since the Knowledge Foundation would only fund one profile, we turned to the innovation agency Vinnova with CAISR. We almost got a yes. We got very good reviews but it turned out that we were in the wrong place. It was perhaps not seen as strategic then to build up research in Halmstad?

CAISR was kept going with project money, until in time it too became a profile. Bertil Svensson notes that some of the early applications started from industrial needs, while others were based on a benefit that the researchers themselves conceived. But the really big breakthroughs for artificial neural networks came after the turn of the millennium, when computers became more powerful.

- It was then possible to show that neural networks were as good as other approaches in the development of, for example, self-driving vehicles. The fact that parallelism is necessary, with perhaps hundreds of thousands of processors in the same computer, really caught on then, says Bertil Svensson.

Bertil Svensson

1983 Recruited to Halmstad University (the same year as HU is established).

1989 Becomes professor at Luleå University of Technology

1991 Becomes professor at Chalmers University of Technology. He continues to lead research at HU on part time.

1999 Becomes professor at Halmstad University

2005 Started and led CERES until 2013.

Bertil Svensson and the CERES team 2006. Bertil led the research profile throughout the profile period until 2013.

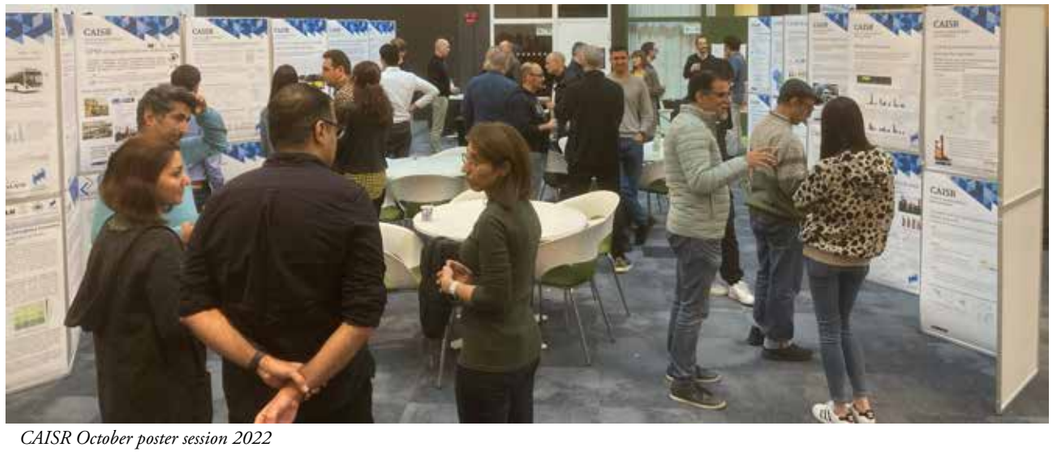
The CAISR Environment

In 2012, CAISR was initiated with the aim to build up a collaborative, international, and well-known research and education environment at Halmstad University on AI technologies. It built on our close long-term relationships with Swedish industry and on three pillars of research: computer vision, machine learning, and robotics (three areas that had developed research at Halmstad University since the mid-1990:ies). Over the years, CAISR has grown a lot and increased in diversity: in the start, CAISR had 28 staff members, of which 2 were women, in 2022, CAISR had 73 staff members, of which 16 are women. In 2012, 39% of the staff were born outside Sweden, in 2022, 75% of the staff are born outside Sweden. CAISR started out as a center that overlapped fully with one single (and small) department, but CAISR developed into a large group of people active in AI research and education, with people from more than one department. Today, CAISR is more a group of researchers with a common vision to do high-level applied AI research together with Swedish industry and the public sector, rather than an organizational entity within Halmstad University.

Computer vision, machine learning, and robotics remain pillars in the research but have been complemented with important research on the use of AI tools and service design with AI tools. The joint scientific vision for CAISR is to work towards systems for autonomous knowledge creation: The ability to create and transfer knowledge efficiently is a key competitive advantage for a company or an organization, and techniques for autonomously creating knowledge from data will be very important. In CAISR, we have joint workshops (the picture shows our October poster session 2022), an annual joint PhD conference, and we collaborate in our education programs and in supervising our Master students. Over the last five years, we have supervised more than a hundred Master theses, many of which have received recognition for their good work. In 2022 one of our Master students, Pooriya Khorramyar, was awarded the first Getinge Sterilization grand prize for the best thesis in Health Innovation: The thesis title was "Visual Transformers for 3D Medical Images Classification: Use-Case Neurodegenerative Disorders", supervised by CAISR staff Stefan Byttner, Farzaneh Etminani, and Amira Soliman.

At CAISR we aim to allow inspiration and creativity to develop by nurturing an environment with a positive attitude and much collaboration, both within the center and with partners external to the center.

Amira Soliman and Sepideh Pashami at the yearly PhD student conference, arranged by the PhD students at the School of Information Technology, Halmstad University



CAISR October poster session 2022

Industrial Advisory Boards

CAISR is an industry guided research and education center. Most of our projects emanate from discussions between academics and external partners, industrial or public sector, typically starting out with a challenge and exploring if and how that can be taken on with state-of-the-art machine learning methods and what scientific challenges may be hidden in the challenge. In our two main application directions, predictive maintenance and information driven care, we work with industrial advisory boards (IABs) who give advice on high-level aspects, e.g., vision and next steps in the cooperation, express industrial opinions on the industrial value and the quality of the coproduction, and express desires and suggestions for valuable industrial outcomes from the cooperation (e.g. demonstrations, reports, etc.). The IABs meet 2-4 times per year, depending on the needs.

CAISR+

The IAB for CAISR+ predictive maintenance has six members: one chairperson, and one representative each from the industrial partners Volvo Trucks, Volvo Buses, Volvo Group Connected Solutions, Volvo Group Trucks Technology, and Toyota Material Handling. These are the industry partners in the big CAISR+ project. During 2022, the IAB for predictive maintenance met three times: in April, in June, and in October. In October, the meeting included a large poster session with all ongoing research projects in CAISR.

Jenny Erneman, chairperson CAISR+, Industrial advisory board

Member	Organisation
Jenny Erneman	Volvo
Jörgen Hansson	Volvo Trucks
Johan Lindell	Toyota Material Handling
Ervin Omerspahic	Volvo Buses
Leo Petrin	Volvo GTT
Robert Valton	Volvo GCS

CAISR Health

The IAB for CAISR Health information driven care has eight members: one chairperson, and one representative each from the industrial and public sector partners Mölnlycke, InterSystems, Visiba Care, Capio, Novartis, Cambio, and Region Halland, These are the industry and public sector partners in the big CAISR Health project. In 2022, the IAB for CAISR Health met three times: in March, May, and October.

Member	Organisation
Thomas Davidsson	Hallandia V
Jan Boberg	Mölnlycke
Otto Medin	InterSystems
Peter Tyreholt	Visiba Care
Niklas Sundler	Capio
Anna Lundberg	Novartis
Johanna Hultcrantz	Cambio
Magnus Clarin	Region Halland

Thomas Davidsson, chairperson CAISR Health, Industrial advisory board

The IAB design builds a very positive attitude. It is a forum where the company partners get a chance to discuss their perspectives on development with each other and with academic researchers. This is great; such opportunities don't come easy.

Thomas Davidsson

Predictive Maintenance

Predictive maintenance (PdM) with machine learning methods is a major research topic in CAISR. Predictive maintenance is about estimating when a system should be maintained to achieve an optimal tradeoff between repair costs and uptime. It is based on the idea that systems can be monitored, often using IoT-based sensors, such that it is possible to estimate their health status and make predictions concerning their remaining useful life or risk of failing. Machine learning techniques allow for cost-efficient automatic or semi-automatic analysis of large amounts of data, taking into account not only the symptoms most directly related to the failures but also the long-term effects of varying usage patterns or external conditions.

In CAISR, we explore machine learning for knowledge creation from real data; this means data from companies' everyday operations, including all the real-world uncertainties, such as missing or strange values, and ambiguities in repair records. This is in contrast to the vast majority of published PdM research, which is based on well-defined data measurements obtained under lab-like experimental circumstances, sometimes even simulated, with annotations and known faults. A concrete example of this is PdM research on bearings, which makes up almost 25% of the published PdM research worldwide. We chose this direction in 2005 when we realized that many of the PdM challenges faced by our industrial partners are inherently connected with this non-perfect data, with a lack of known ground truth. These challenges must be handled for solutions to be used in practice.

One research direction in CAISR PdM is estimating critical subsystems' remaining useful life and survival functions based on equipment usage and maintenance data. The research is most often done together with our partner Volvo, and examples of subsystems are turbochargers, coolant pumps, and electrical vehicle (EV) drive batteries.

Electric Volvo truck with batteries. Photo: Volvo Trucks

During 2022, CAISR and Volvo researchers developed an approach to turbocharger failure prediction, using ideas on multitask learning and recurrent networks, that succeeded in predicting an oncoming turbocharger failure about 90 days in advance. This research had the specific challenge that very few turbochargers fail in the field; they are generally replaced before that happens due to the extremely high potential for collateral damage. Still, even with a very small number of failed turbochargers, the researchers were able to come up with a good predictor using domain adaptation and ideas from survivability analysis.

Also, in 2022 CAISR and Volvo researchers explored representation learning and survivability analysis ideas for predicting coolant pump failures. Here a particularly interesting challenge in the operations data was a very high ratio of "no fault found", meaning that many coolant pumps that get replaced turn out to function fine in warranty tests after the replacement. So, an important direction for the research is to detect if a pump replacement has been done prematurely.

For EV drive batteries, CAISR and Volvo researchers showed how EV state-of-health estimations could be improved for buses in different markets, where these vehicles are driven differently. The proposed solution builds on transfer learning and domain adaptation to utilize data from one market to make better predictions in another market.

Predictive maintenance is about estimating when a system should be maintained to achieve an optimal tradeoff between repair costs and uptime.

A potentially exciting development for the remaining useful life research during 2022 was connecting to the Volvo Truck Monitoring Center data analytics team in Ghent. The plan for 2023 is to take selected results from the EV drive batteries work targeting the buses and see if they can be applied, as a pilot, to heavy-duty trucks across Europe.

Another CAISR research direction deals with characterizing vehicle usage. This can, e.g., be to recognize what operations a forklift truck does, so that the use of the forklift can be described in much more detail than what is currently done. This research is done together with Toyota Material Handling. The problem, which may at first sound simple, turns out to be quite complex. Different drivers do the same operation differently; the type of goods affects how the operations are done, and compromises between sensor cost and precision mean, as an example, that certain light goods are not detectable by the load sensor. During 2022, CAISR and Toyota Material Handling researchers developed a method based on recurrent networks and context ensembles to use the onboard streaming data to recognize forklift operations with high accuracy, including detecting the transport of "invisible" loads by inferring it from the context. This method achieves almost perfect accuracy on a small test set, but we know that extending this to other warehouse sites will be a significant challenge. Another example is to use weekly telematics data to recognize how heavy-duty trucks are used. Does a truck do long-distance hauls with overnight stays, or does it always come back to a hub? Is a truck operated by only one driver or several drivers? Is a truck doing repetitive work, or is each trip unique? These questions are simple to answer with access to GPS locations and high-frequency data. However, in many settings, the GPS traces cannot be used for GDPR reasons; and high-frequency operational data is expensive and thus only available for a fraction of the vehicles. CAISR and Volvo researchers showed in 2022 that many truck usage profiles can be recognized with high accuracy even from low-frequency, weekly, aggregated data without GPS. However, it took several attempts at clever combinations of numerous machine learning techniques, including snapshot ensembles and multitask learning, to reach this result.

Picture from the CAISR workshop on streaming data analysis in September 2022. From left: Kenneth Ulrich (StreamAnalyze), Magnus Gedda (StreamAnalyze), Erik Zeitler (StreamAnalyze), Albert Bifet (U. Waikato, NZ), Slawomir Nowaczyk, Thorsteinn Rögnvaldsson, Kunru Chen, Felix Nilsson (HMS Industrial Networks), Sepideh Pashami, and Yibin Sun (U. Waikato, NZ).

Toyota Fork Lift Triago80. Photo Toyota Material Handling

A third CAISR research direction is the practical implementation of PdM methods. This deals, e.g., with the tradeoff between edge computing and back-office computing. The company StreamAnalyze has been involved with many

CAISR partners in tests to do much of the onboard processing. In 2022 we ran an internal workshop with StreamAnalyze, our partner HMS Networks, and our guest professor Albert Bifet, on important and interesting challenges in industrial streaming data. The discussions during these workshops led to a new project, "Federated Learning and Edge Processing for Safe and Efficient Operation," submitted to Vinnova in early 2023. We also published a paper with HMS Networks on interactive human-machine knowledge discovery from industrial communications data.

A CAISR assistant professor works together with Alfa-Laval, developing PdM research together with them, focusing on Alfa-Laval's separator machines. In early 2022 they concluded a project on data-driven virtual sensors for separator machines, where there was a need for filling in missing data for the estimation of tensors.

Hadi Fanaee assistant professor at CAISR works together with Alfa-Laval.

A paper was presented at IDA 2022 on a new suggested method to deal with this: tensor completion with post-correction (TCPC). A major challenge here, as in most other projects involving real industrial data, is the lack of labeled data. Also, the results of unsupervised learning methods most of the time are not verifiable by the experts. Therefore, there has also been development on assisting users to label data in semi-automatic ways. In 2022, a shift was made toward time series modeling. We developed a novel multi-paradigm composite time series forecasting model that includes three different forecasting paradigms: model-based, statistical, and shape-based, with two other mechanisms for modeling context and machines. The obtained results look astonishingly good compared to the prior state-of-the-art.

The explainable predictive maintenance (XPM) project is a CHIST-ERA EU-funded that aims to provide several different types of explanations for PdM solutions (anything from visual analytics through prototypical examples to deductive argumentative systems) and demonstrate their usefulness in four selected case studies: electric vehicles, metro trains, steel plants, and wind farms. Among project results, the publication of the MetroPT dataset (in Nature Scientific Data) is worth highlighting: it supports the development and comparative evaluation of online anomaly detection and failure prediction machine learning methods. With analog sensor readings, digital signals, and GPS data, the dataset presents a unique and comprehensive platform for predictive maintenance research. Another development was a novel approach, Wisdom of the Contexts (WisCon), for detecting contextual anomalies, especially when true contextual and behavioral attributes are unknown. WisCon builds an ensemble of various contexts with different importance scores, estimated using an active learning strategy with a unique query method. We demonstrate that WisCon substantially outperforms existing state-of-the-art across multiple categories on 18 datasets, thus supporting the hypothesis that no singular context can reveal all contextual anomalies; rather, harnessing multiple contexts is essential. In collaboration with researchers from Porto, members of CAISR studied an LSTM autoencoder-based, data-driven anomaly detection framework and applied it to several subsystems of a public transport bus, effectively identifying abnormal data and reducing false alarm rates. Another research direction introduced the concept of "heterogeneity of decision boundaries" as a potential explanation for the increased difficulty of multi-class classification problems as the number of classes rises. It demonstrates that higher heterogeneity generally results in reduced performance across most classification approaches. Incorporating such heterogeneity knowledge in problem decomposition has improved classification performance and reduced model training times. These theoretical findings were then applied to predictive maintenance for complex machinery, particularly for predicting time-to-failure, where monitoring data might not be distinct for every possible fault. Conventional prognostic approaches, which use independent models for each fault, prove inadequate, especially when multiple faults share similar symptoms. Instead, we introduce the Hierarchical Multi-fault Prognosis (HMP) framework, creating a fault hierarchy based on symptom similarity and training a regression model at each node.

In the broader scope of CAISR projects beyond specifically predictive maintenance, there is, of course, also a number of findings with high relevance to this topic. To highlight one, as part of the FREEDOM project (From Connected to Sustainable Mobility), we demonstrate the use of traffic simulators and machine learning in combination to generate comprehensive synthetic traffic data, which circumvents ethical, privacy, and cost issues and facilitates analysis of challenging real-world scenarios. Our proposed Synthetic Traffic Data Generator (STDG) overcomes a limitation of traffic simulators: the inability to generate internal vehicle parameters crucial for areas like energy efficiency, driver behavior optimization, and predictive maintenance. We show that a model trained on internal vehicle parameters in one setting can reliably synthesize data for another, reducing the need for expensive, original data collection across different environments.

The **EVE** project

The EVE research project is co-funded by Vinnova and explores the use of data, analytics, and machine learning to prolong the lifetime of electric vehicles. The project has focused on the most crucial components of an electric drivetrain, such as the batteries, ECUs, charging hardware, and charging infrastructure, to identify the potential for extending the lifetime of these components. Extending the lifetime of these vital components has a large impact on the total cost and environmental impact of electric vehicles, as the drivetrain and energy storage systems stand for a significant amount of the cost and environmental footprint of heavy-duty vehicles.

Several techniques and methods have been developed, used, and evaluated in the project. For example, Transfer Learning methods were utilized to transfer insights from older hybrid buses into newer generations, providing a significant increase in the ability to calculate and model Battery State of Health over supervised regression models. The project utilized Machine Learning methods to create predictive maintenance algorithms for the drivetrain, enabling faster identification of errors and, therefore, a longer lifetime of the vehicles. The project explored using FLAML (the Fast and Lightweight AutoML Library in Python) to identify and train machine learning models on real-world data to predict the energy consumption of full-electric vehicles in different driving scenarios, giving insights into critical components and drivers of energy consumption in the vehicles.

Magnus Löwenadler: student in the national **PhD School Smart Industry Sweden**

Human operators bring to bear an array of critical abilities that Magnus Löwenadler's research seeks to integrate into predictive maintenance systems based on AI/ML. One of these abilities is active engagement in hypothesis testing. When humans discern a potential anomaly, they engage in proactive actions to either validate or refute their hypothesis. This implies an inherent capability to reason, adapt, and learn from dynamic environments. Furthermore, human drivers possess an intuitive understanding of the consequences associated with different vehicular states and symptoms. They can distinguish a problem – such as unusual vibration or diminished engine power – from benign anomalies that might arise from atypical usage or external factors. This distinction is vital as it allows for the differentiation between innocuous effects and those that unquestionably signal vehicular issues. In contrast, current AI systems struggle to perform this task consistently and reliably. Moreover, humans excel in their ability to generalize knowledge, exceeding the capabilities of contemporary AI systems. Such a human-like ability to abstract knowledge from one situation and apply it to another will be a key component in creating reliable and robust autonomous vehicles. Magnus Löwenadler's research revolves around the practical implementation of such capabilities into AI/ML systems. This must involve localized deployment onboard vehicles, or through nearby edge computing nodes.

Information Driven Care

The Research Profile CAISR Health

The Knowledge Foundation funded CAISR Health Research Profile started 2021-07-01 with seven industrial partners together with Region Halland. During 2022 five subprojects were active within CAISR Health (see a summary below). About 15 journal and conference publications were associated with CAISR Health for 2022. We have conducted several activities to promote the development of different projects, to emphasize co-production, and for the fulfillment of our objectives. This includes running three workshops together with our industrial partners on the topics of AI research, Design research, and Implementation research. We also started a series of cross-disciplinary seminars during 2022 to promote learning across subprojects and across disciplines. The first seminar was focused on explainable AI.

In each project, the project group met regularly during 2022 for project planning and discussions about challenges, research questions, ethics, methods as well as expected value and impact. A central part during 2022 was writing ethics applications to be able to start the projects. The work with ethics applications was valuable from a learning perspective, as the companies usually do not have experience with this. Overall, the activities in each project have contributed to a shared understanding of the latest level of state of know-how in a field from both practical- and theoretical perspectives as well as a greater understanding of the researched subject by understanding the company context, needs and challenges. Here is a summary of the projects and activities during 2022.

Photo from the 2nd IAB Meeting for CAISR Health, hosted by Visiba Care. The organizations and people in the photo are as follows (Novartis was unable to attend this meeting):
Top row: Hallandia V (Thomas Davidsson and Karin Moberg); InterSystems (Otto Medin);
Middle row: Region Halland (Magnus Clarin); Visiba Care (Peter Tyreholt); Halmstad University (Jonathan Burgos and Kobra Etminani)
Front row: Capio (Niklas Sundler); Mölnlycke Health Care (Jan Boberg); Cambio (Jonas Andersson)

Mattias Ohlsson and Petra Svedberg, director and co-director for CAISR Health

CAISR Health Partners
Brigham and Women's Hospital
Cambio
Capio
Inter Systems
Mölnlycke
Novartis
Shaarpec
Region Halland
Visiba Care

CAISR Health projects running 2022

Project 1: HaRP – Heart failure Readmission Prediction: The main goal of this project is towards completion, calibration, and practical implementation in practice of the 30-day readmission prediction model as a clinical decision support system (CDSS) for clinicians in several selected clinical endpoints for hospitalized HF patients at the time of discharge. This project is in collaboration with Cambio AB and Region Halland, and a team of researchers from School of ITE (AI and informatics researchers) and School of HOV. The AI researchers together with data scientists at Cambio AB, and clinicians from Region Halland have been working on designing and developing a 30-day readmission prediction algorithm using retrospective data from Region Halland patients. Cambio AB, then is preparing a prototype to integrate that into their EHR system and later in 2023 to be assessed by clinicians within various scenarios.

Project 2: PadAI – AI for better mental health in young people: PadAI stands for Participatory and Information Driven Anxiety/Depression Healthcare Journeys of Young Adults. The purpose of the project is to develop knowledge and strategies for coherent, good, and close care for the target group of young adults with mental illness. Research shows that young people and young adults with mental illness do not have access to or do not receive satisfactory and effective support measures when they seek help for their problems. To promote young adults' mental health and prevent ill-health, a joint research project has been initiated by Region Halland, Halmstad University, and Capio Healthcare. Several stakeholder interviews have been conducted during 2022 to understand the problem. There are a number of mobile applications available in the market to help mental health seekers. Informatics researchers have been looking to investigate a few of them. Extensive data access was granted for the project in late 2022.

Project 3: CAISR Wound: In today's healthcare system, the burden of wound care is growing as a national and global concern. Acute and hard-to-heal wounds cause major problems, both from a human and financial perspective. From a human perspective, wounds have a major impact on the patient in the form of suffering, pain and reduced quality of life, and from an economic perspective, the need for resources and the costs of wound treatment are significant. The overall purpose of this project is to increase knowledge about of care delivery pathways and processes for patients suffering from wound problems and is a collaboration between Region Halland and Mölnlycke AB. Data access from region Halland was granted during 2022. Initial studies are underway investigating how can AI-based analyses be used as a tool to develop deeper knowledge about wound care processes, wound treatment, and its effects. During 2022 it was decided to recruit an industrial PhD student to the project, co-supervised by Mölnlycke AB.

Project 4: VAAT - Validating the quality and the performance of AI-assisted triage and diagnostic tools: The overarching aim of this project is to design and implement a standardized, comprehensive validation process to systematically evaluate the effectiveness, accuracy, and benefits of AI-assisted triage and diagnostics tools in the healthcare system. More specifically, the project will develop new methodologies and metrics to quantify the clinical, economic, and societal values of these technologies in the healthcare system in Sweden by using real-world health records of patients. The project is run in collaboration with Region Halland and Visiba Care AB, manufacturer of the AI-based automatic triage tool Red Robin. Initial feasibility studies were performed in 2022 in preparation for the ethical application process.

Project 5: Cardiovascular Health: How could high-risk Atherosclerotic cardiovascular disease (ASCVD) patients and patient trajectories be described from a demographic, clinical, and resource perspective? How could AI-assisted retrospective analysis be used as a tool to create actionable knowledge about disease progression, treatment, and care flows for the ASCVD cohort? These are the main research questions for this subproject run in collaboration with Region Halland and Novartis Sverige AB. The project is in its initial phases and much of the focus in 2022 was on running feasibility studies, formulating the research plan, and preparing the ethical review board application.

The CAISR Health profile started in 2021 and in 2022 a strategic research program was initiated with strategic funding from the vice-chancellor. The CAISR Health profile is now part of an ecosystem of partners, Schools, projects, and innovation arenas. For example, CAISR Health interacts closely with the innovation center Leap for Life, which hosts innovation activities like the European Digital Innovation Hub (see below), and the national PhD school on Health Innovation (described in last year's report).

Large scale strategic research program initiated

In 2022, the vice chancellor initiated the strategic research program *Information Driven Care.* This is a long-term (up to ten years) strategic investment from the university to establish an internationally strong research grouping on information driven care, a research group that can position the research at the university. The research group behind the CAISR Health research profile wrote the proposal, which was evaluated by external and international evaluators with a very good outcome. The additional strategic funding from the vice chancellor is expected to be close to fifty million SEK for the first five years.

The Information Driven Care research program focuses on the development of multidisciplinary research on information driven care, connecting the fields of AI and machine learning, implementation, and innovation. The research program takes a broad approach to examine information driven care and the integration of AI systems in healthcare. The program will work to enhance and strengthen the evidence to use AI systems in the transformation of healthcare, thus finding new ways of working to meet growing demands of efficiency and equality in healthcare, while limiting costs and improving quality and patient experience. The goal is to take a strong position nationally and internationally through a unique combination of multidisciplinary perspectives on information driven care. The research program is based on the long-standing collaboration between Halmstad University, Region Halland, and companies with an ambition to increase knowledge and solutions for transformation into information driven care in relation to urgent and relevant healthcare problems.

The Information Driven Care research program focuses on the development of multidisciplinary research on information driven care, connecting the fields of AI and machine learning, implementation, and innovation.

Real-World Evidence (RWE) projects

In 2022, we set the forms on how to run the so-called Real-World Evidence (RWE) projects. Four RWE projects were done in 2022 on heart failure, chronic kidney disease, and diabetes. Three of them resulted in publications accepted or published preprints during 2022.

Project 1: Soliman et al. (2022). "The Price of Explainability in Machine Learning Models for 100-Days Readmission Prediction in Heart Failure", *Journal of Medical Internet Research (JMIR).* This project showed that a widely used deep prediction model did not outperform an explainable machine learning model when predicting readmissions among HF patients. Thus, model transparency does not have to come at a price of lower performance, which could support clinical adoption.

Project 2: Davidge et al. (2023). "Clinical characteristics at hospital discharge that predict cardiovascular readmission within 100 days in heart failure patients – An observational study", *Int'l Journal of Cardiology Cardiovascular Risk and Prevention,* vol. 16. This project looked at heart failure patients and found clinical factors already present at discharge that are associated with increased risk of readmission, factors that should be considered at discharge.

Project 3: Jendle et al. (2022). "Patterns and Predictors Associated With Long-Term Glycemic Control in Pediatric and Young Adult Patients with Type 1 Diabetes", *Journal of Diabetes Science and Technology*. This project studied individuals with type 1 diabetes, and found that more frequent visits to physicians, and a visit to dietitians, and psychologists were associated with improved glucose control in individuals with T1D 0 to 25 years. Increased resources, including access to more advanced technologies, may be required to aid young adults with T1D

Readmission is connected with high costs and personal suffering


Increased resources, including access to more advanced technologies, may be required to aid young adults with T1D

Two new Vinnova funded projects

The project *Information Driven Care – federated learning and synthetic data* generation started in August 2022 and will continue to March 2023. The project is a Vinnova-funded pre-study for a much larger national system demonstrator project (up to 30 million SEK) that will be applied for in 2023.

The project tests the possibility of sharing information from several regions via so-called federated learning. That is, how to train a machine learning model on data from multiple regions without the data leaving the regions. In this project, clinical and resource-related data from heart failure patients are used. Region Halland has already analyzed and researched this data and the goal is to be able to do the same kind of analysis with heart failure data from Region Örebro län.

Synthetic generation of health data is also tested, primarily by one partner in the project, the company Hallandia V. They are developing a method to synthesize health data, where the quality of the data is maintained but individual privacy is preserved. It has resulted in an article that has been sent to NPJ Digital Medicine Nature journal: Nikolentzos, G. et al. "Synthetic electronic health records generated with variational graph autoencoders", NPJ Digital Medicine, 6(1), 83.

The pre-study has seven partners: Halmstad University, Region Halland, Region Örebro län, Region Kronoberg, Örebro University, AI Sweden, Astrazeneca AB, and Hallandia V AB.

Synthetic generation of health data is tested.

The project *Prevention 360* was applied for in 2022 and started early 2023. Prevention 360 is a pre-study project to build a proposal for a Vinnova-funded national strategic innovation program (to be applied for in October 2023). This pre-study also has seven partners: AI Sweden, Halmstad University, Region Halland, Region Västra Götaland, Uppsala University, SIR (Zero Vision Cancer), and Fokus Patient.

Partner in an EU-funded national innovation hub

In 2022, the consortium and project Health Data Sweden was granted to be one of Europe's digital innovation hubs (EDIH). One of the aims of Health Data Sweden is to increase the use of health data to contribute to more efficient healthcare. An important task will therefore be to meet the great need for services that contribute

to small and medium-sized companies in collaboration with the public sector being able to develop new digital health and welfare services. In addition to better health for the individual, these services can also contribute to solving major demographic societal challenges, for example making care more accessible and equal.

One of the aims of Health Data Sweden is to increase the use of health data to contribute to more efficient healthcare.

The partners in Health Data Sweden are Blekinge Digital Health, Bron Innovation, DigitalWell Arena, eHealth Arena, EIT Digital, EIT Health, Halmstad University, Karolinska Institute, The Royal Institute of Technology, Linnaeus University, Livsmedicin, Region Stockholm, RISE, Stockholm Science City, Stockholm University, STUNS Life Science, and Uppsala University.

Computer Vision

The main research directions in the computer vision group in CAISR are applications for biometrics and autonomous driving. Professor Josef Bigun is the top Swedish researcher in Biometrics and an IEEE Fellow. The group is highly cited and has a strong scientific position, with a track record of several consecutive projects funded by the prestigious Swedish Research Council. The group members are very active in teaching, e.g. in Halmstad University's popular IT-forensics program and in the machine learning courses on deep learning.
In 2022, two new projects were granted with funding from Vinnova (Sweden's Innovation Agency):

BigFun: Big Data-Powered End User Function. A project together with Volvo Trucks. The project is exploratory and aims to understand how to apply quantitative analytic methods to identify moments of interest in real-world vehicle journeys. The combination of these findings with advanced qualitative analytic methods will generate actionable insights such as a deeper understanding of challenges and opportunities for improving truck function, feature, and service design to better suit commercial mobility needs.

To the right: The Big Fun project group

DIFFUSE: Disentanglement of Features for Utilization in Systematic Evaluation. A project together with RISE (Research Institutes Sweden) and the company SmartEye for controllable synthetic data generation (mainly faces). A challenge in generation of datasets is to create a good combination of realism, control, and variation. In the DIFFUSE project we propose an improvement of current algorithms for data generation by developing their ability to disentangle features in the input. A specific part of the input should control a specific and understandable part of the output data. This has applications in increasing the understanding of what a generated dataset contains to give a clearer picture of in what situations a network trained on it could be expected to work.

In 2022, the group also got an EU Horizon project granted, ROADVIEW, which is described in details in the following pages. An ongoing project is **Facial Analysis in the Era of Mobile Devices and Face Masks**, funded by the Swedish Research Council.
The Computer Vision group has five active PhD students, of which two are enrolled in the national industrial PhD school Smart Industry Sweden (see next page), and two are working in the EU-funded ROADVIEW project (see following pages). The fifth student is getting very close to his dissertation.

RISE is Sweden's research institute and innovation partner. In international cooperation with companies, academia and the public sector, they contribute to a competitive business life and a sustainable society. The 3,000 employees drive and support all types of innovation processes. RISE is an independent, government research"that offers unique expertise and around 100 test and demonstration environments for future-proof technologies, products and services.

The main focus area of my research is explainability in artificial intelligence. The intention is to direct machine learning models from the opaque box structure they commonly are described as today towards a more transparent and interpretable state. This is done by increasing the model's ability to display its decision-making process. Common methods include surrogate models, saliency methods and counter factual arguments.

Martin Torstensson

Ph D Students at Smart Industry Sweden. Felix and Martin works towards the goal to strengthen the competivness and innovativeness of Swedish Industry.

My research focuses on anonymization of image and video data without destroying rich attribute information, validation of these methods and potential security issues using deep learning-based anonymization. The research has a strong focus on facial and traffic related data, in particular to be able to store large amounts of data for training deep learning object- or road user detection models and driver monitoring systems.

Felix Rosberg

Roadview

Complex environment and traffic conditions have a major impact on the safety and operations of Connected and Automated Vehicles (CAVs). Weather affects not only the vehicle performance but also the roadway infrastructure, thereby increasing the risk of collision and traffic scenario variations.
So far, most automated vehicles have been primarily trained and tested under optimal weather and road conditions with clear visibility. However, the systems must prove that they are equally reliable and accurate under any weather and road condition before they can see widespread acceptance and adoption.

The challenges for automated driving systems caused by harsh weather conditions, such as fog, rain and snow are substantial, as these affect the functioning of their key technologies and their development: sensors, detection, control and system testing.

There is currently a strong push globally for automated vehicles in general and towards solving harsh-weather-related challenges.

The project brings together 16 partners who together aim to solve challenging autonomous driving problems under harsh weather conditions using AI. The consortium is a perfect combination of leading universities in the field and research institutes, high-tech SMEs, and strong industry leaders. Beyond their research excellence, the consortium members bring a unique portfolio of testing sites and testing infrastructure, ranging from hardware-testing facilities and rain and wind tunnels to test tracks north of the Arctic Circle.

Complex environment and traffic conditions have major impact on the safety and operations of Connected and Automated Vehicles (CAVs). Weather affects not only the vehicle performance but also the roadway infrastructure, thereby increases the risk of collision and traffic scenarios variations. So far, most automated vehicles have been primarily trained and tested under optimal weather and road conditions with clear visibility. However, the systems will have to prove that they are equally reliable and accurate under any weather and road condition before they can see widespread acceptance and adoption. ROADVIEW integrates a complex in-vehicle system-of-systems able to perform advanced environment and traffic recognition and prediction and determine the appropriate course of action of a CAV in a real-world environment, including harsh weather conditions. ROADVIEW develops an embedded in-vehicle perception and decision-making system based on enhanced sensing, localisation, and improved object/person classification (including vulnerable road users). ROADVIEW ground-breaking innovations are grounded on a cost-effective multisensory setup, sensor noise modelling and filtering, collaborative perception, testing by simulation-assisted methods and integration and demonstration under different scenarios and weather conditions, reaching TRL 7 by the end of the project. ROADVIEW implements the co-programmed European Partnership "Connected, Cooperative and Automated Mobility" (CCAM) partnership by contributing to the development of a more powerful, fail-safe, resilient and weather-aware technologies.

The ROADVIEW system is a culmination of interdisciplinary challenges and brings together key players on standards and system requirements, sensor performance, data processing and management for automated vehicle operation in adverse weather, collaborative perception, decision-making systems, testing and validation, demonstration and EU project management, communication and dissemination.

Partners

- Halmstad University (coordinator)
- Lapland University of Applied Sciences
- Technische Hochschule Ingolstadt
- Swedish National Road and Transport Research Institute
- Centre d'études et d'expertise sur les risques, l'environnement, la mobilité et l'aménagement
- RISE Research Institutes of Sweden AB
- Finnish Geospatial Research Institute FGI
- Repli5
- Aurora Snowbox OY
- Sensible 4 OY
- Konrad GmbH
- Ford Otosan
- Canon Research Centre France
- ZF Friedrichshafen AG
- accelopment Schweiz AG
- The University of Warwick

On 8-9 September 2022, the kick-off for the Horizon Europe granted research consortium ROADVIEW was held at Halmstad University.

ROADVIEW

Perception systems

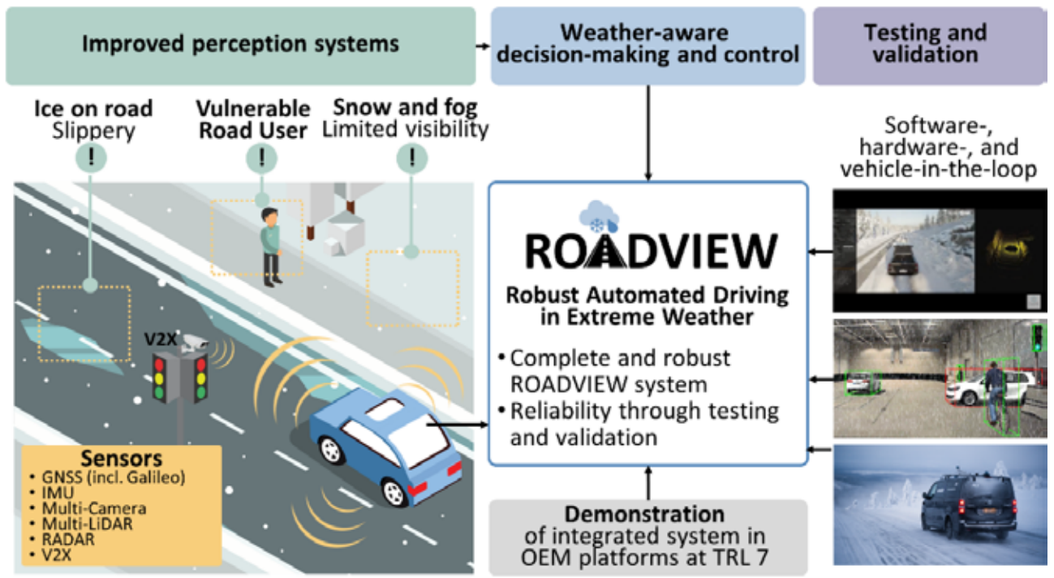
ROADVIEW will deliver more powerful and reliable in-vehicle perception systems, with improved resilience and accuracy under harsh weather conditions.

- Improved sensor and noise models
- Using noise filtering to improve detection of objects and vulnerable road users
- Enhanced sensing by using additional sensors, such as thermal camera and imaging RADAR
- Using adaptive sensor fusion and collaborative infrastructure-based perception for improving object and drivable area (free space) detection
- Improved localisation and use of HD map technology

Testing and validation

ROADVIEW will develop novel noise models and integrate them into the different test systems. For their operation, we will achieve modularity in an X-in-the-loop test environment in which different sensor models can be integrated to generate synthetic sensor data and test sensor hardware. Furthermore, standard interfaces (e.g., OSI) will enable a gradual migration from sensor to vehicle-in-the-loop testing without any modification of the system-under-test.

Eren Aksoy, Project coordinator ROADVIEW



IT Forensics

Student programme

In 2022, the IT-forensics and information security program was the most popular program for new students to Halmstad University, i.e. the program with the largest number of applicants.

In the IT forensics and information security program, students learn the basics of computer technology, computer networks, and IT security systems. They further learn to use forensic tools to extract digital information from computer systems and to practically apply methods to encrypt or hide data. The students also gain knowledge in how to search for and secure traces and document the work in criminal investigations. The education includes basic criminology and law with a focus on IT-related crimes.

The program started in 2008. Over the 15 years since then, more than 700 students have started the program and the alumni work with the Swedish Police, the Swedish National Forensic Center, the Swedish National Operative Department, the Security Police, the Swedish Customs, the Swedish Armed Forces, and at all the large banks. The IT forensics and information security program at Halmstad University is very well known in the relevant sectors in Sweden.

In 2021, three key persons in the program staff were awarded the Halmstad University award for cooperation and innovation, see picture, for successfully developing collaboration between academia, public and private sectors to support society in the fight against the rapidly increasing IT crimes.

The IT forensics and information security program is a unique gem at Halmstad University, where some CAISR staff teach and create research projects connected to the education.

Research : AI-Powered Crime Scene Analysis

The project, funded by Vinnova, is about automatic analysis of indoor crime scenes."We will study AI technologies for environment mapping, segmentation and classification of objects and traces found at such scenarios worthy of immediate investigation, eg to avoid contamination of the scene or warn for hazardous situations.

Crime scene investigation is normally done by forensics experts upon arrival. The present project will automatize these tasks, allowing the team to directly concentrate on the analysis of important cues, thus saving precious time during the first moments after a crime. Outputs will also remain as an uncontaminated model of the scene, allowing post-analysis, if necessary, during any step of the investigation.

To achieve our aims, we will explore vision technologies like visible, IR, thermal, and non-vision depth sensors like LIDAR. To ensure that the scene is contaminated to the least possible extent, we will investigate the use of nanodrones. This is a challenge, since existing drones equipped with those sensors are usually big and unsuitable, for example, for small flats. To counteract potential difficulties in such innovative task, we will also investigate the use of smartphones or bodycams worn by first-responders.

The MAISTR program...

The MAISTR programme was initiated in 2021 to provide an offering of courses to professionals in AI, service design and innovation management. The first batch of courses were delivered starting in 2022, a total of 17 courses was given out of the whole programme of 26 courses. The remaining 9 courses are planned to be delivered for the first time in 2023, along with a second run of each course that was given in 2022. For the courses that were given in 2022, the number of students typically varied between 17 to 69 students, where most courses had about 30-40 registered students. The course evaluations along with the overall student satisfaction index was good, where most courses had in the range of 70-95% student satisfaction index. Because of the many interesting responses in course evaluations, we are planning an interview series of students, companies and teachers during 2023 where we will dig deeper into the values and learnings from the courses so far. We have also during the year interacted with all the partner companies, to get input on our offering and what kind of competence needs they have. Some of the companies have also participated in the courses as guest lecturers, to provide an applied industrial perspective on the topics.

During 2022 there was also started development of a podcast connected to MAISTR ("Eliza: The beyond AI podcast"). The intention with the podcast is to allow insight into the topics of the program, be able to get to know the teachers and other experts in the field, as well as to listen to our pedagogical reflections related to life-long learning. The podcast is hosted by Sepideh Pashami (HU and RISE) and Amanda Åberg (InUse).

Sepideh Pashami and Stefan Byttner

...and Eliza

Eliza is the podcast where you will meet a wide range of scientists, professors and professionals within AI who will share their perspectives and knowledge about the technology already forming our everyday lives today. The aim of the podcast is not only to give our listeners a deeper understanding of what AI is capable of today but also to give different points of view on the technology and its usage.

Hosting the podcast are Sepideh Pashami, Senior Lecturer in AI/Machine Learning from Halmstad university, and Amanda Åberg, UX & Service Designer from the design agency inUse. Together, and in conversation with the guests, they take on different subjects related to AI and make it understandable for a broad audience in order to shine a light on this important topic and its impact on our lives.

Outreach

Outreach activities

Besides several workshops with industry partners during 2022, we also organized thematic workshops at conferences, podcasts, short courses, talks in non-research contexts, and educational seminars. Some highlights are provided here (the MAISTR short courses for professionals and the Eliza podcast are described on the previous page).

- **Information driven healthcare - turning data into health for patients and quality of care.** A workshop organized jointly by CAISR and Region Halland at the International Forum on Quality and Safety in Healthcare conference, in June 2022 (workshop organizers: Farzaneh Etminani, Markus Lingman, Martin Engström, and Carolina Samuelsson). The forum was organized by the Institute for Healthcare Improvement and BMJ (formerly the British Medical Journal).
- **The Halmstad Professionals Network.** We contributed to lunch talks online, where professionals could follow and get updated. Two examples during 2022 were:
  - Rune Prytz (Head of R&D at Stratio), who talked about Predictive Maintenance and how Stratio's proprietary technology combines large-scale processing with the latest machine learning techniques to prevent hundreds of thousands of breakdowns from happening every day.
  - Panel discussion on "AI researchers meet healthcare professionals: vision for the common future", with Markus Lingman (Region Halland and CAISR), Ricard Gavaldá (UPC), Martin Atzmüller (Osnabrück University and DKFI), Myra Spiliopoulou (Otto-von-Guericke University, Magdeburg), Miltiadis Triantafyllou (Region Halland), and Martin Engström (Region Halland).
- **Pod "Digital Conversations"**. Pontus Wärnestål participated in a pod discussion on considering AI as a new design material, when developing AI-based services.
- **Intensive course in India on service design with AI.** Pontus Wärnestål, CAISR member and adjunct professor at Woxsen University in Hyderabad, gave a two-week intensive course on service design, AI, and reflective sustainable design practice.
- **Workshop on IoT Streams for Predictive Maintenance.** CAISR staff co-organized this workshop at the ECML-PKDD conference 2022.

Awarded students

The students we supervise or teach often get awarded for their thesis projects or other achievements. 2022 was no exception.

- Getinge grand award for Health Innovation went to Pooriya Khorramyar for his M.Sc. thesis work *Visual Transformers for 3D Medical Images Classification: Use-Case Neurodegenerative Disorders.* Supervisors Amira Soliman, Stefan Byttner, and Farzaneh Etminani.
- The 3rd prize from Sten Fåhré memorial was awarded to Fahad Hassan & Sebastian Hagblom for their M.Sc. thesis work *Virtual sensing och hauler engine sensors.* Supervisors Yuantao Fan and Zahra Taghiyarrenani.
- The Devoteam prize for best thesis work on the civilingenjör in computer engineering/intelligent systems program went to Leif Sulaiman and Sebastian Larsson for their thesis work *Genre style transfer*. Supervisors Yuantao Fan and Peyman Mashhadi.
- Sparbanksstiftelsen Kronan awarded one of their top prizes to Bachelor students Joel Pålsson and Otto Zell for their thesis *Fire detection in industrial environments.* Supervisors Kevin Hernández Diaz, CAISR, and Felix Nilsson, HMS Industrial Networks.
- Nadia Benamer was nominated to Tech Girl of the Year 2022 by Microsoft Sweden. Nadia was a student in the IT Forensics and Information Security program

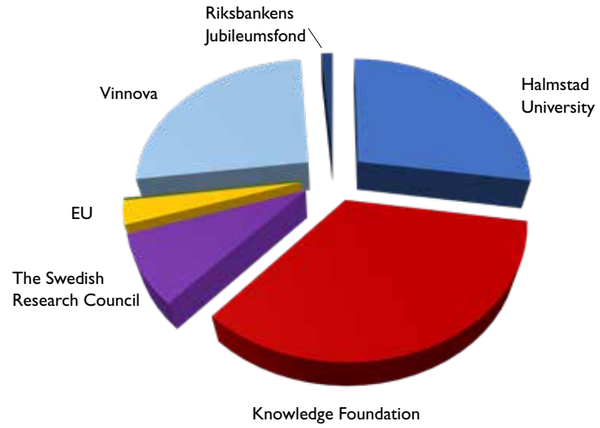
"The message I want to spread to others is that as long as you have an interest and are willing to fight for it, no dream is too big."

Nadia Benamer, student, IT forensic and information security programme

Funding and publishing

In 2022, the research turnover in CAISR was 31.3 MSEK (million Swedish kronor) on the university side, i.e. not including in-kind efforts by our partners. This is almost a 20% increase from 2021 (26.4 MSEK). The external funding ratio increased (73% in 2022, cf. 69% in 2021). The sources of research funds to CAISR (on the Halmstad University side) are illustrated in the pie diagram to the right. The three largest sponsors were the Knowledge Foundation, Halmstad University, and Vinnova (Sweden's Innovation Agency). The fourth largest funder was the Swedish Research Council. Both the Knowledge Foundation and Vinnova support projects that are done in close collaboration between academics and industry (or the public sector). The funding from the Swedish Research Council, which sponsors more fundamental research, more than doubled cf. 2021.

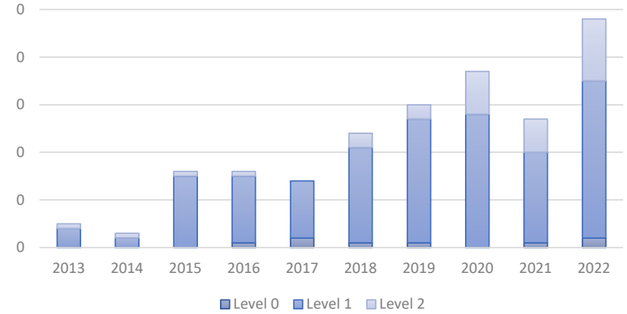
Research funding on the university side



Scientific publications and impact

After a temporary drop in publications 2021, the CAISR researchers reached a new high in 2022, with 48 publications, of which 27% were published in level 2 journals (in the Norwegian ranking system). This is very good and it is an impressive development over the last ten years, as illustrated in the figure, with an increase of 4-5 times in scientific journal publications per year. Over this period, the focus has also shifted from conference publications to journal publications. In 2013, 29% of the total were journal papers. In 2022, 74% of the total were journal papers.

CAISR Journal Publications (Norwegian levels)



Strengths of the core research directions

The three core research directions in CAISR are computer vision, predictive maintenance, and information driven care. The table lists some key publication indicators (KPIs) for the research staff working in each direction, as an indication of each directions' potential. Visiting researchers (e.g. visiting professors) are not included. The KPIs are based on Web of Science data.

Several of the staff work in more than one of the research directions but the KPIs are based on placing them into only one.

	Staff with PhD	*PhD students (2022)*	*WoS publ. 2018-2022*	*WoS citations 2018-2022*	*WoS H-index*
Computer Vision	*5*	*5*	*50*	*452*	*15*
Predictive Maintenance	*14*	*7*	*121*	*782*	*15*
Information Driven Care	*10*	*4*	*86*	*1533*	*20*

Visiting professor with an interest in **streaming data**

Banking systems, flood threats, and predictive maintenance – these are a few of the things CAISR's visiting professor Albert Bifet is working on. His research area is AI development for streaming data.

When data comes in continuously and is analyzed in real time, high capacity, efficiency, and flexibility are required. In Professor Albert Bifet's research, machine learning is performed on data that passes through the system without being stored. Therefore, the learning methods must also be adjusted in real time.

- How do you adapt your systems effectively when circumstances change? This is a question that interests me a lot. During the pandemic, it became so clear that many machine learning systems failed because they had been trained with data from previous situations that were no longer relevant. It's easy to see that something is starting to change - but predicting something that has never happened before is much more difficult, says Albert Bifet.

He is from Barcelona, holding a professorship at the LTCI at Télécom Paris but spending most of his time in New Zealand, where he leads the Te Ipu o te Mahara Artificial Intelligence Institute at the University of Waikato. Much of his work is based on open source software, Moa in Java and River in Python.

Albert Bifet
Guest Professor

AI helps banks and environmental researchers alike

In France, Albert Bifet collaborates with the bank BNP Paribas in a project where real time machine learning is used to detect small anomalies in the system before they grow and cause a server crash. His research group work a lot with explainable AI, mainly the SHAP values method, Shapley additive explanations, which Albert Bifet also develops further.

- Today many algorithms are used without anyone checking that they do the job well enough, but in the future I think we will want an explanation from each system.

In New Zealand, the focus is on environmental projects. The aim is to help environmental scientists improve and streamline their work, such as analyzing images using deep learning, or more accurately predicting extreme weather and natural events.

- One of the problems with AI today is that the large models require so much energy. It is important that we develop 'green AI', so that the new methods for solving environmental problems do not contribute with new problems.

One project is about predicting floods, another about irrigation and water resources in cultivated forests. They combine satellite images and data from sensors mounted in the trees.

- We use a new data architecture called data mesh, a distributed architecture that allows us to collect huge amounts of data in real time from all these tree sensors," says Professor Bifet.

Predictive maintenance is the core in Halmstad

In Halmstad, there will be less work on forests and more on predictive maintenance, an area that attracted Albert Bifet when he accepted the visiting professorship. In France, he runs a project on maintenance solutions for railways based on data from the state-owned SNCF, and together with employees from CAISR, he has helped organizing a major European workshop on machine learning and data mining in predictive maintenance.

- I was very happy when they offered me a two-year position here. I have a lot to learn and I am convinced that we will create great research collaborations, says Albert Bifet.

More broadly, he hopes that the use of AI will lead to a future in which people can do their jobs more efficiently and thus have more free time. While regulation is needed to prevent AI from being developed for harmful purposes, the problem is not the technology but who uses it, says Professor Bifet.

- As a researcher, I am proud to contribute to open-source tools. The rapid progress of AI is largely due to open source, and avoiding 'black boxes' also helps us control the technology and avoid dangers. Openness brings both better innovation and greater safety.

Motivated by being involved **from research to the clinic**

After graduating from Cairo University with a degree in computer science, Amira Soliman got a job in industry but grew tired of the routine. In her research, she can be driven by her own curiosity.

In industry, everything was so systematic, you had to follow instructions and not question directions.

- But I really like to ask questions about everything, like in research!

Amira Soliman became a research assistant at Alexandria University, then applied for PhD positions abroad, came to the Royal Institute of Technology (KTH) in Stockholm and defended her thesis on graph-based analyses. As a postdoctoral researcher at RISE (Research Institutes of Sweden), she realized the possibilities in healthcare. Her focus was already on data analysis in real world situations, and at RISE she worked with data from cancer patients at the Karolinska Hospital.

- When working with healthcare, it is not enough to understand the data, you also need to understand the expectations of the staff. If you develop a tool to help clinicians, it must fit into their workflows," says Amira Soliman.

She is now an assistant lecturer in Halmstad. In CAISR Health she saw the opportunity to work with both research and practical implementation.

AI for heart failure and mental health problems

One of Amira Soliman's projects involves a decision support tool to assess the risk of recurrence for heart failure patients. The model is based on clinical data but also some administrative data, such as whether the patient came through the emergency room or another department. The tool will assess the risk that the patient, if dismissed from the hospital, will return within 30 days. It should also indicate which information that led to the conclusion.

Amira Soliman
Associate Senior Lecturer

- The clinics should therefore be able to understand the logic used by the model and thus learn more about the risk factors. Our partners in the project are Region Halland and the company Cambio, which is developing a prototype so that we can carry out an implementation study.

Region Halland is also a partner in a project on depression and anxiety in young adults. Using anonymized patient data from diagnosed patients, Amira Soliman and her colleagues are tracking healthcare contacts back in time. The goal is a model that predicts which symptoms signal the risk of mental health problems.

- We have had several meetings with clinicians to be able to group the data correctly and build a model that can be used in practice. We want to find patterns in the data that make it possible to help young people as early as possible, perhaps through stress management or support and activities that make them feel better.

Important to work closely with the healthcare personnel

AI development with patient data is always a challenge because of the absolute importance of patient privacy. Therefore, Amira Soliman also works with synthetic data; when researchers use a real dataset to develop a model that can then generate 'fictitious' data with the same characteristics as the real data. This results in data that can be used to train AI systems but cannot be linked to a person.

Amira Soliman says that physicians and nurses are often very positive about AI technology if it can relieve their workload. But of course, patient safety always comes first. The new technology must be linked to clinical expertise, and CAISR researchers' collaboration with healthcare professionals is important for both trust and functionality.

- The clinical ecosystem is so complex, from medical guidelines to patient management and cost recording systems – you can't just put an AI tool anywhere and expect it to work.

When Amira Soliman came to Sweden, she was worried about feeling different among the Swedish students and researchers, but she was pleasantly surprised. The KTH campus was teeming with people from all over the world. Even in Halmstad, the workplace is multicultural and interdisciplinary.

- I really like it. We have so many types of expertise and we get to be involved all the way from data collection to prototyping. Starting with research and ending up with something that actually helps doctors to help their patients - this motivates me at work every day.

From a village without electricity to **quantum computing**

Prayag Tiwari was 18 years old when he saw a computer for the first time. Now, an assistant professor at CAISR, he researches quantum machine learning, multimodal analysis, and much more.

Prayag Tiwaris describes his research interests as "very broad". No exaggeration, if you look at the list of topics on his website: artificial intelligence, quantum machine learning, graph neural networks, federated learning, reinforcement learning, cognitive science, healthcare, bioinformatics, IoT, multi-modal fusion...

After graduating from Rajiv Gandhi Technical University in Bhopal, studies, research, and scholarships took him to Russia, Italy, Finland, and finally to Halmstad University. His doctoral thesis was on quantum machine learning: new methods for extracting information from data using methods and knowledge from the world of quantum physics. Prayag Tiwari describes the two quantum physics concepts of superposition, where a particle is in two states at the same time, and entanglement, where two particles are linked together in such a way that they share a common quantum state, no matter how far apart they are from each other.

- In very simple terms, quantum physics provides greater degrees of freedom when making decisions. I want to encode classical data into quantum states with those degrees of freedom.

Algorithms detect depression and side effects

Some of Prayag Tiwari's projects are basic science while others are applied. For example, he has been developing depression detection systems using different types of data including, text, video, image, audio, and multi-modal information.

Prayag Tiwari
Assistant Professor

- The aim is to be able to screen people and assess whether they need to seek medical attention. Our model combines text with analyses of facial expressions and voices to make the assessment very effective.

Another project deals with drug interactions, where different drugs interact in ways that cause side effects. Prayag Tiwari and his colleagues have used data from social media where people write about both their treatments and their well-being, and designed an algorithm that uses natural language processing to detect phrases that indicate side effects. 'They used social media because it is a simple and cheap source of data,' explains Prayag Tiwari. The project is now being further developed in collaboration with Aalto University, which will give the Halmstad researchers access to patient data from the healthcare system.

"Since then, I have kept moving"

Prayag Tiwari was born in the state of Uttar Pradesh, India, in a village with no electricity or telephone. His childhood was struggling and at the age of 15 he moved to the city of Deoria to start further education.

- Since then I've continued to move around. I hadn't even seen a computer until I was eighteen, nineteen years old, but after high school I got a scholarship to move to Russia and there I learnt to code.

He trained as an electrical engineer after his Bachelor degree and worked for a few years but found it boring. A university lecturer suggested that he study computer science. This led to a master's degree at MISIS Technical University in Moscow and a job as a research assistant. He was then accepted as a doctoral student at the University of Padua in Italy, and after completing his thesis, moved to Aalto University in Finland for a postdoctoral position.

Prayag Tiwari writes dozens of scientific articles a year. When asked how he finds the time, he laughs a little and says that he works very hard. At times he has worked 12 hours a day, seven days a week.

- I work less now, you need some time off. But I really enjoy exploring new things and it's so nice to contribute to a field. Even if it's just something small, it will help other researchers. It gives me inspiration. And, of course, I want to make life better for my family. They depend on me, I support them. It drives me forward in my work.

Towards Reliable, Stable and Fast Learning for Smart Home Activity Recognition

Abstract

The current population age grows increasingly in industrialized societies and calls for more intelligent tools to monitor human activities. The aims of these intelligent tools are often to support senior people in their homes, to keep track of their daily activities, and to early detect potential health problems to facilitate a long and independent life. The recent advancements of smart environments using miniaturized sensors and wireless communications have facilitated unobtrusively human activity recognition.

Human activity recognition has been an active field of research due to its broad applications in different areas such as healthcare and smart home monitoring. This thesis project develops work on machine learning systems to improve the understanding of human activity patterns in smart home environments. One of the contributions of this research is to process and share information across multiple smart homes to reduce the learning time, reduce the need and effort to recollect the training data, as well as increase the accuracy for applications such as activity recognition. To achieve that, several contributions are presented to pave the way to transfer knowledge among smart homes that includes the following studies. Firstly, a method to align manifolds is proposed to facilitate transfer learning. Secondly, we propose a method to further improve the performance of activity recognition over the existing methods. Moreover, we explore imbalanced class problems in human activity recognition and propose a method to handle imbalanced human activities. The summary of these studies are provided below.

In our work, it is hypothesized that aligning learned low-dimensional manifolds from disparate datasets could be used to transfer knowledge between different but related datasets. The t-distributed Stochastic Neighbor Embedding(t-SNE) is used to project the high-dimensional input dataset into low-dimensional manifolds. However, since t-SNE is a stochastic algorithm and there is a large variance of t-SNE maps, a thorough analysis of the stability is required before applying Transfer learning. In response to this, an extension to Local Procrustes Analysis called Normalized Local Procrustes Analysis (NLPA) is proposed to non-linearly align manifolds by using locally linear mappings to test the stability of t-SNE low-dimensional manifolds. Experiments show that the disparity from using NLPA to align low-dimensional manifolds decreases by order of magnitude compared to the disparity obtained by Procrustes Analysis (PA). NLPA outperforms PA and provides much better alignments for the low-dimensional manifolds. This indicates that t-SNE low-dimensional manifolds are locally stable, which is the part of the contribution in this thesis.

Licentiate exam

Rebeen Ali Hamad

Human activity recognition in smart homes shows satisfying recognition results using existing methods. Often these methods process sensor readings that precede the evaluation time (where the decision is made) to evaluate and deliver real-time human activity recognition. However, there are several critical situations, such as diagnosing people with dementia where "preceding sensor activations" are not always sufficient to accurately recognize the resident's daily activities in each evaluated time. To improve performance, we propose a method that delays the recognition process to include some sensor activations that occur after the point in time where the decision needs to be made. For this, the proposed method uses multiple incremental fuzzy temporal windows to extract features from both preceding and some oncoming sensor activations. The proposed method is evaluated with two temporal deep learning models: one-dimensional convolutional neural network (1D CNN) and long short-term memory (LSTM) on a binary sensor dataset of real daily living activities. The experimental evaluation shows that the proposed method achieves significantly better results than the previous state-of-the-art.

Further, one of the main problems of activity recognition in a smart home setting is that the frequency and duration of human activities are intrinsically imbalanced. The huge difference in the number of observations for the categories means that many machine learning algorithms focus on the classification of the majority examples due to their increased prior probability while ignoring or misclassifying minority examples. This thesis explores well-known class imbalance approaches (synthetic minority over-sampling technique, cost-sensitive learning and ensemble learning) applied to activity recognition data with two temporal data pre-processing for the deep learning models LSTM and 1D CNN. This thesis proposes a data level perspective combined with a temporal window technique to handle imbalanced human activities from smart homes in order to make the learning algorithms more sensitive to the minority class. The experimental results indicate that handling imbalanced human activities from the data-level outperforms algorithm level and improved the classification performance.

Learning from Multiple Domains

Abstract

Domain adaptation (DA) transfers knowledge between domains by adapting them. The most well-known DA scenario in the literature is adapting two domains of source and target using the available labeled source samples to construct a model generalizable to the target domain. Although the primary purpose of DA is to compensate for the target domain's labeled data shortage, the concept of adaptation can be utilized to solve other problems.

One issue that may occur during adaptation is the problem of class misalignment, which would result in a negative transfer. Therefore, preventing negative transfer should be considered while designing DA methods. In addition, the sample availability in domains is another matter that should also be taken into account.

Considering the two mentioned matters, this thesis aims to develop DA techniques to solve primary predictive maintenance problems.

This thesis considers a spectrum of cases with different amounts of available target data. One endpoint is the case in which we have access to enough labeled target samples for all classes. In this case, we use the concept of DA for 1) Analyzing two different physical properties, i.e., vibration and current, to measure their robustness for fault identification and 2) Developing a denoising method to construct a robust model for a noisy test environment.

Next, we consider the case where we have access to unlabeled and a few labeled target samples. Using the few labeled samples available, we aim to prevent negative transfer while adapting source and target domains. To achieve this, we construct a unified features representation using a few-shot and an adaptation learning technique.

In the subsequent considered setting, we assume we only have access to very few labeled target samples, which are insufficient to train a domain-specific model. Furthermore, for the first time in the literature, we solve the DA for regression in a setting in which it adapts multiple domains with any arbitrary shift.

Licentiate exam

Zahra Taghiyarrenani

Sometimes, due to the dynamic nature of the environment, we need to update a model to reflect the changes continuously. An example is in the field of computer network security. There is always the possibility of intrusion into a computer network, which makes each Intrusion Detection System (IDS) subject to concept shifts. In addition, different types of intrusions may occur in different networks. This thesis presents a framework for handling concept shift in one single network through incremental learning and simultaneously adapting samples from different networks to transfer knowledge about various intrusions. In addition, we employ active learning to use expert knowledge to label the samples for the adaptation purpose.

During adaptation, all cases mentioned so far have the same label space for the source and target domains. Occasionally, this is not the case, and we do not have access to samples for specific classes, either in the source or target; This is the final scenario addressed in this thesis.

One case is when we do not have access to some classes in the source domain. This setting is called Partial Domain Adaptation (PDA). This setting is beneficial to network traffic classification systems because, in general, every network has different types of applications and, therefore, different types of traffic. We develop a method for transferring knowledge from a source network to a target network even if the source network does not contain all types of traffic.

Another case is when we have access to unlabeled target samples but not for all classes. We call this Limited Domain Adaptation (LDA) setting and propose a DA method for fault identification. The motivation behind this setting is that for developing a fault identification model for a system, we don't want to wait until the occurrence of all faults for collecting even unlabeled samples; instead, we aim to use the knowledge about those faults from other domains.

We provide results on synthetic and real-world datasets for the scenarios mentioned above. Results indicate that the proposed methods outperform the state-of-art and are effective and practical in solving real-world problems.

For future works, we plan to extend the proposed methods to adapt domains with different input features, especially for solving predictive maintenance problems. Furthermore, we intend to extend our work to out-of-distribution learning methods, such as domain generalization.

Learning Representations for Machine Activity Recognition

Abstract

Machine activity recognition (MAR) is an essential and effective approach for equipment productivity monitoring. Developing MAR methods for forklift trucks, a vital piece of the industry, can benefit productivity efficiency, maintenance service, product design, and potential savings. With the growth of the Internet of Things, a large amount of sensory data has become accessible. Conventional MAR methods that have been developed primarily focus on data collected from external sensors, such as inertial measurement units (IMUs) and cameras. However, they are not effective for forklift applications: the IMU data does not reflect kinematic patterns due to a lack of large articulated parts, while the vision-based data collection requires many cameras to create sufficient coverage of an indoor environment, which, in result, risks the privacy and is less economical. Moreover, typical objectives in the existing MAR works are heavy equipment in construction sites where the working environment and tasks differ from the logistics sector. Therefore, it is necessary to develop intelligent and innovative approaches that are more suitable for forklift trucks.

Licentiate exam

Kunru Chen

This thesis demonstrates developing and utilizing representation learning methods to solve forklift MAR problems, based on the assumption that forklift activities are formed by a series of basic movements that can be detected from the onboard communication, i.e., signals in a Controller Area Network (CAN). Most of the methods proposed in this thesis incorporate semi-supervised techniques to deal with the limited amount of labeled data and to capitalize on a large amount of unlabeled data in our experiments. Deep neural networks are implemented to overcome different challenges of recognizing forklift activities and learn various representations of the data: i) learning invariant features to reconstruct input CAN signals by applying autoencoders, ii) learning discriminative features to recognize forklift activities by fine-tuning pre-training networks, and iii) learning temporal coherence to capture activity transitions by implementing gated recurrent units. Apart from achieving promising classification performance for forklift MAR problems, the representations obtained also support visualization and interpretability of the data as they are three-dimensional. Our ongoing works are new experiments about learning domain-invariant features, where domain adaptation methods are implemented to recognize activities performed by forklift trucks from different sites.

Toyota fork lift truck. Photo: Toyota material handling

PhD Graduation

Awais Ashfaq

Deep Evidential Doctor

Abstract

Recent years have witnessed an unparalleled surge in deep neural networks (DNNs) research, surpassing traditional machine learning and statistical methods on benchmark datasets in computer vision and natural language processing. Much of this success can be attributed to the availability of numerous open-source datasets, advanced computational resources and algorithms. These algorithms learn multiple levels of simple to complex abstractions (or representations) of data resulting in superior performances on downstream applications. This has led to an increasing interest in reaping the potential of DNNs in real-life safety-critical domains such as autonomous driving, security systems and healthcare. Each of them comes with their own set of complexities and requirements, thereby necessitating the development of new approaches to address domain-specific problems, even if building on common foundations.

In this thesis, we address data science related challenges involved in learning effective prediction models from structured electronic health records (EHRs). In particular, questions related to numerical representation of clinical concepts, sequential modelling of EHRs and quantifying prediction uncertainties are studied.

This is a compilation thesis including five articles. It begins by describing a healthcare information platform that encapsulates clinical, operational and financial data of patients across all public care units in Halland, Sweden. The thesis presents evidence that expert features are powerful predictors of adverse patient outcomes and are well complemented by clinical concept embeddings; gleaned via language modelling methods. In particular, a novel representation learning framework (KAFE: Knowledge And Frequency adapted Embeddings) is proposed that leverages medical knowledge schema and adversarial principles to learn high quality embeddings of both frequent and rare clinical concepts. In the context of sequential EHR modelling, an attention based hierarchical recurrent net is proposed that represents individual patients as weighted sums of ordered visits, where visits are, in turn, represented as weighted sums of unordered clinical concepts. In the context of uncertainty quantification and building trust in models, the field of deep evidential learning has been extended. In particular for multi-label tasks, simple extensions to current neural network architecture are proposed, coupled with a novel loss criterion to infer robust prediction uncertainties without compromising on accuracy. Moreover, analyzing the correlations learned by the model has also been an integral part of the research, to facilitate model transparency.

Put together, we develop Deep Evidential Doctor (DEED). DEED is a generic predictive model that learns efficient representations of patients and clinical concepts from EHRs and quantifies its confidence in individual predictions.

PhD Defense facts
Title: Deep Evidential Doctor
Author Awais Ashfaq
Supervisors at Halmstad University Professor Slawomir Nowaczyk Professor Mark Dougherty
Chairman of the defence: Docent Kobra Etminani, Halmstad University
Opponent: Associate Professor Cristina Soguero Ruiz, Universidad Rey Juan Carlos, Spain.
Examination Board: Prof. Myra Spiliopoulou, Otto-von-Guericke-Univ. Germany Prof. Ricard Gavalda, Univ. Politècnica de Catalunya, Spain Professor Martin Atzmüller, Osnabrück Univ. Germany

Better care at a **lower cost** by using data

With a growing elderly population, many chronic conditions are increasing rapidly in our society. These conditions, for example cancer, dementia, diabetes, and heart diseases, as well as the rising numbers of mental health disorders, are both challenging and resource-intensive for the healthcare system. To meet this, healthcare organizations must improve the quality of care and, at the same time, reduce costs.

"There are several initiatives in Sweden with the goal to develop healthcare by using artificial intelligence. What is notable in Halland is that we work with real world data in sharp research projects where we collaborate across organizations and disciplines", says Markus Lingman, Medical Doctor and Strategist on the Halland Hospital board and Adjunct Professor of Medicine at Halmstad University.

"This collaboration between Region Halland and Halmstad University has broken new ground – we are already contributing to the necessary shift of our healthcare system to become more information driven. It is time to move up the cognitive pyramid! Let the computers do what they are best at, and humans what we are best at", says Markus Lingman.

Markus Lingman is a Medical Doctor and Strategist on the Halland Hospital board and Adjunct Professor of Medicine at Halmstad University.

Information from today's patients can help prevent future diseases

Information-driven care is where artificial intelligence (AI) is applied to data collected within healthcare organizations. Machine learning algorithms can find patterns in large amounts of data and predict outcomes. This information can be used by clinicians to decide on what is the best care and to enable early disease detection and prevention. The management of healthcare providers can also use the models to optimize resources without compromising the quality of care.

"The machine learning models that we develop can be used to predict patient outcomes. Most often, we are interested in predicting adverse outcomes so that necessary actions can be taken to avoid or prepare for them. An adverse outcome can, e.g., be disease onset, hospital readmission, or death", says Awais Ashfaq.

Deep learning and readmission for heart failure patients

One of the articles in Awais Ashfaq's thesis shows the result of a hospital readmission prediction study for patients with heart failure, using deep neural network models. Typically, one out of four patients in this patient group is readmitted within 30 days of discharge. Being readmitted poses a significant health risk for the patient due to hospital-acquired infections and clinical errors. Readmissions also lead to increased care costs for the healthcare system. To reduce readmissions, targeted intervention programs must be initiated for high-risk patients. Awais Ashfaq and the other researchers used data from 7500 heart failure patients in Halland to identify high-risk patients.

"The results of this study will contribute to the gradual and safe adoption of artificial intelligence in the clinical setting", says Markus Lingman, one of Awais Ashfaq's supervisors during his PhD research.

Professor Slawomir Nowaczyk was Awais Ashfaq's principal supervisor: "From a data science and machine learning point of view, this study is specifically interesting since it combines deep theoretical and algorithmic developments in the field of artificial intelligence with practical and impactful considerations from direct interactions with the healthcare system. Awais has made strong contributions towards how machine learning algorithms can represent the data and the knowledge, quantify uncertainty, and deal with surprising situations. At the same time, the work is very well anchored with clinicians within Region Halland, and motivated by real challenges", says Slawomir Nowaczyk.

Next step is explainability

Awais Ashfaq has collaborated with several researchers during his PhD, mainly from Halmstad University, Region Halland, Lund University, Harvard Medical School, Brigham Women's Hospital, and the companies Novartis and AstraZeneca. A concrete research result is the development of a generic prediction model called Deep Evidential Doctor (DEED). The model learns representations of clinical concepts and patient trajectories from EHRs for personalized predictions, along with robust and reliable confidence estimates.

"While the prediction scores facilitate identification of patient risk groups, the confidence estimates support user-trust in these prediction models by allowing us to understand when they say, 'I don't know'. Thus, if need be, design redundancy into their applications to avoid dubious predictions", says Awais Ashfaq.

"For future works, we aim to extend the DEED framework to incorporate wider data modalities such as clinical notes, signals, and daily lifestyle information. We will also work to equip DEED with explainability features to enhance the acceptance in real clinical practice", says Awais Ashfaq.

PhD Graduation

Ece Calikus

Together We Learn More: Algorithms and Applications for User-Centric Anomaly Detection

Abstract

Anomaly detection is the problem of identifying data points or patterns that do not conform to normal behavior. Anomalies in data often correspond to important and actionable information such as frauds in financial applications, faults in production units, intrusions in computer systems, and serious diseases in patient records. One of the fundamental challenges of anomaly detection is that the exact notion of anomaly is subjective and varies greatly in different applications and domains. This makes distinguishing anomalies that match with the end-user's expectations from other observations difficult. As a result, anomaly detectors produce many false alarms that do not correspond to semantically meaningful anomalies for the analyst.

Humans can help, in different ways, to bridge this gap between detected anomalies and "anomalies-of-interest": by giving clues on features more likely to reveal interesting anomalies or providing feedback to separate them from irrelevant ones. However, it is not realistic to assume a human to easily provide feedback without explaining why the algorithm classifies a certain sample as an anomaly. Interpretability of results is crucial for an analyst to be able to investigate the candidate anomaly and decide whether it is actually interesting or not.

In this thesis, we take a step forward to improve the practical use of anomaly detection in real-life by leveraging human-algorithm collaboration. This thesis and appended papers study the problem of formulating and implementing algorithms for user-centric anomaly detection-- a setting in which people analyze, interpret, and learn from the detector's results, as well as provide domain knowledge or feedback. Throughout this thesis, we have described a number of diverse approaches, each addressing different challenges and needs of user-centric anomaly detection in the real world, and combined these methods into a coherent framework. By conducting different studies, this thesis finds that a comprehensive approach incorporating human knowledge and providing interpretable results can lead to more effective and practical anomaly detection and more successful real-world applications. The major contributions that result from the studies included in this work and led the above conclusion can be summarized into five categories: (1) exploring different data representations that are suitable for anomaly detection based on data characteristics and domain knowledge, (2) discovering patterns and groups in data that describe normal behavior in the current application, (3) implementing a generic and extensible framework enabling use-case-specific detectors suitable for different scenarios, (4) incorporating domain knowledge and expert feedback into anomaly detection, and (5) producing interpretable detection results that support end-users in understanding and validating the anomalies.

PhD Defense facts

Title:
Together We Learn More: Algorithms and Applications for User-Centric Anomaly Detection

Author
Ece Calikus

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Professor Slawomir Nowaczyk

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Professor Jesse Davis, KU Leuven, Belgium
Professor Jesse Read, École Polytechnique, France

Human-machine collaboration improves the detection of ***anomalies***

When a deviation in a data set is found, it can implicate that something is wrong. It can, for example, be a machine part that does not work, a computer intrusion or a first sign of illness. By combining human knowledge and machine learning, the detection of anomalies will become more efficient and improved

"In data science, anomaly detection is the identification of rare events and observations in a data set that significantly differs from the majority of the data. User-centric anomaly detection plays a key role in making data-driven anomaly detection approaches more effective and practical in real-world applications. My research shows a comprehensive approach enabling human-machine collaboration and where the parts learn from each other. This can significantly improve anomaly detection performance and its practical use in a specific application domain, for example, district heating."

"In our research, we focus on designing and evaluating algorithms for user-centric anomaly detection in which people investigate, interpret and learn from the detectors' results, and then themselves provide domain knowledge or feedback to the system."

Where can anomalies be found?

"Anomalies can be found in different areas and situations that affect our daily lives. They can, for example, be intrusions in data systems, finance fraud, faults or breaks in production units, diseases or conditions in medical diagnostics."

Can anomaly detection be problematic?

"All types of abnormal observations are not equally interesting to the end-user. For example, anomalies such as abnormally high temperatures can be recorded occasionally in a domestic hot water heat-pump system due to disinfecting pipes from Legionella bacteria. In that case, the deviation is normal and not very interesting for an analyst looking for actual faults in the hot water system, such as compressor faults in the pumps."

"The large gap between detected anomalous behaviours and ´anomalies of interest´ can produce many false alarms and easily render anomaly detection unusable in practice. Human domain knowledge plays an essential role in bridging this gap. For example, an analyst might give clues to create more likely features to indicate interesting anomalies or provide feedback to separate them from irrelevant ones."
It sounds like humans and machines must work together to create more accurate and efficient ways to detect deviations. Can you tell us more about this?

"After the anomalies in the data are identified, human experts typically investigate them for root cause analysis, troubleshooting, or action planning. As shown in the previous example, one cannot automatically schedule repair without knowing the anomaly is caused by a compressor failure, not by killing bacteria. Interpretability of the detected outliers, which provides reasons for abnormal behaviours, can significantly reduce the effort of such manual inspections."

You have also focused on contextual anomaly detection. What is that and how can it be helpful?

"With contextual anomaly detection, we want to identify abnormal objects that might be disguised as normal within specific contexts. For example, high energy consumption in a heating system during summer is abnormal, while the same consumption level can be totally normal in winter. We try to provide context-based explanations of anomalies that can explain what makes an object stand out as deviating. Such explanations can help characterize and interpret different types of anomalies and normal groups."

"With anomaly detectors, we want to effectively separate rare and unusual observations from the majority. However, the rare data instances reported as anomalies may cause discrimination against the minority groups existing in the data. For example, surveillance applications designed to detect criminal activities can be racially biased if the detection heavily relies on humans' appearance. Additional information on what makes certain behaviour stand out enables us to discover biased decisions of the algorithms and improve algorithmic fairness."

How does your research contribute to the development of society?

"The user-centric anomaly detection helps us to distinguish anomalies better. Furthermore, improving the work for the interpretability of detection results allows end-users to validate the algorithm's performance and facilitate trust in the anomaly detection system. This is especially important for data sets that include sensitive features such as sex, ethnicity or age."

PhD Graduation

Shiraz Farouq

Towards conformal methods for large-scale monitoring of district heating substations

Abstract

Increasing technical complexity, design variations, and customization options of IoT units create difficulties for the construction of monitoring infrastructure. These units can be associated with different domains, such as a fleet of vehicles in the mobility domain and a fleet of heat-pumps in the heating domain. The lack of labeled datasets and well-understood prior unit and fleet behavior models exacerbates the problem. Moreover, the time-series nature of the data makes it difficult to strike a reasonable balance between precision and detection delay. The thesis aims to develop a framework for scalable and cost-efficient monitoring of industrial fleets. The investigations were conducted on real-world operational data obtained from District Heating (DH) substations to detect anomalous behavior and faults. A foundational hypothesis of the thesis is that fleet-level models can mitigate the lack of labeled datasets, improve anomaly detection performance, and achieve a scalable monitoring alternative.

Our preliminary investigations found that operational heterogeneity among the substations in a DH network can cause fleet-level models to be inefficient in detecting anomalous behavior at the target units. An alternative is to rely on subfleet-level models to act as a proxy for the behavior of target units. However, the main difficulty in constructing a subfleet-level model is the selection of its members such that their behavior is stable over time and representative of the target unit. Therefore, we investigated various ways of constructing the subfleets and estimating their stability. To mitigate the lack of well-understood prior unit and fleet behavior models, we proposed constructing Unit-Level and Subfleet-Level Ensemble Models, i.e., ULEM and SLEM. Herein, each member of the respective ensemble consists of a Conformal Anomaly Detector (CAD). Each ensemble yields a nonconformity score matrix that provides information about the behavior of a target unit relative to its historical data and its subfleet, respectively. However, these ensemble models can give different information about the nature of an anomaly that may not always agree with each other. Therefore, we further synthesized this information by proposing a Combined Ensemble Model (CEM). We investigated the advantages and limitations of decisions that rely on the information obtained from ULEM, SLEM, and CEM using precision and detection delay. We observed the decisions that relied on the information obtained through CEM showed a reduction in overall false alarms compared to those obtained through ULEM or SLEM, albeit at the cost of some detection delay. Finally, we combined the components of ULEM, SLEM, and CEM into what we refer to as TRANTOR: a conformal anomaly detection based indusTRiAl fleet moNiTORing framework. The proposed framework is expected to enable fleet operators in various domains to improve their monitoring infrastructure by efficiently detecting anomalous behavior and controlling false alarms at the target units.

PhD Defense facts

Title:	Towards conformal methods for large-scale monitoring of district heating substations
Author	Shiraz Farouq
Supervisors at Halmstad University	Associate professor Stefan Byttner Associate professor Mohamed-Rafik Bouguelia Associate professor Henrik Gadd
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Monitoring district heating substations important to the future smart city

Ineffective and incorrect behavior of district heating substations causes unnecessary energy loss. In his recently published thesis, Shiraz Farouq proposes the use of models based on statistical and machine learning techniques as a possible solution to the problem. In this way, the substations can be monitored, irregular patterns can be identified, and operationally ineffective substations can be detected, without overwhelming their operators with numerous false alarms.

Traditionally, district heating substations are monitored by constructing models based on the individual substation's historical data. In his research, Shiraz Farouq found that observing other operationally similar substations' behaviour is also important.

"Substations in a district heating network can be thought of in terms of a fleet, where operationally similar substations constitute sub fleets. Therefore, we developed models based on the idea of collective monitoring, where the behaviour of each substation in a network is tracked by a sub fleet of other similar substations. Any substation that does not behave in accordance with its tracking sub fleet provides a basis to believe that something is wrong", he explains.

Framework to reduce false alarms

One of the observations that Shiraz Farouq made was that models based on historical behaviour and the tracking of sub fleets have their strengths and weaknesses. A framework based on a combination model was presented as a remedy to this.

"By fusing the two model constructs, it is possible to reduce false alarms without compromising too much on the detectability of anomalous patterns. We believe that this framework can be adapted to the requirements of various other industrial setups where fleets of units or machines are a common occurrence", says Shiraz Farouq.

Findings relevant for the future smart city

Shiraz Farouq's results can not only be applied to the field of district heating, but also to areas that are important for future smart cities, for instance, robotics in industries, truck platoons, wind farming, and substations in electric-utility networks.

"While technical tools, such as machine learning, are important in solving the problem of energy inefficiency in district heating, they are not the only solution. We need to pair the technical tools with insights from industry through active collaboration", says Shiraz Farouq, who has worked together with the Swedish power company Öresundskraft.

"The largest amount of data for the research comes from Öresundskraft. In addition, valuable insights from both data and discussion with domain experts were obtained from the company Halmstad energi och miljö. Moreover, Halmstad University cooperates with the Smart Energy Collaboration wihtin Disitrict Heating and Cooling, which is a collaboration between various district heating utilities and universities across Sweden. The research work was presented at this forum, and valuable insights were obtained on possibilities and challenges in deploying data-driven approaches at district heating utilities", he explains.

Research that makes a positive impact

Shiraz Farouq joined Halmstad University as a PhD student back in 2016, and before that he got a master's degree in Computational Science at Uppsala University.

"I chose Halmstad University because of its position as an innovation-driven university that aims to contribute towards the betterment of society by solving practical problems in industries and public services", he says.

The strive to contribute to a better society is also clear in Shiras Farouq's research goals:

"The research will hopefully lead to more efficient ways of using district heating. It contributes to increased sustainability, cost efficiency, and the development of future smart cities. Energy efficiency is one of the important objectives in the United Nations Sustainable Development Goals for 2030. In this context, the research has a positive impact on the environment, economy, and society."

Shiraz Farouq now hopes to apply his findings to an industry setting.
"The very reason I chose to pursue doctoral studies was to acquire skills to deal with today's complex and challenging problems from both the philosophical as well as the scientific point of view. I believe these skills will enable me to make a positive impact in the world", he sums up.

PhD Graduation

Pablo Del Moral

Hierarchical Methods for Self-Monitoring Systems: Theory and Application

Abstract

Self-monitoring solutions first appeared to avoid catastrophic breakdowns in safety-critical mechanisms. The design behind these solutions relied heavily on the physical knowledge of the mechanism and its fault. They usually involved installing specialized sensors to monitor the state of the mechanism and statistical modeling of the recorded data. Mainly, these solutions focused on specific components of a machine and rarely considered more than one type of fault.

In our work, on the other hand, we focus on self-monitoring of complex machines, systems composed of multiple components performing heterogeneous tasks and interacting with each other: systems with many possible faults. Today, the data available to monitor these machines is vast but usually lacks the design and specificity to monitor each possible fault in the system accurately. Some faults will show distinctive symptoms in the data; some faults will not; more interestingly, there will be groups of faults with common symptoms in the recorded data.

The thesis in this manuscript is that we can exploit the similarities between faults to train machine learning models that can significantly improve the performance of self-monitoring solutions for complex systems that overlook these similarities. We choose to encode these similarity relationships into hierarchies of faults, which we use to train hierarchical supervised models. We use both real-life problems and standard benchmarks to prove the adequacy of our approach on tasks like fault diagnosis and fault prediction.

We also demonstrate that models trained on different hierarchies result in significantly different performances. We analyze what makes a good hierarchy and what are the best practices to develop methods to extract hierarchies of classes from the data. We advance the state-of-the-art by defining the concept of heterogeneity of decision boundaries and studying how it affects the performance of different class decompositions.

PhD Defense facts

Title:
Hierarchical Methods for Self-Monitoring Systems: Theory and Application

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Collaboration between Halmstad University and Getinge Sterilization AB

Halmstad University and Getinge Sterilization AB, which creates sterilisers that are used for sterilising hospital equipment, have been collaborating for many years. In 2020, they began a ten year long strategic collaboration agreement, and together the parties want to promote development within research, innovation and education with a specific focus on digitalisation. The aim is to find solutions for different societal challenges within the health area.

Safer healthcare with smart systems

Self-monitoring systems were originally developed to avoid catastrophic machine breakdowns but required that you knew about the mechanics and the specific error you wanted to avoid. In his PhD thesis, Pablo del Moral has researched so called hierarchical methods for self-monitoring systems. The aim is to able to predict more types of errors in hospital equipment

Self-monitoring systems avoid catastrophic breakdowns

Solutions with self-monitoring systems were originally developed to avoid catastrophic breakdowns in safety-critical mechanisms. The design relied on sensors and required that you knew about the mechanics and the specific error you wanted to avoid. In his research, Pablo del Moral instead focuses on self-monitoring of complex machines – in this case sterilisers used by hospitals to sterilise medical instruments – that are composed of multiple components where a great number of different errors can occur.

There are currently many models that monitor complex machines, but they often lack the ability to correctly monitor all specific problems that could occur in the system. What Pablo del Moral's research contributes to is identifying symptoms of ongoing faults in the available data. These symptoms are then used to identify which specific fault that is occurring and when this fault will result in a machine failure.

"Some faults will show distinctive symptoms in the data, and some faults will not. More interestingly, there will be groups of faults with common symptoms in the recorded data", says Pablo del Moral.

Exploiting similarities between errors improve performance

Pablo del Moral's thesis is that you can teach the machine learning models to exploit the similarities between different faults to improve the performance of self-monitoring systems. In his research, he has chosen to encode these similarities into hierarchies of faults.

"When these hierarchical methods are applied, they provide significant improvements in both fault diagnoses and fault prognoses", says Pablo del Moral.

Pablo del Moral and his research colleagues have also identified common pitfalls in the development of methods to extract hierarchies. They have found that the heterogeneity – in other words the diversity – of decision boundaries can explain why some hierarchies perform better than others.

Improvements lead to increased security

When Pablo del Moral is asked whether he is particularly surprised by any result, he replies:

"When doing fault prognoses in complex systems, the right hierarchy of errors can improve the overall performance significantly. In particular, it allows for some types of errors to be predicted that could not have been otherwise. In that way, the improvement of the technology behind self-monitoring systems leads to machines with better performance, security and reliability."

Getinge Disinfection Washer Photo: Getinge AB

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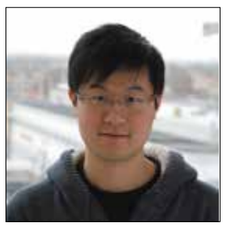

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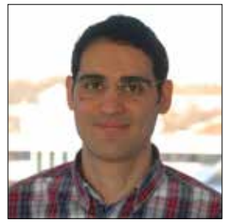

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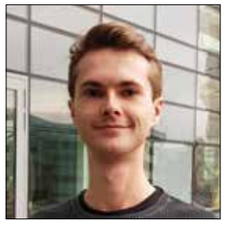

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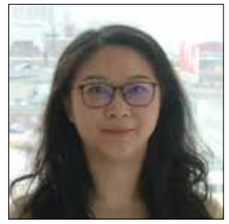

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CAISR Publications 2018–2022

JOURNAL PAPERS

2022

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The Knowledge Foundation funds research and competence development at Sweden's new universities. The Foundation was established by the Swedish government in 1994, and the Foundation's overall mission is to strengthen Sweden's competitiveness.

The Knowledge Foundation has the following objectives:

- to support the exchange of knowledge and skills between the business sector on one hand, and universities, higher education institutions (HEIs), and research institutes on the other.
- to fund research at smaller and mid-sized HEIs and Sweden's new universities (founded after the foundation was formed) in special profile areas.
- to promote information technology.

The Knowledge Foundation achieves these objectives by helping young universities build internationally competitive research environments, work long-term on strategic profiling and increase the cooperation between academia, industry and institutes. The Foundation funding programs are all characterized by a long-term perspective and requirements for co-production with industrial partners.

VINNOVA
Sweden's Innovation Agency

Vinnova is Sweden's innovation agency. Vinnova is a government agency under the Ministry of Trade and Industry and the national liaison authority for the EU Framework Program for Research and Innovation.

Vinnova's task is to promote sustainable growth by financing needs-motivated research and the development of effective innovation systems. "Innovation systems" refer to networks of public and private actors where innovations and new knowledge are developed, disseminated, and used. In order to achieve sustainable growth and strengthen Sweden's competitiveness, the authority must, from a challenge-driven perspective, work for the utilization of research and the promotion of innovation.

Every year, Vinnova invests approximately SEK 3 billion in research and innovation. This is done in many forms, typically cooperative projects between partners with complementing competencies. For CAISR one particularly important funding program is FFI, the Vehicle Strategic Research and Innovation program, which is a collaboration between the government (Vinnova, the Swedish Transport Administration and the Swedish Energy Agency) and the Swedish automotive industry (Scania CV AB, AB Volvo, Volvo Car Group and FKG - Vehicle Component Group).

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CAISR

CAISR, the Center for Applied Intelligent Systems Research, is a long-term research program on intelligent systems established by Halmstad University. The program is funded by the University and the Knowledge Foundation with support from Swedish Industry.

The subject expertize in the center is in signal analysis, machine learning and mechatronics. Several industrial partners are collaborating with researchers from the University in joint projects, and take an active part in the development of CAISR. The key application areas that the center does research in are intelligent vehicles and health technology. The industrial partners include multinational companies as well as research-based growing companies.

The mission of CAISR is to serve and promote the development of industry and society. It is a center for industrially motivated research on the future technologies for and application opportunities with aware intelligent systems. CAISR will serve as a partner for industry´s own research and development, as a recruitment base for those who seek staff with state-of-the-art knowledge in intelligent systems technologies, and as a competence resource for industry and society. All research is conducted within different research projects.

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