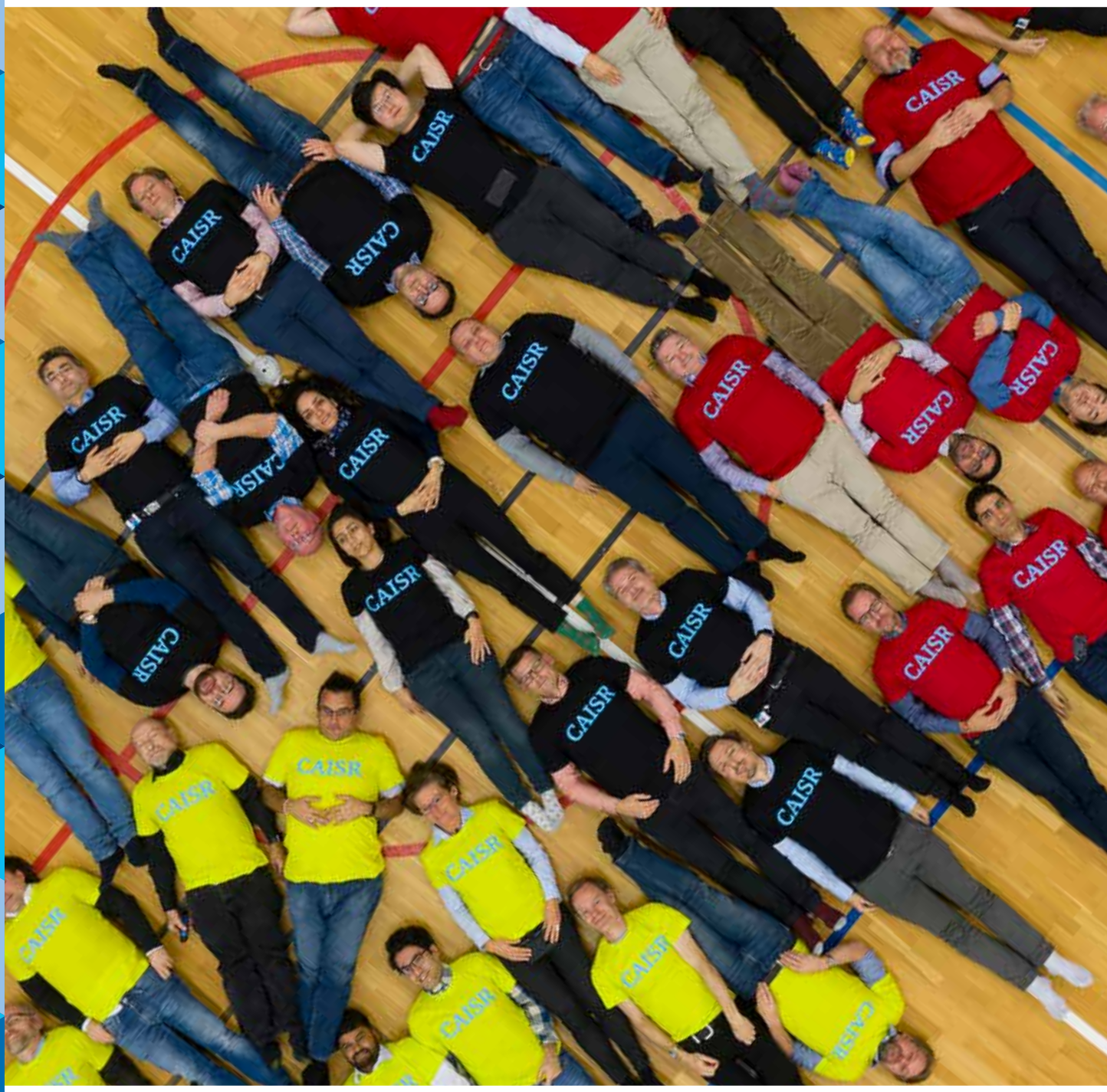
ANNUAL REPORT 2019



CAISR

Center for Applied
Intelligent System Research

HALMSTAD
UNIVERSITY

Cover: The Swedish painter and sculptor Olle Baertling (1911-1981) was born in Halmstad and active in Paris. The area around the Halmstad University campus is called "The Baertling District" and has several of Baertling's sculptures and paintings on display. The forms, shapes, and colors in Baertling's paintings inspired us to do the cover photo (see example to the right: detail from "Medam").

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Intelligent Systems Research

Annual Report 2019

Knowledge Foundation

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CAISR

Annual report 2019

Director's statement

Indeed, 2019 was a great year! It marked the eighth year since we established CAISR, and we were reviewed by our main sponsor, the Knowledge Foundation. The outcome showed that we are a top-performing research, education and cooperation center. We received continued center funding to move towards excellence in applied intelligent systems for predictive maintenance for machines, together with core Swedish export industry partners. We were also granted projects in cooperation with Region Halland and other partners, with a focus on what we call predictive maintenance for humans. Our plan to direct CAISR towards autonomous knowledge creation in predictive maintenance applications (for both machines and humans) got a kick start.

The Swedish government is investing more into AI and machine learning. As an example, Sweden's innovation agency (Vinnova) expects to fund AI-projects with 200 million Swedish kronor for the years 2020 and onwards[1], which would correspond to a 33% increase from before. This is, however, still only 1/20 of Vinnova's annual project budget, and AI and machine learning were not hot topics in Sweden ten years ago when CAISR was planned. An illustration is the government's investment in twenty strategic research areas in 2009, none of which were directed at or emphasized AI. Less than ten years later, the government needs to stress the importance of investing into AI research for Swedish competitiveness[2].

The scientific publication output of Swedish universities show that some of the young universities have (and have had) a much stronger profile and higher fraction of their output in AI than the other universities. These are Halmstad University, Mälardalen University, University of Skövde, and Blekinge Institute of Technology. These are also universities where a vast majority of the research is done in close cooperation with Swedish industry and the public sector.

From this, my point should be obvious. When the government wants to invest in research that is important and relevant for Swedish industry, they should look closer at environments where there is a commitment to cooperating with industry in both education and research. CAISR is such a place.

Thorsteinn Rögnvaldsson

1 https://digital.di.se/artikel/ai-pengaregn-over-foretagen-ministern-vi-maste-vara-pa-tarna

2 "Nationell inriktning för artificiell intelligens" https://www.regeringen.se/49a828/contentassets/844d30fb0d594d1b9d96e2f5d57ed14b/2018ai_webb.pdf

CAISR **scientific agenda**

The ability to create and transfer knowledge efficiently is a key competitive advantage for a company or an organization[1]. It follows that being able to use computers to automatically, or autonomously, create transferable knowledge from product and customer data is a key competitive advantage. Autonomous knowledge creation is the common research vision for CAISR, and we refer to a system that can autonomously create knowledge as an *aware* system.

A good formalism for discussing how to create knowledge is the *Data, Information, Knowledge, and Wisdom* (DIKW) hierarchy[2], often illustrated with a pyramid (see figure below); the higher a system reaches on the pyramid, the more aware it can be. There can be interactions both upwards and downwards in the pyramid.

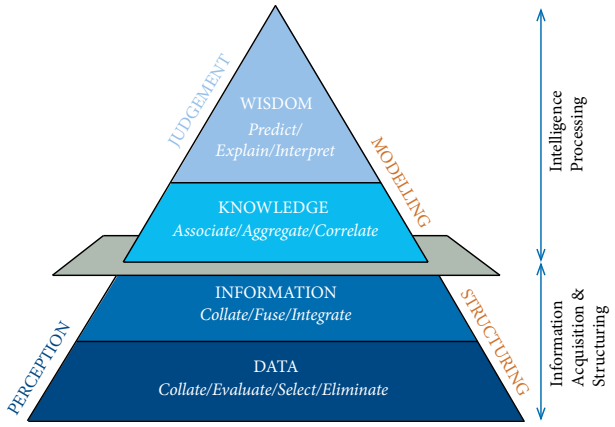


Figure 1. The knowledge pyramid, adapted from Ackoff (1989). "From Data to Wisdom". Journal of Applied Systems Analysis 16: 3–9.

The bottom level in the pyramid, *data*, deals with collecting and representing data. A key research question here is how to autonomously select what data to collect. How can a system decide what data are (or will be) relevant, and what representations to use? Can general features be learned that apply to many problems or transferred from one setting to another? With endless streams of data (the "internet of things"), it is impossible and uninteresting to save all data; it is necessary to save snapshots, compressed, or aggregated representations of the data. These representations should apply to many different tasks. Also, features that look unimportant today may end up being important tomorrow. An aware system needs to be curious, able to explore, and learn.

The *information* level relates to questions that begin with "who, what, when, and how many", creating "events" from the data in the layer below. This deals with classification, rearranging/sorting, aggregating, performing calculations, and selection. Much machine learning research (including that on deep learning models) is devoted to this stage. Important open research questions here regard autonomous clustering and categorization of events. Can events be autonomously grouped for later use?

1 Nonaka & Takeuchi. The Knowledge-Creating Company : How Japanese Companies Create the Dynamics of Innovation. Oxford University Press (1995)

2 Rowley, J. (2007), "The wisdom hierarchy: representations of the DIKW hierarchy", Journal of Information Science, 33, pp. 163-180.

The *knowledge* level is about creating "rules" from the information, which requires combining information from different sources. Is an "event" from one data source associated with another "event" from another data source? Can such associations be formulated into rules? An obvious example is the supervised learning setting, which matches "events" (input) with correct responses (target) provided by an expert. A very relevant question deals with knowledge representations; can knowledge be represented so that it can be used better for reasoning and prediction, or easier to transfer from one scenario to another? A knowledge structure should evolve from experience, allowing for learning from data and human experts, and be capable of taking into account initial domain knowledge.

The top level, denoted the *wisdom* level, relates to the question "why" or "what will happen"? It is about the ability to project into the future and reason back into the past. An aware system must be capable of extrapolating information into the future, to evaluate the consequences of actions, and able to explain why something happened.

It is obvious that to do tasks on each of these levels autonomously would be a sought after ability, and even more attractive to merge them into an autonomous knowledge-creating, or even wisdom-creating, system. Hence, the CAISR scientific vision of aware systems.

Two clear examples where these abilities can be demonstrated are predictive maintenance in machines and for people (healthcare). Here, the complexity of the problem(s) is so high that it is difficult for a human expert to grasp it all, but the amount of data is growing fast and the aim is to have AI systems uncover (surprising) knowledge for human experts and to illustrate relations that are not apparent to the experts. Information-driven healthcare represents a step up in awareness from data-driven healthcare (although we would call it "knowledge-driven" rather than "information-driven" to match with the DIKW hierarchy).

The majority of CAISR publications focus on aware systems research, and three particularly interesting publications from 2019 are:

- Aein, Aksoy & Wörgötter, "Library of actions: Implementing a generic robot execution framework by using manipulation action semantics". *The International Journal of Robotics Research*, **38**(8), pp. 910-934. The work presents a knowledge representation framework for robot object manipulation. The framework is learned by observing how human operators manipulate objects.
- Calikus, Nowaczyk, Sant'Anna, Gadd & Werner. "A data-driven approach for discovering heat load patterns in district heating". *Applied Energy*, **252**, 113409. In the paper, they propose a data-driven approach that enables large-scale automatic analysis of heat load patterns in district heating networks without requiring prior knowledge. The method has a high potential to be deployed and used in practice to aid experts to analyze and understand customers' heat-use habits.
- Muhammad & Åstrand. "Predicting agent behaviour and state for applications in a roundabout-scenario autonomous driving". *Sensors*, **19**(19), 4279. The paper presents methods for modeling and predicting agent behavior and state in a traffic roundabout.

CAISR **impact**

Together with Volvo

HEALTH (Hazard Estimation and Analysis of Lifelong Truck Histories) is a predictive maintenance project together with Volvo that ended during 2019. The project results produced in HEALTH were deployed in the Volvo Trucks production environment VOSP (Volvo Service Planning tool), for prediction of vehicle component status and breakdown prognosis of trucks. VOSP is a software developed by Volvo to optimize the service planning of the trucks, and is used by Volvo authorized workshops.

The deployment is offered as an advanced service for trucks under so-called gold contracts between Volvo dealers and customers. This is for a couple of reasons. It is important to be able to have access to the entire service and maintenance history of the trucks, and gold contract customers tend to use only authorized Volvo workshops. Furthermore, there is a data management agreement in place for gold contract trucks, which allows use of the data for the uptime service. The deployment is piloted in a few selected markets, and for a specific set of components. The four pilot markets are Sweden, Switzerland, Finland, and Denmark. The predictive maintenance alerts are used for sophisticated components where a measurement by a single sensor can not detect the wear or failure of the component. The selected target components include air compressor, turbocharger, front and rear air bellows, and alternator.

The predictive maintenance system produces warning messages that inform the dealer of an increased risk of failure for a specific component on a specific truck. The system also recommends actions to the dealer; like planning an earlier visit for the customer to check the component or to consider repairing or replacing the component during the next workshop visit.

The alerts support the service planning process of the truck. Predicting possible future failures avoids extra visits to the workshop and potential extra costs related to unexpected breakdowns like towing costs or uptime promises. Based on the prognosis, the workshop staff can plan the repair process and order the required spare parts well in advance and make sure that they have the right technician available for delivering the service.

Volvo Flexi-Gold Contract truck
Photo: Volvo Trucks

CAISR alumnus receives multiple innovation awards

Not only is Siddhartha (Sid) Khandelwal a smart and charming man – he is also a driven entrepreneur who embodies the innovation driving spirit of CAISR and Halmstad University. He defended his Ph.D. thesis and founded the company VectorizeMove (https://www.vectorizemove.com/) in 2018 to commercialize his research results. Already by the end of 2018, VectorizeMove was ranked among the twenty best startup business ideas in the country in competition with 300 contributions in Venture Cup 2018. At the time, we were very proud that he did so well, but little did we know that this was just the beginning of a chain of innovation awards that followed.

In early March 2019, VectorizeMove received a competitive Innovative Startups grant from Vinnova (the government innovation agency).

Later in March 2019, Sid and VectorizeMove were placed on the prestigious Royal Swedish Academy of Engineering Science's top 100 list of the most innovative researchers in Sweden.

In May 2019, VectorizeMove won the best traction award in the Venture Cup West Sweden for startups. They also received the JCE accelerator award and the audience's special prize, which meant that VectorizeMove came home with three out of six awards.

Siddhartha (Sid) Khandelwal

In September 2019, VectorizeMove went on to win the best traction award in the national finals in Venture Cup West. The jury commented that "The jury sees a given place in the market for the company thanks to an exciting mix of access to the buyer-oriented target group and the unique technical solution."

In October 2019, Sid and VectorizeMove were awarded 2019's Innovation prize at Halmstad business gala. On the same occasion, VectorizeMove was awarded the prize for the year's new digital company in Halmstad, by HMS Industrial Networks – a company also started and built up by Halmstad University students.

In November 2019, VectorizeMove was awarded the national Swedish Embedded Award in the Enterprise class. This meant that the jury considered them to be the most promising Swedish new company based on products with embedded intelligence.

Also, in November, Sid and VectorizeMove were awarded the Halland Skapa prize for being the best innovator in Halland 2019.

Sweden is considered a very innovative country[1] with excellent strength in the IT sector. Receiving all these awards and recognition in stiff competition shows the potential of Sid's entrepreneurship. Furthermore, one of his final papers in his Ph.D. thesis has attracted several citations, and he looks well-positioned to win one of CAISR's internal awards for most cited scientific paper in the future, which shows the excellence of his research work.

1 Sweden is ranked number two on the Global Innovation Index 2019, after Switzerland (https://www.globalinnovationindex.org/gii-2019-report).

CAISR research **futures workshop**

In October Professor Mark Dougherty led a research futures workshop for CAISR. The purpose of the workshop was to take a long-term perspective about where our research is going. What major research questions, both basic and applied, do we believe we should be working towards? What resources, investments and collaborative links are needed in order to reach these goals?

Professor Mark Dougherty

What does long term mean in this context? Mark defines it as one research life cycle for an academic. In other words the average length of time it takes a PhD student to reach the grade of professor and be responsible for training the next generation of scientists. This is generally of the order of 15-20 years.

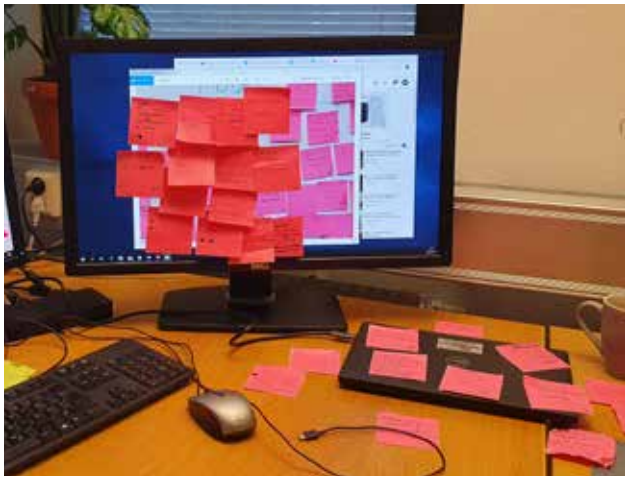
In order to try and achieve a reasonable degree of consensus the process was deliberately run as a bottom up process. Everybody was encouraged to put forward ideas.

This yields a multi-stage process with several distinct phases:

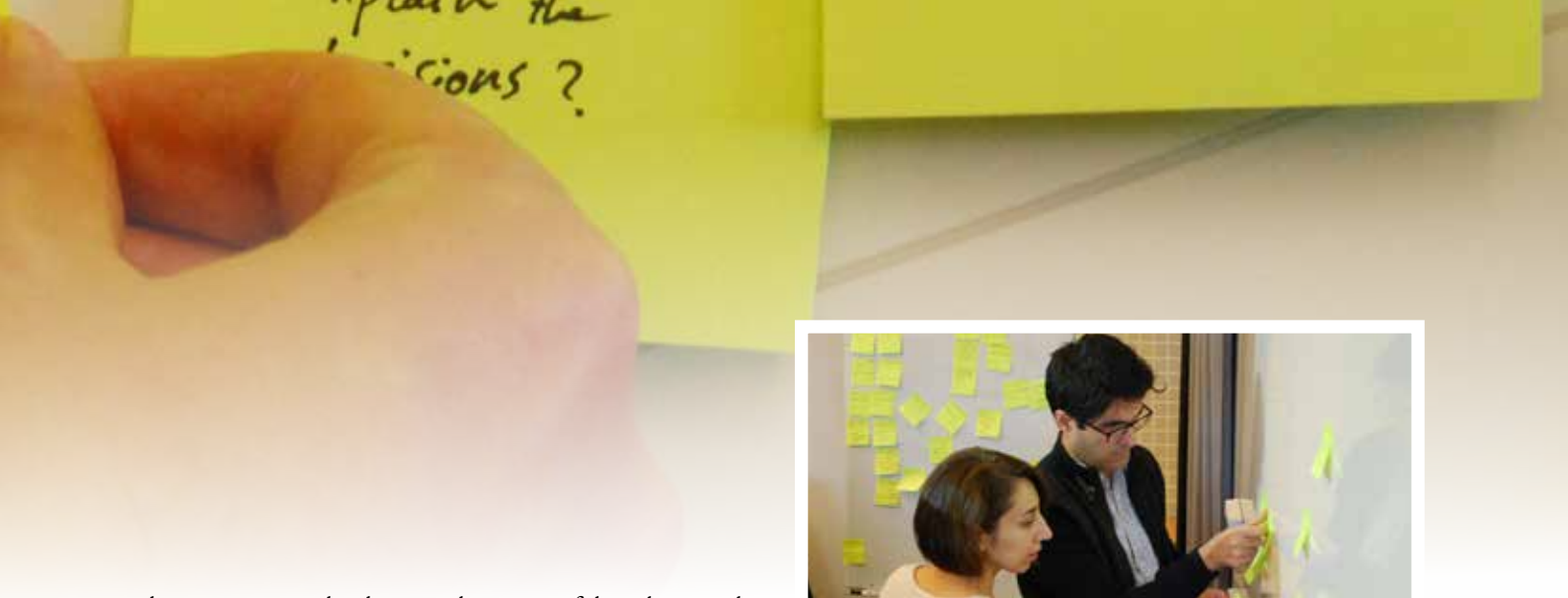
- Applied research questions
- Basic research questions
- Establishing a timeline
- Identifying required resources
- Prioritisation

Although it's low-tech, the most convenient way of representing all these concepts is by writing them on Post-it notes of different colours and sticking them up on the white board. They can then be easily rearranged from one stage to the next and regrouped in order to form clusters and so on. One disadvantage is the need to digitize all of the notes afterwards. Visitors to Mark's office found a rather colourful and slightly chaotic scene while this work was underway.

The first two parts involve the use of a modified Johari window and were done in smaller groups. Research questions were classified according to two binary –dimensions, we are doing/not doing and activities in the present/future.



Where analogue meets digital



lt seems intuitively obvious why it is useful to discuss what we are doing now and might be doing in the future. But it is also important to discuss what we are not doing, especially in terms of identifying areas that it can be strategic to stay out of for various reasons. For example, an area where there are already several strong competitors or a lack of suitable industry partners.

After the first two stages were completed, all of the Post-it notes (excluding the activities we are not planning to do) were repositioned by the entire research team onto a time line which represents the development of the research group over the next 15+ years. The horizontal axis is time and the vertical axis represents growth, both in terms of quantity and quality of research. Applied problems (yellow notes) were placed above the line and basic research questions (pink notes) below the line.

Next the team had to identify resources required. These could be both internal resources such as staffing or equipment (orange notes) and external resources such as cooperations with specific partners (blue notes).

Having done all of this, the fun could really begin. The team was given the task of prioritization and asked to remove as many of the notes as possible. In a heated atmosphere similar to an oriental bazaar, Post-it notes became as valuable as banknotes! Some notes were removed and placed on a nearby table, only to be placed back up on the white board by someone else. Others were seen being pulled in different directions by multiple sets of fingertips. Happily, all of this took place in a goodhumored spirit and when the dust finally settled the final time line contained only about half the original number of notes.

Finally the team were given an even tougher prioritization task. Four groups were each given four tokens they could spend on indicating a particularly higher level of priority to individual notes. These were indicated by placing a dot on an activity. The teams actually managed to place out a total of 18 dots, two more than they were allocated, but it was decided not to hold an inquiry into this slight numerical discrepancy!

Four activities each received two priotisation tokens:

- Causality in AI
- Explainable AI
- Federated learning in health
- Interactive anomaly detection

These all land squarely within CAISR and can be seen as logical continuations of both applied and theoretical work currently underway. It seems natural enough that the main thrust of what we are working on today has a clear long-term goal. However, one or two of the notes with one prioritization token indicate some interesting ambitions:

- Security aspects of AI
- AI capable of understanding

The aspect of security in AI has perhaps been slightly lacking in earlier work. But as AI moves into practical applications in healthcare, transport and so on, security risks are increasing and need to be addressed. An obvious strategy is to build closer links to CAISR's sister department CERES, where there is considerable expertise in security coupled to our educational activities.

AI capabable of understanding, in other words a self-aware system, is one of the ultimate goals of AI research. It is exciting that our young researchers want to pursue such an ambitious agenda.

After some debate, the team decided on an overall goal of "autonomous knowledge creation". Future CAISR reports will make an interesting read!

An **excellent** review

CAISR reached eight years in 2019 and the end of the first period with profile funding from the Knowledge Foundation. Therefore, the Knowledge Foundation commissioned an external review of our development from 2012 to 2019. The review and analysis were conducted by DAMVAD Analytics, who has reviewed several Knowledge Foundation funded profile centers in Sweden.

The review was based on a site visit with interviews with Halmstad University management and CAISR researchers, various written documentation like bibliometric data, staff statistics, financial reports, our annual reports, quality assurance systems, and interviews (using questionnaires) with our industrial partners.

The review looked at three questions.

1. Has the research investment contributed to building up a research environment with international impact?

2. Has the research been important for the industrial partners? Has it resulted in economic value for the partners?

3. How well has the cooperation between partners worked? Are there visible synergy effects from the partnership?

The three questions were broken down into three indicators each, making a total of nine indicators for the overall outcome (see next page). For each indicator, the result was categorized into three levels: clear development (very good), some development (neutral), and little or no development (less good).

In short, the outcome for CAISR was excellent development. Out of nine possible indicators, CAISR was deemed very good on seven, and neutral on two. No profile evaluated by DAMVAD has been rated very good on more than seven indicators. Based on previous evaluations of profiles, CAISR's performance falls in the top 10% for Knowledge Foundation profiles[1,2,3]

DAMVAD summarized the outcome for CAISR in the following way (translated from Swedish).

Question 1 – building up a research environment with international impact: The research activities within the profile have a clear link to Halmstad University's KK Environment *Research for Innovation*, where Health Innovation activities take place as well as Smart Cities and Communities. The profile has shown a development where the staffing has about doubled 2012-2019. Publications produced within the environment are cited somewhat lower than corresponding research in Sweden and the Nordic countries. However, the citation rate is higher than the average in OECD. Thirteen percent of the CAISR publications are among the ten percent most cited within each field, and 16 percent of the papers are published in the top ten percent ranked journals. The bibliometric parameters for CAISR are just below the average for Knowledge Foundation profiles.

1 Utvärdering av tre forskningsprofiler - COMPCAST, E2mp-rp och SUMAN", DAMVAD Analytics, 2017
2 Utvärdering av två forskningsprofiler - ESS-H och MD3S", DAMVAD Analytics, 2018
3 Utvärdering av fyra forskningsprofiler - CAISR, Future Energy, NGBI och SISB", DAMVAD Analytics, 2019

Question 2 – value for industrial partners: CAISR has collaborated with many regional companies of smaller size. A large majority of the industrial partners are interested in continuing the collaboration with CAISR beyond 2019. They have established new or deeper partnerships with academic researchers, increased the scientific level within the company, and gained increased access to materials and competence. Furthermore, the industrial partners think that the added value from participating in CAISR by far exceeds the costs.

Question 3 – cooperation quality: The collaboration with the industrial partners has worked well within the framework of the profile, but some individual subprojects have been limited due to rotation of partners and staffing of the respective collaboration partners. The degree of co-publication between academics and industry partners is slightly below the average for Knowledge Foundation profiles. A partial explanation for this is that collaboration takes place with smaller companies that do not prioritize the production of scientific articles. The industrial partners consider communication with CAISR to have worked very well. However, relatively few industrial partners have cooperated with other industrial partners.

DAMVAD also commented that CAISR recruits competitively with other academic institutions and businesses. Artificial Intelligence and Machine Learning are booming subjects, and there is a high demand for talent. For example, the demand for equivalent competence is high among research-intensive vehicle manufacturers, who can often offer both a qualified environment and competitive salaries. Other universities in Sweden are conducting or building up research in the same fields as CAISR. However, CAISR has in this competition succeeded in attracting expertise and building up a critical mass of researchers in the environment. Still, CAISR needs to continue to grow to stay competitive.

We are, of course, delighted with the outcome of the review. Seven top grades out of nine possible is a strong feat. Not least when we also achieved almost all our own goals with CAISR (reviewed in the annual report for 2018). However, there is room for improvement and we are focusing on those aspects in the CAISR+ effort that starts 2020.

Issue 1: Has the research funding helped to set up a research environment with international impact?	Bibliometric index 0.75-1 in relation to benchmark with OECD / Nordic region.	OECD: 1,09 Nordic reg: 0,9
	Strong staff growth (25% +) in the environment between 2012-2018.	Growth: 89% (2012-2018)
	Published in the top 5% of journals, at least 10% of articles published in top 10% journals.	Top 5%: 3% Top 10%: 16%
Issue 2: Has the research had relevance and created economic added value for business?	Indication of (i) patents and (ii) process or product development and (iii) R & D investment.	All three are fulfilled
	Average Response of 5+ to survey questions if value added exceeds costs.	Score achieved: 5.9
	75% + of the companies replied that they want to continue their cooperation within the profile.	Share: 86%
Issue 3: How is the collaboration with the university and business worked?	Average response of 5+ to the question about how the collaboration generally has worked with the university.	Score achieved: 5,4
	Average response of 5+ to the question about how the collaboration generally has worked with other companies.	Score achieved: 5,5
	Percentage of publications published together with authors from business is 10-33%.	Share: 15%

Predictive maintenance in **healthcare**

The care ecosystem is becoming more complex, and healthcare systems around the globe face new challenges, such as an increasing demand and resource utilization due to an aging population and higher prevalence of chronic diseases, and increasing demand for precision healthcare with individualized diagnosis and treatments. Moving towards information-driven healthcare, utilizing the recent developments in AI and machine learning, will be important for meeting these challenges.

Information-driven healthcare[1] provides an extraordinary opportunity to deliver significant benefits for patients, the regions, the municipalities, and society. It has the potential to improve individual care, as well as public health, medical research, and innovation. It can provide earlier diagnoses, suggest personalized and tailored treatments and medications, empower patients through self-monitoring, intelligent healthcare management, and so on.

CAISR cooperates with Region Halland to make Halland a role model for information-driven continuous care in Sweden (and worldwide). The basis is Region Halland's strategic healthcare analysis and research platform[2], which offers a unique integration of data sources for people in Halland, from all levels of the care chain including measurements from primary care, ambulance, emergency care, inpatient care, and electronic health records together with resource data – it will soon also include the municipalities' healthcare data.

This platform has led to international collaboration with very high profile partners from, e.g., Harvard Medical School and Brigham Women's Hospital.

Information-driven healthcare is more than data-driven healthcare, and higher in the awareness hierarchy (see the Section on CAISR Scientific Agenda). Information and knowledge enable decision making and taking action. Our collaboration with Region Halland allows real-life (and almost real-time) studies, and CAISR researchers are employed with both parties so that they work in the IT environment where the solutions will be applied, and talk directly to the people involved in healthcare decisions.

Achieving the vision of information-driven healthcare is not just about "AI" and making better predictions from data; It requires the engagement of patients, the public, healthcare providers, and relevant companies. It requires changing the way of working in healthcare organizations. Therefore, Halmstad University aims to establish a large scale long-term effort that involves industry, healthcare organizations, and researchers from health management, health economy, implementation sciences, and AI.

Vinnova – Information-driven healthcare

AI Innovation of Sweden coordinates a big project in information-driven healthcare, with the main objective to establish an innovation environment so that Sweden can offer a more information-driven, personalized and scalable healthcare with the use of AI. Halmstad University is responsible for two work packages, one on implementation and evaluation of information-driven care solutions, and the other on the implementation of federated machine learning methods (CAISR manages the latter).

The partners in the project are AI Innovation of Sweden, SKR (Swedish Association of Local Authorities and Regions), Region Halland, Halmstad University, and Karolinska University Hospital.

https://www.ai.se/en/projects-7/information-driven-healthcare

1 Anderson & Lingman, "Information driven healthcare", presentation at Lindholmen Applied AI, https://www.youtube.com/watch?v=Xkwp3onCYIc (2019)

2 Ashfaq et al., "Data resource profile: Regional healthcare information platform in Halland, Sweden, a dedicated environment for healthcare research", *International Journal of Epidemiology*, doi: 10.1093/ije/dyz262 (2020)

Mattias Ohlsson and Kobra Etminani work with the research projects mentioned in the text.

Within AI and data science, where CAISR's role is, we work with precision healthcare, user motivation, distributed data mining, and explainable AI. Precision healthcare refers to the idea of delivering the right treatment to the right patient at the right time. Precision healthcare represents a shift to more proactive and personalized care that empowers people to lead more independent healthy lives, propelling them to use healthcare services everywhere and not restricted to healthcare centers. We call this "Healthcare as a Service".

User motivation focuses on "nudging" the user to follow healthcare advice. In the iMedA project, Halmstad University and Region Halland work together to improve medication adherence directly, and reduced healthcare costs indirectly, for hypertensive patients through personalized digital interventions delivered via an AI agent implemented in a mobile app.

Distributed and anonymized data mining is crucial. Using machine learning to develop tools for clinical decision support requires plenty of high-quality data. The sensitive nature of medical data means that the potential gain of combining medical databases from different organizations has been difficult to exploit because of privacy restrictions. However, recent developments in federated machine learning allow utilizing several databases while preserving privacy, and such approaches are explored in the Vinnova funded project for information-driven healthcare (see separate box).

Explainable AI is how to "open the black box." AI-based advice will hardly be accepted unless there is an explanation accompanying it. This can be achieved by reverse-engineering machine learning models and attach the observed relationships to previous clinical knowledge. CAISR researchers are exploring this in a project together with Linköping University Hospital and the European DLB consortium (see separate box).

Swedish Research Council - AIR

The overall aim of the "Artificially Intelligent use of Registers" (AIR) project is to establish an environment for critically assessing how machine learning methods applied on the Swedish health register infrastructure can contribute to increased quality and efficiency of healthcare while addressing well-founded ethical and legal concerns related to the use of complex data-demanding algorithms in clinical practice. Three specific subprojects within AIR focus on cardiometabolic diseases, improved diagnosis at the emergency ward, and improved long-term forecasting of patient outcomes and healthcare needs.

The AIR environment is a collaboration between Lund University, CAISR and Region Halland.

Vinnova SIP: MedTech4Health - AIDA-LBD

In this project, we study whether AI algorithms (including shallow and deep learning algorithms) can be trained to predict the final clinical diagnoses in patients who have undergone 18F-FDG PET scans of the brain and, once trained, how these algorithms compare with the current standard clinical reading methods in differentiation of patients with final diagnosis of Lewy Body Dementia (LBD) or no evidence of dementia. The hypothesis is that the AI algorithms would detect features or patterns that are not evident on standard clinical review of images (both visual and quantitatively with the currently available commercial programs for brain quantification), and thereby allow earlier detection of pathology.

The work is done in collaboration between CAISR, Linköping University Hospital, and the European DLB consortium.

https://medtech4health.se/aida/projekt/

Predictive maintenance for **machines**

CAISR researchers and industrial partners from Volvo Group and Toyota Material Handling at the kick-off for the CAISR+ project. The meeting took place at Volvo Group's "Assar's Garage" location in Gothenburg.

Predictive maintenance is about predicting when a system needs to be maintained (e.g., repaired, serviced, parts replaced, etc.). It builds upon the idea that components or subsystems can be monitored such that it is possible to estimate their health status and predict their remaining useful life. This enables optimization of the maintenance operations. Predictive maintenance is very different from prescriptive or time-based maintenance, which has been the industry standard for a long time.

Predictive maintenance has always been one of the core research directions in CAISR. It fits our scientific agenda: the operation and service histories of machines is an excellent testing ground for knowledge creation algorithms. As more operation data become available for machines and better data become available for service histories, it is to be expected that the combination of predictive maintenance and machine learning[1] (ML) becomes a hot (even hyped) topic. There are today more than 1000 published scientific papers on the use of machine learning for diagnostics, condition-based maintenance, and predictive maintenance for machines. The figure on the right shows the development of the scientific publication output in the field, and it is evident that it is snowballing since 2016.

Many, if not all, multinational companies are investing in predictive maintenance, and the market grows rapidly. Market Research Future[2] estimates that the predictive maintenance market increases at a cumulative annual growth rate that exceeds 25%. IBM claim that using predictive maintenance could reduce maintenance costs by half[3] compared to the current practice, which is mostly time-based maintenance. At first, this may sound like a good deal for everyone but becomes problematic in the perspective that many manufacturing companies make a lot of money on the maintenance services (aftermarket). The use of predictive maintenance will affect not only the maintenance operations but also the business models for equipment manufacturers. It becomes essential for equipment manufacturers to be on top of the development in predictive maintenance technology.

Predictive maintenance is thus very relevant for Sweden, whose export incomes depend heavily on manufactured goods. Researchers in CAISR have been active in the field for 15 years and have noticed the growing importance of the area, and the increased interest from industry. We have seen a steadily growing number of projects in this direction, which has allowed us to recruit a substantial amount of young and international talent in this field. The subject also fits the CAISR scientific agenda very well. We, therefore, focus CAISR even more on predictive maintenance with the continued center funding from the Knowledge Foundation (for 2020-2022), with the project CAISR+.

There are four main directions in our continued research in predictive maintenance: machine activity recognition, survivability analysis, early failure detection, and deployment of ML-based algorithms and services on-board machines.

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1 In the term "machine learning" we include neural networks (including deep learning), decision trees, random forest, support vector machines, and Bayesian belief networks.

2 Market Research Future, "Predictive Maintenance Market Research Report – Forecast to 2022", https://www.marketresearchfuture.com/reports/predictive-maintenance-market-2377

3 IBM, "As much as half of every dollar you spend on preventive maintenance is wasted", https://www.ibm.com/blogs/internet-of-things/as-much-as-half-of-every-dollar-you-spend-on-preventive-maintenance-is-wasted/

Volvo bus B8RLE Euro 6 chassi.
Photo: Volvo Bus Corporation

Machine activity recognition is about labeling and characterizing the use of machines, using streaming (onboard) data. It is similar to human activity[4] recognition , which typically uses either external cameras or body-worn sensors, where deep neural networks are becoming state-of-the-art because of their ability to learn good features by using unsupervised learning. Comparatively little has been published on machine activity recognition, but the work there is also based on inertial sensors mounted on the equipment or using external cameras. We follow a slightly different route that however, builds on representation learning with deep neural networks.

In survival analysis, the objective is to model the expected duration of time until the occurrence of an event (the end-of-life of the equipment). Censoring is what makes survival analysis more complicated than just using a regression approach to estimate the event times. Machines in operation are generally not allowed to run to their end-of-life, which means that the final events are seldom observed. This is referred to as right censoring, and when censored events dominate and real failure events are rare, modeling becomes difficult. We explore the use of deep models and usage characterization to better model component survivability.

Early failure detection builds on our several years' work on change detection and predicting time to failure, using either onboard data or off-board aggregated data. This work has resulted in our COSMO method and led to implemented services with our industrial partner (see Section on impact).

Finally, the deployment of ML algorithms encompasses the practical aspects of getting a solution to work together with our industrial partners. A lot of work on ML assumes a somewhat idealized setting when all the relevant data is available in the cloud and ready to be processed. In reality, though, collecting and storing data is costly, and the challenges begin way before that point. Edge computing, distributed processing, decentralized computations, and more are different approaches towards a more holistic view of data collection and processing, with the right balance and optimal use of onboard hardware. We do not consider these aspects to be the core of our scientific research, but we have to understand them well. The practicalities put constraints on the algorithms and methods; for the work to be useful to our industrial partners, it must fit into their frameworks. Many available methods are not, out of the box, suitable – which requires significant expertise and systems-level research from our side.

4 Bulling, A., Blanke, U. and Schiele, B., "A Tutorial on Human Activity Recognition Using Body-Worn Inertial Sensors", ACM Computing Surveys, 46, Article 33 (2014)

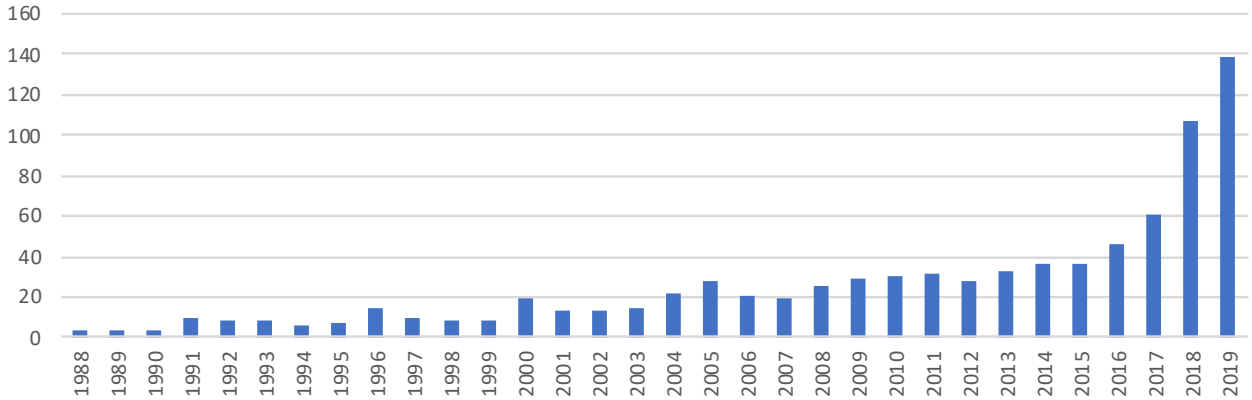


Figure: Illustration of how the annual number of published scientific papers has developed in the area predictive maintenance, diagnostics and condition monitoring with the use of machine learning.

ECML/PKDD Workshop

Multiple people from CAISR were involved in organizing a combined tutorial and workshop on IoT Streams for Data-Driven Predictive Maintenance. It was co-located with one of the premier machine learning conferences, the European Conference on Machine Learning and Principles and Practice of Knowledge Discovery in Databases, ECML PKDD 2019. This was the 20th edition of that conference, this time held in Würzburg, Germany.

Sepideh Pashami from CAISR organized the workshop part, together with João Gama and Rita Ribeiro from Laboratory of Artificial Intelligence and Decision Support, University of Porto, Portugal; Albert Bifet from Telecom-ParisTech, France; and Anders Holst from RISE SICS, Sweden. Slawomir Nowaczyk from CAISR organized the tutorial part, together with Moamar Sayed-Mouchaweh from Institut Mines-Télécom Lille Douai, France and Ricardo Sousa from Laboratory of Artificial Intelligence and Decision Support, University of Porto, Portugal. The keynote talk was delivered by Myra Spiliopoulou from Otto-von-Guericke-University Magdeburg, Germany, who leads the research group on Knowledge Management and Discovery.

Maintenance is critically important in the industrial context as the means to avoid high costs and prevent injuries. This concerns all types of industrial machines, medical equipment, energy systems, passengers transport vehicles and home appliances, among others. Cost reduction, machine reliability, operation, safety and downtime reduction have been the main concerns of most organizations. The emerging technologies of Industry 4.0 have empowered data production and exchange, leading to new possibilities and methodologies for predictive maintenance. The intensive research efforts have in recent years focused on data-driven approaches, producing impressive results.

The main objective of the workshop was to raise awareness of research trends and promote interdisciplinary discussion in this field. It was centred on questions such as when to perform a maintenance action? How to estimate components current and future status? How accurate are the existing methods? Which data should be used? What decision support tools should be developed for prognostic? How can Data Mining, Machine Learning, and Artificial Intelligence in general, contribute to answering these questions? This event was an opportunity to bridge researchers and engineers to discuss emerging topics and key trends.

Overall, both the tutorial and the workshop were very successful. With over 40 participants we ran out of seats in the room, but that did not stop people from listening.

Commemorative photo after the workshop.

Machine learning in China

In May 2019 two teachers from CAISR, Sepideh Pashami and Slawomir Nowaczyk, went to Northwestern Polytechnical University 西北工业大学 in Xi'an, Shaanxi, China to deliver a course on "Joint Human-Machine Learning" at Chang'an Campus. It was attended by 19 Chinese and 7 international students.

ML has proven to be exceptionally successful in extracting knowledge from data across many important domains, such as economy, industry, health and media. It is often advertised as fully automatic, however, in practice, humans almost always play a central role in developing and tuning ML systems. Good performance is only achieved by leveraging human expertise and expectations, and building upon feedback and demonstrations during the design and evaluation of the solutions. This essential need for interaction between a human and a learning system goes beyond providing input and labels. One of the common critiques of ML techniques is the difficulty of interpreting the results, and the ability to communicate what has been learned to the user is often critical. This course presented, through a combination of lectures and lab assignments, different techniques for keeping humans in the ML loop.

We have provided an overall introduction to Artificial Intelligence with focus on ML and Data Mining, including motivation for "joint human-machine learning", i.e., why do we need combined powers of humans and computers to solve complex problems. We had two lectures on visualization techniques, followed by examples of supervised and unsupervised methods. Then we moved to interpretable and explainable ML, presenting approaches like LIME and SHAP.

The course was quite intense, with lectures and labs taking place almost every day, usually for 3-4 hours straight. Since we know this kind of schedule can be very challenging for students, we have tried to make the course activities as varied and interactive as possible. Each course session was divided into different parts, generally starting with a lecture-like introduction of the topic, followed by a lab-like programming exercise where students had a chance to try things out on their own, hands-on. We have also used various multimedia contents a lot, including movies and visualizations.

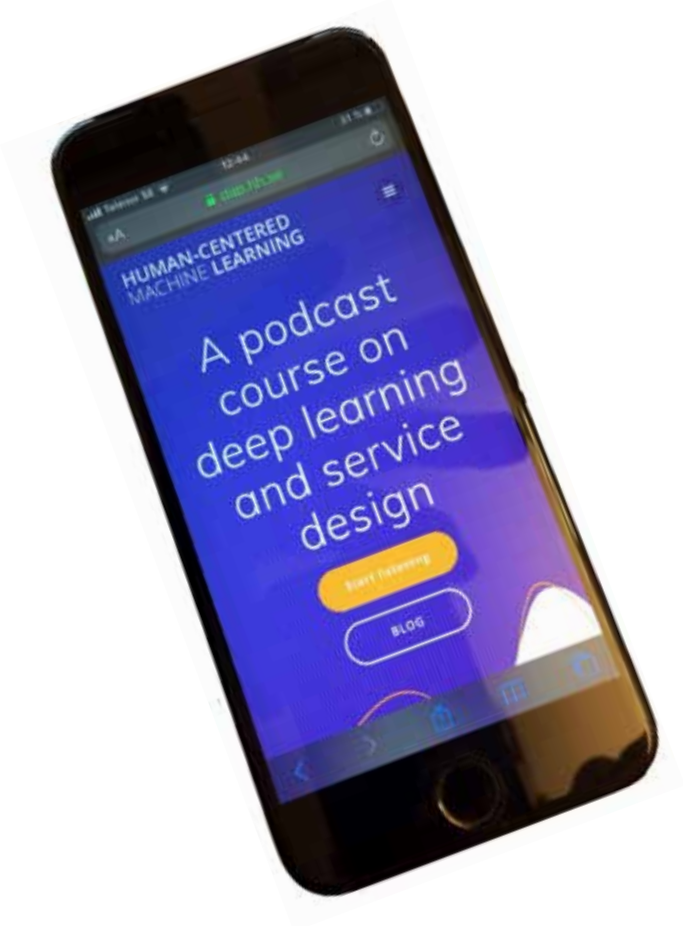
In the end, we believe the students liked the course quite a bit, even if they generally considered it pretty difficult. As teachers, we also had a great time in China, even though the busy schedule left us very tired and allowed almost no time for sightseeing. We are looking forward to giving the course again in the future.

This course was part of a bigger collaboration between Halmstad University and Northwestern Polytechnical University that is planned to continue at least in 2020 and 2021. In addition to our course, Wojciech Mostowski has given "Formal Verification of Imperative Programs with Program Logics and Interactive Theorem Proving" course, Tony Larsson has given "Autonomous Driving" course, and Torben Svane has given "Project Methodology and Agile Methods" course. In addition, both universities are interested in exploring opportunities for broader collaboration on both research and education.

Podcast course about AI

In 2019, Halmstad University launched a podcast-based course about AI (Artificial Intelligence). It is mainly targeted towards professionals within digital service innovation, such as UX designers and developers, who want to know more about AI as design material. The course is also relevant for individuals who want to understand what AI is, how it can be used and its ethical aspects.

"We want to make knowledge about AI accessible in an easy way and contribute to lifelong learning. Halmstad University, as an educational institution, should be relevant to people throughout their professional lives, not only during their studies. In addition, we see a great need to concretise the concept of AI and cut through the hype surrounding the subject", says Pontus Wärnestål, Associate Professor in Informatics and project manager for the DAP (Digital design and Artificial Intelligence Podcast) project in which the podcast has been produced.



12 episodes – from basic AI knowledge to application areas and ethics

The podcast is called Human-Centered Machine Learning and consists of 12 episodes of varying length, most of them around 40 minutes. The first episodes elaborate on the basic concepts of AI, followed by episodes describing how AI can be used when designing services. Examples are given of how AI as a design method can be applied in the areas of Health Innovation as well as Smart Cities and Communities, which are Halmstad University's two profile areas. The podcast ends with an ethical and social reflection on AI. The podcast is in English and each episode is based on a dialogue between two or three experts. "We have focused on flexible learning at an individual pace. Many other E-learning initiatives are based on videos, but since we want to offer a more easily accessible educational material that the recipient can listen to at any time, we chose a podcast-based course", says Jeanette Sjöberg, Senior Lecturer in Pedagogy at Halmstad University and part of the DAP team.

Pontus Wärnestål, Associate Professor in Informatics during the production of the podcast Human-Centered Machine Learning.

All episodes of the Human-Centered Machine Learning podcast can be listened to both on the project's DAP website and through various podcasting platforms such as Apple Podcasts, Google Play and Spotify. There is no examination on the course, and everyone is free to listen to it at any time. DAP (Digital design and Artificial Intelligence Podcast) is a project financed by Vinnova for a flexible education for professionals.

Winner of the Wiman prize 2019

Weather and climate can destroy crops, but Erik Karlsson has a solution to the problem. His box, where the roots are surrounded by nutritious water fog, gives faster results than traditional cultivation.

Erik Karlsson, an electrical engineer from Halmstad University, chose in his thesis to develop a prototype of a culture box with automated nutrition, temperature and air control. The technique is called aeroponic cultivation and is based on nutrient-rich water mist surrounding the roots of the plants instead of soil. Erik Karlsson was 2019's winner of the Wiman Prize for the best degree project at Swedish engineering programs.

"I developed the prototype for testing the technology; in reality, the boxes would be smaller and piled up in large warehouses, he says.

That he chose the degree project in aeroponic cultivation was a coincidence. During a visit to the school incubator with a friend, they came up with the idea to investigate the technology.

"The technological development in the cultivation industry has been relatively slow for a long time, he says.

The technical part was a significant challenge, with many variables in the process; it was challenging to find the optimal levels. Through several test periods, Erik Karlsson navigated towards ever better results.

"The timing of the water system was tricky, how often it should spray and what temperature the air around the vegetables should have. The focus was on getting the crops to grow as much as possible, he says.

The prototype was further developed

The result showed that the crops grow faster with aeroponic than traditional cultivation. After the degree project, Erik Karlsson received funding from Sweden's innovation authority Vinnova to investigate the business potential of the technology. He further developed the prototype and produced a LED lamp to find optimum brightness and heat.

A market survey was also conducted to explore the demand. The technology can be used by Swedish growers to grow local produce even during the winter months, but severe price pressure from abroad means that the interest is not sufficiently high.

"There is a lot of talk about new cultivation methods in the industry. But in the supply chain, it is still so cheap for retailers to import vegetables from abroad during the winter season that there is no incentive for Swedish growers to use the technology right now, he says.

Erik Karlsson in front of his cultivation box with automated nutrient supply, temperature and air control. Photo: Patrik Leonardsson

Erik Karlsson points out that the LED lamps draw much power and that further development of the technology is required. He has not continued in the cultivation industry after his degree project.

"I recently started a new job where I work on 5G development", says Erik Karlsson.

Adapted from a Swedish text by Caroline Le Ridou, Ingenjören

The thesis work was supervised by Eren Erdal Aksoy and Cristofer Englund, both researchers at CAISR.

The Wiman prize

The Wiman Prize is the Swedish Engineers' annual prize for the best degree project at any Swedish engineering degree program. The prize was first awarded in 2000 and is named after Ernst August Wiman, one of the founders of the Swedish Inventor Association.

Eren Erdal Aksoy

If my research turns out a success, my research will definitely affect society. I would really like to see my different scientific theories applied in the real world. That would make me quite happy.

Robots that understand, learn and imitate humans

How to make robots more intelligent. That is the ultimate question Eren Erdal Aksoy wants to find the answer to.
"I am not interested in designing the latest version of a human robot with two legs or two arms. Instead I want to make them more intelligent. How can they observe us, pursue us, learn from our behavior and transform that knowledge into their own internal system.

Eren Erdal Aksoy, assistant professor at Halmstad University, got his bachelor degree in electrical and electronics engineering in Turkey. Because of one professor and his way of approaching problems, he got inspired enough to decide to stay in the academic world and focus on robots and how to build and program them.

I really enjoy when I have programmed the robots myself, says Eren Erdal, and then get to see them up and running.
"I get the feeling that everything in front of me is my creation and I have full authority to change whatever needs changing. I also enjoy teaching the younger generation how to build and program a small robot from scratch with electronic components".

Several areas of application

There are several different areas of application for this intelligent system. You can put it in a robot, a vehicle, a smartphone or in a pair of glasses. You can design a robot with two arms and two legs that will come to your house, says Eren Erdal, observe you and then imitate you when you clean and do general house work.
As the number of people over 65 will threefold over the next decades while the number of young working age people will diminish, intelligent service robots can be useful help to the elderly.
"Your smartphone could use the same technique. In the grocery store for example, you can use the camera to identify a tomato, display the weight, colour, size and price. Your phone could also detect if a person approaching you is a criminal. The glasses can be helpful in domestic situations such as cooking when they can help guide you through a recipe.

Robots imitate human actions

In his PhD thesis Eren Erdal Aksoy showed how we can understand human actions.
"For example, if a human demonstrates how to make a sandwich, using tomatoes and cucumber, and the next day uses cheese and tomatoes – how do we build a robot that has the capacity to observe and learn how to use a variation of objects and actions?
Eren Erdal Aksoy has actually already developed a framework that can capture variations in objects and actions, enabling robots to understand, learn, and to some degree imitate what you are doing.

Eren Erdal Aksoy is also part of an artificial intelligence team at Volvo that currently works to implement intelligent perception modules for autonomous trucks. The aim is to make a robot understand the environment enough to go from A to B without colliding with vehicles or pedestrians.
"Autonomous intelligent systems will save human lives. Studies show that most accidents are due to human error.

Applied scientific theories

The dream is to create a robot that can understand observed human actions, recall the most similar previously experienced episodes and imitate them, even in different contexts. If you, for instance, ask the robot what it remembers about your food preferences, it might tell you "I remember you once having pasta, so let me prepare a pasta dish for you."
"If my research turns out a success, my research will definitely affect society. I would really like to see my different scientific theories applied in the real world. That would make me quite happy".

Fernando Alonso-Fernandez

Increased security with facial recognition

With the many services available on smartphones, secure transactions are essential. Fernando Alonso-Fernandez wants to develop new AI-solutions for human identification and the understanding of human behaviour, using for example, smartphone devices. The goal is increased security and enhanced user experience.

"If someone steals your phone or your computer, private information like banking details and email account details can leak and security be compromised. You might even have the credit card number stored somewhere accessible for someone else, says Fernando Alonso-Fernandez, associate professor at Halmstad university.

To validate the identity of a person, we have traditionally used passports, keys, cards, identity cards, birth certificates or a piece of knowledge like a password or a PIN.
"These things can be lost, copied and forgotten – or stolen and used by a third party who can potentially get access to your bank account or car. Another problem is that there are so many passwords in our lives these days that many end up using the same one everywhere.

Fingerprints instead of a PIN

One solution to these issues is facial recognition –this constitutes a biometric technology, recognizing a person based on body traits – something that you are.
"When measuring biometric characteristics, it's important that they are unique and permanent.
They can be of physical character like fingerprints, palmprints, vein pattern, face or iris but they can also be behavioral, like a signature, keystroke, voice or the characteristics of a person's walk".

To choose which biometric to use, accuracy is key. Other factors to consider are if the person is aware of the monitoring and if it is ethical to use it, what the cost is, and the willingness to accept the biometric.
"For example, in the past, fingerprints used to be associated with criminals, but with the use of fingerprints on the smartphones it has become more accepted than before".

Periocular biometrics are superior

Facial cues are the most natural way for humans to recognize each other. There are three levels of analyzing the face: at close level: the iris, at far level: the whole face, and at an intermediate level: the region around the eye.
In his research, Fernando Alonzo-Fernandez, is focusing on periocular biometrics, the region around the eye.

– If you concentrate on just selected parts of the face you are less sensitive to changes of overall expression, downsampling, obscured or partial faces such as are common in surveillance or forensics. Periocular biometrics is also superior to iris recognition in difficult conditions like entrance ways and with images taken at distance or at low resolution by, for example, a smartphone.

The technology could be misused

A risk with this technology though, is that it can create a feeling amongst people of being monitored at all times. There is an ongoing debate in academia how to protect people's privacy whilst simultaneously implementing these solutions.

This collaboration between academia and industry is enriching and necessary to ensure that my research can be applied in the real world

"What the technology allows us to do is one thing, but what you should do with the technology is another. It could be misused if it ends up in the wrong hands.

Fernando Alonso-Fernandez got his PhD in Spain in 2008, after which he decided to apply for a post doctoral grant at Halmstad University, and came here in 2010. Since he had some experience both from industry and academia, he wanted to combine the two and found Halmstad University where companies are more aware of the importance of research and the connection with academia than in Spain.

Applied research is essential

Currently Fernando Alonso-Fernandez is in Spain, working with a company that sells security solutions to smart phones. By taking a selfie with the mobile phone, the user can identify herself when using the bank's mobile application.
"This collaboration between academia and industry is enriching and necessary to ensure that my research can be applied in the real world", says Fernando Alonso-Fernandez.

Kobra Etminani

Artificial intelligence could predict and prevent diseases

She wants to see a healthier society by using artificial intelligence in the health care system. Artificial intelligence, AI, can help doctors diagnose patients, recommending the right treatments and prognosis.
"I want to take it one step further and find out how we can predict and prevent different diseases with the help of AI, says Kobra Etminani, assistant professor at Halmstad University.

Using AI there are a lot of opportunities for improvements within the healthcare system, especially nowadays when chronic diseases are the one of the biggest challenges within medicine.
"AI could have a great impact, either as an assistant or complement, to help physicians be faster and more accurate, or as a tool to reveal new knowledge".

Preventive and prescriptive healthcare

AI has been successful, using machine learning techniques, when it comes to diagnosing and prognosis. Now, physicians want to know more about how these AI models work. By opening up the models to medical experts, new areas of knowledge will be revealed.
"Therefore, going beyond prognostic models to preventive and even prescriptive healthcare is much more likely to become a reality".

To be able to predict future diseases, the researchers in this field need information from the healthcare system, like medical records. They also collect data from individual patients.
"Nowadays we use a lot of smart sensors in our daily lives and smartphones can monitor our sleeping pattern, number of steps and heart rate".

Involving the patient through artificial intelligence

To prevent future diseases, it is also necessary to involve the patient, says Kobra Etminani, and make them more responsible for their own care. AI can help them to get a better understanding of themselves and their needs.
"We want to empower patients to get to know more about their health status, what kind of medication and treatment they need, how to follow the plan and what the consequences can be if they don't".

Increase patient motivation

Kobra Etminani is currently working on a project to improve the adherence of hypertension patients to their medication regimen. Hypertension is a risk factor for many other diseases like heart failure, stroke and kidney disorder, so she is examining how patients are dealing with their diseases in relation to that.

These conditions can often be prevented by controlling blood pressure. But patients with hypertension typically do not feel sick and therefore are not always motivated to listen to the doctor and follow adviced treatments. Thus, an important goal with the research project is to increase the patient's motivation.
"For instance, if I get in touch with my friends and colleagues who have a similar situation to mine, seeing what they do can have a huge impact on my motivation", says Kobra Etminani.

Precision healthcare

One way to work with motivation is to empower patients by raising awareness on hypertension and a healthy lifestyle and other aspects that are important to hypertension patients.

"There are enormous amounts of information about hypertension on the internet, but no one has the time to read all of it. Our job is to find the right sort of intervention for the right person at the right time, so called precision healthcare".
In other words, the information will be more individualised, since each of us have different needs. One person might for example need a reminder to take her medication and a little bit of information. An older person might have different needs.

Using AI, the healthcare system could be managed with greater speed and ease, with less expense and stress and without the patient even having to visit a doctor.
"Simply by increasing the level of knowledge from the beginning and having it individualised through the use of AI, we can prevent a lot of diseases and societal costs".

Mohamed-Rafik Bouguelia

Algorithms that learn how to learn

I believe that this is one step towards true artificial intelligence – to design algorithms that allow the machine to learn how to learn.

Mohamed-Rafik Bouguelia is designing machine learning algorithms that interact with humans. He dreams of AI that can make decisions at the same level as the human brain. A machine that can consciously analyze its decisions and explain them.

"These algorithms are not yet widespread", says Mohamed-Rafik Bouguelia, assistant professor at Halmstad university.

"We have systems that actively support you in your decisions, but they are not yet capable of explaining why they made a specific decision."

Detect abnormal behaviour

Today, there are innumerous complex machines on the market, with a lot of sensors that collect data continuously over time. When experts want to monitor these machines, they create special rules to detect specific faults or failures. But one cannot always manually design rules to predict all possible faults that can occur.

In order to detect failures in the systems before they happen, Mohamed-Rafik Bouguelia designs algorithms that are able to learn, what constitutes a normal behaviour and what constitutes an abnormal behaviour, from this data.

"If the data is show symptoms that indicate imminent failures, these algorithms can automatically detect this and raise an alarm to point out the problem".

Algorithms that learn over time

The algorithms are interactive, which means that they can interact with a human expert during the learning process. The algorithms improve their own accuracy by integrating the expert feedback and learn over time to detect new faults that are more relevant.

Currently Mohamed-Rafik Bouguelia is involved in several research projects related to detecting anomalies in complex systems.

"You want methods that indicate the need for maintaining the machines before they break down in a dangerous situation.

Human feedback essential

Interactive machine learning algorithms could be used in many areas, from vehicles to trains to heat-pumps and district heating substations.

When monitoring district heating substations, or when monitoring heat pumps to detect failures, the data that is collected from those machines sometimes show atypical events that happens, but they are not necessarily anomalies.

"Without feedback from human experts, the algorithm has no way of distinguishing between those atypical events and real anomalies. This is why it is important to design these interactive machine learning algorithms, that are able to interact with a human during their learning process and take the expert feedback into consideration.

Increased trust in predictions

Most companies that apply machine learning do this without necessarily understanding how they work.

"We design algorithms that can pose questions to the human expert, during the learning process, and can later explain why they made certain decisions – this increases trust in the predictions that these algorithms produce".

If you, for example, apply your anomaly detection algorithm in a medical domain where you have a decision support system that helps doctors making decisions, the doctor can not blindly trust the prediction made by the algorithms.

"If the algorithm predicts that the patient has a certain problem, it also needs to provide explanations and evidence of why it made this prediction, so that it is more interpretable and trustable".

Letting machines learn how to learn

Mohamed-Rafik Bouguelia believes that these intelligent algorithms will be all around in the future, for instance in smart homes helping elderly people. Instead of having cameras, you can place sensors that collect data, wand by monitoring this data you can detect if there is a dangerous situation.

The aim is to work more with meta learning.

"I believe that this is one step towards true AI – to design algorithms that allow the machine to learn how to learn.

Data science for **social good**

The DSSG Fellowship

Data Science For Social Good (DSSG) helps not-for-profit organisations and government bodies to achieve more with their data by improving their services, interventions and outreach so that they can fulfil their mission of bettering the world and people's lives.

The programme brings together top-tier data science talent from all over the world to come up with solutions to real societal challenges, harnessing the use of machine learning, big data and data science. During the 12-week programme, they work in small interdisciplinary teams on projects with social impact, including areas such as healthcare, education, energy, transport and social services, in collaboration with government departments and non-profit organisations.

The Alan Turing Institute and the University of Warwick hosted the 2019 summer program, which ran from early June to the end of August. A second initiative was run, in parallel, at Imperial College London.

DSSG Summer Fellows in 2019 at the Turing and Warwick addressed five projects in total. Our project dealt with the problem of quantifying and reducing inequalities in transportation in the West Midlands, UK.

Our project

Our project partner, West Midlands Combined Authorities (WMCA), is a cluster of 18 local authorities and four Local Enterprise Partnerships (LEPs), working collaboratively on many projects ranging from transport, jobs growth, industrial strategy, public service reform etc. to deliver their vision of a more prosperous West Midlands. As the region grows, both economically and in terms of population, it is becoming increasingly important to ensure high quality and equal access to transportation.

The goal of the project was to make transportation access in the West Midlands region fairer. The partner has indicated that there is a problem of areas being isolated from public transport lines, with poor access to private vehicles and have a congested highway network – this is particularly prevalent among areas with high minority and low-income populations. Although the partner has an idea on which areas are experiencing isolation, the volume, scope, and extent of the problem has not been analyzed and quantified.

Ece Calikus attended the DSSG Summer Fellows in 2019. The Alan Turing Institute and the University of Warwick hosted the program.

The project involved finding a better way to measure equity of access to transportation services, and creating a data product that allows policy makers to analyze if and where the disadvantaged people live, if the system currently fails to serve a particular demographic group, and offer insights on how to make transport better and fairer.

Team WMCA at the Alan Turing Institute

Organization

CAISR is managed by the CAISR director, with support from the academic advisory group, the Industrial Advisory Board, the Reference Group, and a research coordinator overseeing details regarding reporting, coproduction, and information management.

The academic advisory group consists of the professors in CAISR, the head for the department where CAISR is placed, the research manager for the school of information technology (ITE), and the dean for the school of information technology (ITE).

The Industrial Advisory Board consists of representatives from each industrial partner in CAISR. They give advice on industrial issues and partnerships in CAISR, and participate at the meetings with the Reference Group and provide their views on CAISR's development to the Reference Group.

The industrial partners participated in several workshops in the fall of 2018, and the outcome from them was used to formulate the CAISR+ project (see the Section on Predictive Maintenance for Machines). David Johansson from Tappa Service was the chairman during 2019 for the Industrial Advisory Board.

We have decided to change the CAISR management structure from 2020, using a broader Industrial Advisory Board and replacing the Reference Group with a Scientific Advisory Board.

The final Reference Group Meeting took place in November 2019, and the picture below was taken on that occasion. Many previous Reference Group members were invited to the final meeting, to collect perspectives over the full eight years. Many of the Industrial Advisory Board members were also able to participate in the photo.

Participants at CAISR final Reference Group meeting in November 2019. The t-shirt colors are supposed to match Olle Baertling's paintings (Halmstad University is located in the "the Baertling District" in Halmstad, where several sculptures and paintings by him are on display).
Top row from left: *Yuantao Fan (CAISR), Fredrik Heintz (Reference Group), Reza Khoshkangini (CAISR), Slawomir Nowaczyk (CAISR and research manager for ITE), Stefan Byttner (CAISR and head of department), Cristofer Englund (CAISR), Johannes van Esch (CAISR), Sepideh Pashami (CAISR), Kevin Hernandez Diaz (CAISR), Alexander Galozy (CAISR), Kobra Etminani (CAISR), Magnus Clarin (CAISR and dean for ITE).*
Middle row from left: *Lars Niklasson (Reference Group Emeritus), Ervin Omerspahic (Volvo Bus Corporation), Jonas Rahm (Flexlink), Ulf Bering (NEAT Electronics), Mahmoud Rahat (CAISR), Roland Thörner (CAISR and research coordinator ITE), Pablo Del Moral (CAISR), Mark Dougherty (CAISR), Catarina Coquand (Reference Group), Peter Berck (CAISR), Awais Ashfaq (CAISR), Alexey Vinel (CAISR), Christer Fernström (Reference Group), Boris Ahnberg (Toyota Material Handling), Magnus Bergquist (Reference Group Emeritus), Kunru Chen (CAISR).*
Bottom row from left: *Henrik Arleving (HMS Industrial Networks), Thorsteinn Rögnvaldsson (CAISR), Peyman Mashhadi (CAISR), Ghaith Altarabichi (CAISR), Fernando Alonso Fernandez (CAISR), Taha Khan (CAISR), Charlotta Falvin (Reference Group), Misha Pavel (Reference Group), Nicholas Wickström (CAISR), Bob Evans (Reference Group).*

Regional companies apply **AI** with the help of researchers

Over the course of a couple of months, three selected companies have learned more about how artificial intelligence (AI) can be applied to and improve their operations.

"A fantastic opportunity! The project helped us lift our eyes and innovate our business based on our data assets, which has been a whole new way for us to develop the business", says Victoria Ekman, CEO of CE Produkter.

The aim of the collaboration project AI.m is to increase the competitiveness of companies in Halland by disseminating knowledge and competence in AI and service design from University researchers and students to the region's companies.

> *We want companies to see the benefits and opportunities that exist with AI and, above all, how they can utilize this technology to gain a competitive advantage.*
>
> Stefan Byttner
> Associate professor at Halmstad University

In the project AI.m, the University's researchers, together with the company incubator HighFive in Halmstad, trained company representatives in AI-based service innovation, for example, how service design, user experience and interaction design are affected by the introduction of AI technology. Three companies in Halland were selected – CE Produkter, Lagafors and Matpriskollen - to improve their knowledge of AI through lectures and workshops, thereby increasing their innovation capacity and competitiveness.

"This project is the first step towards our goal that SMEs in the region increase their AI competence and become aware of how data-driven decisions can improve their operations. We want companies to see the benefits and opportunities that exist with AI and, above all, how they can utilize this technology to gain a competitive advantage", says Stefan Byttner, associate professor at the School of Information Technology at Halmstad University and researcher in the field of AI.

The project is being explored

Stefan Byttner and his colleague Pontus Wärnestål, associate professor at the School of Information Technology at Halmstad University and researcher in interaction and service design, have for many years researched how different AI methods can be used in both the public sector and the private business sector. They are investigating the AI.m project in themselves, where the results are, among other things, the basis for the innovation model presented by Pontus Wärnestål at the Interaction19 conference in Seattle earlier this year.

"AI.m has proven to be a useful model for putting the research conducted at the University into practice. Researchers in AI and service innovation sit down together with companies in Halland to jointly explore and design how AI can create benefits and value for both companies and their customers", says Pontus Wärnestål.

At the same time, these experiences are linked back to new research projects at the University. One example is the development of a design tool that supports the process of working with AI-driven service development, where humans are at the center.

Voices from the participating companies:

"It has been a useful process to just explain our data assets and our business to outsiders. To be able to look up and see plenty of opportunities. Now we have a whole list of possible development areas within AI" says Magnus Elmblad, CEO of Lagafors.

"A fantastic opportunity! The project helped us lift our eyes and innovate our business based on our data assets, which has been a whole new way for us to develop the business" says Victoria Ekman CEO of CE Produkter.

"The service design opportunity and the customer journey were really good! It helped us understand how the end product and the end experience would be. We've got a new angle on what we actually have to offer" says Ulf Mazur, CEO of Matpriskollen.

"It is unique and positive to combine UX with AI. It has really given the group a common picture of where we want to go with the product" says Ulf Mazur, CEO of Matpriskollen.

Anna Petersson, business developer at HighFive and project manager for AI.m, Pontus Wärnestål, associate professor at Halmstad University and researcher in service design, and Stefan Byttner, associate professor at Halmstad University and researcher within AI.

"Another example is the training program Data Analytics and Service Innovation based on Artificial Intelligence (MAIS-TR), a so-called Expert Competence Program funded by the KK Foundation, which we run. The training is aimed at professionals who want to receive further education in both AI and business and service design based on AI. The program also includes us exploring "best practices" in AI-based service design. AI.m has given us a concrete platform for this", says Stefan Byttner.

Implement AI methods in business models

The companies' various data assets were visualized during the course of the project to see how AI (especially machine learning) can be used to analyze and draw conclusions based on available data. The next step was to look at how these methods can be implemented in companies' business models to increase growth or streamline operations.

"The participating companies have been given inspiration, skills development, business development, a complete list of possible AI applications based on their existing processes and data assets as well as a testable prototype of a priority AI service. Other effects that we have seen in the project, and which have proven to be important parameters for long-term success, are the development of a strategy for anchoring processes and decisions in daily operations, getting help from students to process their data and supporting us to search external funds for their continued AI journey.
"We hope to continue working with this in the future", says Project Manager Anna Petersson, Business Developer HighFive.

"The goal is to establish a regional AI hub that supports companies"

Pontus Wärnestål
Associate professor at Halmstad University

The goal is a regional AI hub

The plans for the next project, AI.m 2.0, are already underway. It will start in the spring 2020 with a new group of companies and there will be an official website for the hub on the site: aimhalland.se

"Our long-term goal is to establish a regional AI hub that supports companies to work strategically with AI-driven service development through the provision of skills from Halmstad University, business and strategy development from HighFive and exchange of experience between each other. This is expected to lead to increased competitiveness and growth in the region's business sector, among other things through new service innovations", says Pontus Wärnestål.

About AI.m

The project group consisted of Anna Petersson, business developer at HighFive and project manager for AI.m, Pontus Wärnestål, associate professor at Halmstad University and researcher in service design, Stefan Byttner, associate professor at Halmstad University and researcher at AI, and Albin Martinsson, digital designer at Digitalseringsbyrån. The group has worked with the selected companies and developed and tested the various tools and models.

CAISR and Halmstad University

For a modern and young university that desires to play a more prominent role nationally and internationally, it is necessary to build a strong reputation and, over time, recruit excellent faculty and ambitious students. This can be done by establishing well-positioned research and education centers that attract interest, so that the university can position itself in strategic international knowledge networks, and develop co-operation with the surrounding community, nationally and internationally. Halmstad University is such a modern and young university, and the intention with CAISR was to build such a well-positioned research and education center.

The plans for CAISR were sketched with the university vice-chancellor as early as 2006, building upon a small group of researchers and their conviction that AI would have high relevance for the Swedish industry and society. Several of the researchers were international recruitments (from Kaunas University of Technology, Oregon Graduate Institute, and the Swiss federal institutes ETH and EPFL). The opportunity to apply for a substantial long-term grant to build the center came in 2010-2011, and in 2011 CAISR was awarded the profile grant from the Knowledge Foundation.

Catarina Coquand, University Director, member of CAISR Reference Group

In 2013 the Halmstad University governing board adopted a vision that expressed that Halmstad University should build a profile as an Innovation Driving University. This meant that Halmstad University's research and education, in addition to having high quality, should be characterized by stimulating creativity, innovation, and involvement and responsibility within the community and society – locally, regionally, and globally. Halmstad University also established two overarching profile areas to encourage multidisciplinary cooperation and further focus the research and education: Health Innovation (established 2014) and Smart Cities and Communities (established 2016).

The development of CAISR has been perfectly in line with the Halmstad University strategy and vision. The two focus application areas in CAISR where healthcare technology and intelligent vehicles (and machines), and CAISR emphasized both excellent applied research and value creation, in cooperation with their industrial partners. Not only were many CAISR publications published in the top publication channels 2012-2018, but CAISR researchers were also co-inventors on seven granted patents together with the industrial partners 2012-2018. Furthermore, a recent CAISR alumnus started a promising spin-off company from his Ph.D. research.

With these results, CAISR serves as an inspiration and model for the University's future research and education environments. The continued development looks very promising. CAISR is taking off in two directions: predictive maintenance for machines, and predictive maintenance for humans. The former through the recently granted CAISR+ project together with the majority of the Volvo Group companies, and the latter through cooperation with Region Halland and their center for information-driven care. The collaboration with Region Halland also involves other parts of the university; in health management, health economy, and healthcare implementation science. This broadening of CAISR to involve and engage more of Halmstad University's research is a very welcome development, and we expect the two CAISR directions to be fundaments in our two profile areas.

Catarina Coquand

Funding

The research turnover 2019 in CAISR was 27.4 MSEK (million Swedish kronor) on the university side (i.e., excluding industrial in-kind efforts). The industrial matching (in-kind) effort equaled 2.7 MSEK, and the total industrial matching to CAISR during the period 2012-2019 exceeds 50 MSEK[1].

For 2019, about 6.7 MSEK were direct research funds from Halmstad University; the remainder were external funds (mostly research grants but also some cash contributions from companies). Thus, CAISR had an external funding ratio of about 75%. The major part of the external funding comes from the Knowledge Foundation: 3.3 MSEK directly for the CAISR profile and about 7.6 MSEK for other projects funded by the Knowledge Foundation, giving a total of about 11 MSEK from the Knowledge Foundation. Another very important funder is Vinnova (Sweden's Innovation Agency) with roughly 7 MSEK. The sources of the different funds to CAISR (on the Halmstad University side) are illustrated in the pie diagram.

The growth of CAISR has been impressive. However, on the Halmstad University side, the economic development for CAISR has very well followed our plan drawn up in 2011, which shows how realistic we were. Building up CAISR has been an effort of almost 165 million kronor in research over eight years, counting the research funds on the university side. This has led to CAISR being quite visible in Sweden. Maintaining the relative strength in Sweden will, according to the DAMVAD review, require increasing the research volume in CAISR even more.

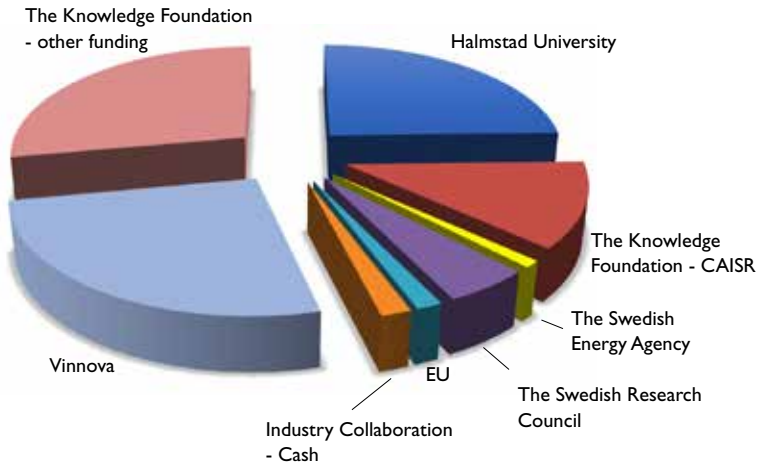
1 This only covers in-kind specifically to match the Knowledge Foundation CAISR funding. We have had other cooperation projects where the total in-kind has been at least 30 MSEK during 2012-2019, so the total in-kind contribution from companies during this period exceeds 80 MSEK.

Financer	Outcome 2019	Total 2012-2019
The Knowledge Foundation - CAISR	3 341 562	36 000 000
CAISR Industrial partners in-kind contribution[1]	2 706 058	50 403 570
Other external funding[2]	17 293 603	84 125 323
Halmstad University	6 724 283	43 588 250
Sum total	**30 065 506**	**214 869 502**

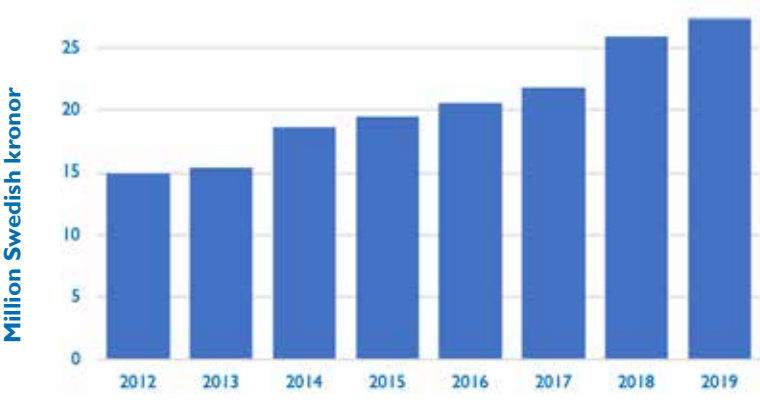
1 All in kind contributions have been computed using the standard tariff of 800 SEK per hour.

2 Funding from other sources (VR, EU, Vinnova, the Knowledge Foundation, companies,...)

Funding on the University side 2019



CAISR total research turnover



PhD Graduation

Hassan Mashad Nemati

Data analytics for weak spots detection in smart distribution grids

Abstract

This research aims to develop data-driven methods that extract information from the available data in distribution grids for detecting weak spots, including the components with degraded reliability and areas with power quality problems. The results enable power distribution companies to change from reactive maintenance to predictive maintenance by deriving benefits from available data. In particular, the data is exploited for three purposes: (a) failure pattern discovery, (b) reliability evaluation of power cables, and (c) analyzing and modeling propagation of power quality disturbances (PQDs) in low-voltage grids.

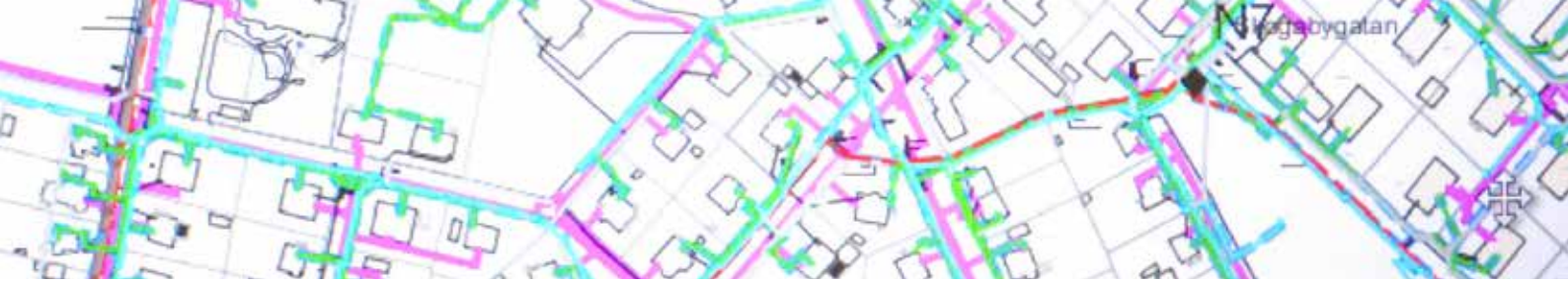
To analyze failure characteristics it is important to discover which failures share common features, e.g., if there are any types of failures that happen mostly in certain parts of the grid or at certain times. This analysis provides information about correlation between different features and identifying the most vulnerable components. In this case, we applied statistical analysis and association rules to discover failure patterns. Furthermore, we propose a visualization of the correlations between different factors representing failures by using an approximated Bayesian Network. We show that the Bayesian Network constructed based on the interesting rules of two items is a good approximation of the real dataset.

The main focus of reliability evaluation is on failure rate estimation and reliability ranking. In case of power cables, the limited amount of recorded events makes it difficult to perform failure rate modeling. Therefore, we propose a method for interpreting the results of goodness-of-fit measures with confidence intervals, estimated using synthetic data.

To perform reliability ranking of power cables, in addition to the age of cables, we consider other factors. Then, we use the proportional hazard model (PHM) to assess the impact of the factors and calculate the failure rate of each individual cable. In reliability evaluation, it is important to consider the fact that power cables are repairable components. We discuss that the conclusions about different factors in PHM and cables ranking will be misleading if one considers the cables as non-repairable components.

In low-voltage distribution grids, analyzing PQDs is important as we are moving towards smart grids with the next generation of producers and consumers. Installing Power Quality and Monitoring Systems (PQMS) at all the nodes in the network, for monitoring the impacts of the new consumer/producer, is prohibitively expensive. Instead, we demonstrate that power companies can utilize the available smart meters, which are widely deployed in the low-voltage grids, for monitoring power quality events and identifying areas with power quality problems. In particular, several models for propagation of PQDs, within neighbor customers in different levels of the grid topology, are investigated. The results show that meter data can be used to detect and describe propagation in low-voltage grids.

The developed methods of (a) failure pattern discovery are applied on data from Halmstad Energi och Miljö (HEM Nät), Öresundskraft, Göteborg Energy, and Växjö Energy, four different distribution system operators in Sweden. The developed methods of (b) reliability evaluation of power cables and (c) analyzing and modeling propagation of PQDs are applied on data from HEM Nät.



Research for **fewer power outages**

The results of his research enable power distribution companies to change from reactive to predictive maintenance. This reduces the risks of long outages annoying the customers as well as costly and time consuming repair actions for the distribution companies. Hassan Nemati has developed methods that can extract information from available data in smart distribution grids.

”The purpose of extracting information as early as possible from already available data is to detect weak spots in electricity distribution grids, e.g. areas with power quality problems. The results of my research enable power distribution companies to, at a larger scale, apply predictive maintenance of their distribution grids instead of costly and time consuming repairs”, says Hassan Nemati.

A reduced number of long outages is beneficial both to power distribution companies and their customers. Less vulnerable distribution grids are becoming increasingly important also at community level.

Large benefit to power companies

The aim of Hassan Nemati’s research project was to reduce the number and duration of electricity outages at the electricity grid at Halmstad Energi och Miljö AB (HEM), which is the electricity distribution company operating in and around Halmstad city.

”The method I proposed for failure pattern discovery got attention from other electricity distribution companies in Sweden such as Öresundskraft, Göteborg Energy, and Växjö Energy. These companies asked if I could analyze their data as well and, after receiving the outcomes, the companies claim that the results were very beneficial.”

Alexander Örning, Electrical Engineering alumnus from Halmstad University, has been one of Hassan Nemati’s supervisors at HEM. He says Hassan Nemati’s research has augmented the company’s perspective of the complex nature of its task. The research is also useful in developing the skill to sort data, both to see what kind of data the company needs more of – and what kind of data that are irrelevant.

”This will help us making better demands in the future. We also have a better insight as of how to develop our IT environment for the years to come. The IT environment is crucial in getting access to relevant measurements”, says Alexander Örning.

Research developed in sharp projects

Hassan Nemati started his postgraduate research studies in 2014. He has been a doctoral student at the Embedded and Intelligent Systems Industrial Graduate School (EISIGS), funded by The Knowledge Foundation, at Halmstad University. At EISIGS the postgraduate students work both at the University and at an industrial research partner. In Hassan Nemati’s case the research partner is HEM.

In his licentiate thesis from 2017, Hassan Nemati described how to estimate the reliability of underground power cables by using historical data and then rank the cables for prioritized maintenance actions.

Mining historical data in different fields

Hassan Nemati’s doctoral thesis focuses on the development of methods in three different areas. Estimating the reliability of underground power cables is one of them. Another one is fault analysis and failure pattern discovery, and the third is smart meter data analysis.

”Finding patterns in the failure records and summarising them with quantitative models is a step towards turning data into information and then information into knowledge. The results of this analysis facilitate reasoning about different features associated with faults and can be used by maintenance staff at distribution companies”, says Hassan Nemati.

PhD Defense facts
Title: Data analytics for weak spots detection in smart distribution grids
Author Hassan Mashad Nemati
Supervisors at Halmstad University Slawomir Nowaczyk and Anita Sant’Anna
Supervisors at Halmstad Energi och Miljö (HEM) Alexander Örning and Peter Addicksson
Opponent: Math Bollen, Luleå University of Technolgy
Grading committee: Anna Fensel, University of Innsbruck, Lina Bertling Tjernberg, KTH Royal Institute of Technology and Ulf Johansson, Jönköping University

Licentiate exam

Awais Ashfaq

Predicting clinical outcomes via machine learning on electronic health records

Abstract

The rising complexity in healthcare, exacerbated by an ageing population, results in ineffective decision-making, leading to detrimental effects on care quality and escalating care costs. Consequently, there is a need for smart decision support systems that can empower clinicians to make better informed care decisions. Decisions, which are not only based on general clinical knowledge and personal experience, but also rest on personalised and precise insights about future patient outcomes. A promising approach is to leverage the ongoing digitization of healthcare that generates unprecedented amounts of clinical data stored in Electronic Health Records (EHRs) and link it with modern Machine Learning (ML) toolsets for clinical decision support, and simultaneously expand the evidence base of medicine. As promising as it sounds, assimilating complete clinical data that provide a rich perspective of the patient's health state comes with a multitude of data-science challenges that impede efficient learning of ML models. This thesis primarily focuses on learning comprehensive patient representations from EHRs. The key challenges of heterogeneity and temporality in EHR data are addressed using human-derived features appended to contextual embeddings of clinical concepts and Long-Short-Term-Memory networks, respectively. The developed models are empirically evaluated in the context of predicting adverse clinical outcomes such as mortality or hospital readmissions. We also present evidence that, surprisingly, different ML models primarily designed for non-EHR analysis (like language processing and time-series prediction) can be combined and adapted into a single framework to efficiently represent EHR data and predict patient outcomes.

Markus Lingman, MD, PhD at Region Halland and Awais Ashfaq are working togehter in order to predict outcomes and demands of congestive heart failure (CHF) patients in Halland using machine learning.

Licentiate exam facts
Title
Predicting clinical outcomes via machine learning on electronic health records
Author
Awais Ashfaq
Supervisor
Slawomir Nowaczyk, Docent, Halmstad University
Opponent:
Jerker Westin, Docent, Dalarna University
Examiner:
Mark Dougherty, Professor, Halmstad University

Using **AI** to **individualize care** for heart patients in Halland

A growing elderly population puts great demands on our increasingly complex healthcare system. Ineffective decision-making can lead to a poorer quality of care for the patients, as well as escalating care costs. By using AI models based on clinical data from patients, doctors can be better informed about their patients and make fact-based and individual care decisions. Awais Ashfaq at Halmstad University is the AI researcher behind these models.

"There is a need for smart decision support systems that can empower clinician's to make better informed care decisions. Decisions, which are not only based on general clinical knowledge and personal experience, but also rest on personalised and precise insights about future patient outcomes", says Awais Ashfaq, a PhD student in Signals and Systems Engineering at Halmstad University who recently published his licentiate thesis "Predicting Clinical Outcomes via Machine Learning on Electronic Health Records".

Awais Ashfaq's research is part of a joint collaboration between Halmstad University and Region Halland with the aim to predict outcomes and demands of congestive heart failure (CHF) patients in Halland using machine learning.

What are your research conclusions so far?

"We developed models that leverage expert features from clinical knowledge and raw Electronic Health Record (EHR) data to predict adverse clinical outcomes such as 30-days post discharge mortality and unplanned hospital readmissions. We provide evidence that the predictive performances of the models are enhanced when data-driven knowledge is complemented with domain knowledge and experience from clinical experts. Accurate prediction models can support clinician's to make better informed care decisions about individual patients. We also exemplify the economic utility of the developed predictive models if targeted intervention plans are initiated for high-risk patients."

Has your research led to any changes in the care?

"The developed models have so far not been introduced in the real clinical workflow to support clinical decision making. It would first require a prospective validation study across several sites."

> *"Accurate prediction models can support clinician's to make better informed care decisions about individual patients."*
>
> *Awais Ashfaq*

Are there any surprising research findings that you can share?

"One of the many qualities of neural networks is their ability to generalize across multiple application domains. Different networks primarily designed for non-EHR analysis, for example language processing and time-series prediction, can be combined and adapted into a single framework to efficiently represent EHR data and predict patient outcomes. "

"In the coming years, we would like to answer the research question: What decides the outcome for a patient?". While the developed models can influence clinical decisions for good, they do not help us solve the root cause of adverse outcomes. This is because we are often unaware of what variables or groups of variables most affect the prediction score and how. Put differently, the goal is not limited to accurate prediction of adverse outcomes but also to facilitate restructuring of care delivery in a way that reduces the number of cases with adverse outcomes in the future.

Licentiate exam

Shiraz Farouq

Towards large-scale monitoring of operationally diverse thermal energy systems with data-driven techniques

Abstract

The core of many typical large-scale industrial infrastructures consists of hundreds or thousands of systems that are similar in their basic design and purpose. For instance, District Heating (DH) utilities rely on a large network of substations to deliver heat to their customers. Similarly, a factory may require a large fleet of specialized robots for manufacturing a certain product. Monitoring these systems is important for maintaining the overall efficiency of industrial operations by detecting various problems due to faults and misconfiguration. However, this can be challenging since a well-understood prior model for each system is rarely available. In most cases, each system in a fleet or network is fitted with a set of sensors to measure its state at different time intervals. Typically, a data-driven model for each system can be used for their monitoring. However, not all factors that can possibly influence the operations of each system in a fleet or network has an associated sensor. Moreover, sufficient instances of normal, atypical and faulty behavior are rarely available to train such a model. These issues can impede the effectiveness of a system level data-driven model. Alternatively, it can be assumed that since all the systems in a fleet or network are working on a similar task, they should all behave in a homogeneous manner. Any system that behaves differently from the majority is then considered as an outlier. This is referred to as the global model at the fleet or network level. While the approach is simple, it is less effective in the presence of non-stationary working conditions. Hence, both system level and global modeling approaches have their limitations.

This thesis investigates system level and fleet or network level (global) models for large-scale monitoring, and proposes an alternative way which is referred to as a reference-group based approach. Herein, the operational monitoring of each system, referred to as a target, is delegated to a reference-group, which consists of systems experiencing a comparable operating regime along with the target. Thus, the definition of a normal, atypical or faulty operational behavior in a target system is described relative to its reference-group. In this sense, if the target system is not behaving operationally in accordance with the systems in its reference-group, then it can be inferred that this is either due to a fault or because of some atypical operation arising at the target system due to its local peculiarities. The application area for these investigations is the large-scale operational monitoring of thermal energy systems: networks of district heating (DH) substations and fleets of heat pumps. The current findings indicate three advantages of a reference-group based approach. The first is that the reference operational behavior of any system in the fleet or network does not need to be predefined. The second is that it provides a basis for what a system's operational behavior should have been and what it is. In this respect, each system in the reference-group provides an evidence about a particular behavior during a particular time period. This can be very useful when the description of a normal, atypical and faulty operational behavior is not available. The third is that it can detect potential atypical and faulty operational behavior quicker compared to global models of outlier detection at the fleet or network level.

Research for more **efficient sustainable heating**

District heating is a sustainable alternative for heating households. In his recently published licentiate thesis from Halmstad University, doctoral student Shiraz Farouq presents data-driven methods for more cost-effective and climate friendly district heating networks.

District heating is one of the most sustainable and cost-effective methods of heating today. This is because it, to a large extent, reuses heat energy that would otherwise go wasted. Examples of such energy sources include excess heat from industries and combustion of domestic waste. However, such energy waste is expected to decrease in the future, both in quantity and content. This would leave district heating utilities with little room for any energy inefficiency, if they do not want to compromise their client's comfort. Thus, the challenge is to make the current district heating networks more energy efficient, and this is where Shiraz Farouq's research can make a difference.

Collected data creates a pattern

Today, ineffective and incorrect behaviour of substations in district heating networks leads to substantial energy losses. Shiraz Farouq has developed models for detecting such substations by identifying various patterns using state-of-the-art statistical and machine learning algorithms. One of these models is based on the idea of collective monitoring, where the behaviour of each substation in a network is tracked by a group of other similar substations. Any substation that does not behave in accordance with its tracking group provides a basis to suspect that something is wrong.

Shiraz Farouq's research will hopefully lead to more efficient ways of using district heating by quickly detecting energy inefficient substations. This contributes to increased sustainability, cost efficiency and the development of future smart cities. In that context, the research has a positive impact on the environment, economy and the society.
"My research will enable district heating utilities to use their renewable energy sources more efficiently", says Shiraz Farouq.

Collaboration with the heating industry

Shiraz Farouq's research is done in collaboration with the Swedish company Öresundskraft. It is also from Öresundskraft most of the data for the research comes. In addition to this collaboration, Shiraz Farouq has also received academic and technical assistance from the Department of Energy and Process Engineering at the Norwegian University of Science and Technology (NTNU).

"My research will enable district heating utilities to use their renewable energy sources efficiently."

In the future, Shiraz Farouq plans to continue his research towards a doctoral thesis. He wants to continue to improve the current diagnostic capacity in district heating. Right now, district heating utilities mostly rely on rule-based thresholds to detect energy inefficient substations. However, this practice usually leads to a large number of false alarms, which most district heating utilities find difficult to cope with, both administratively and technically.

"Today, the majority of diagnostic functions are created by human experts in a time-consuming and expensive manner. I will therefore continue my research on improving the efficiency of the district heating networks with the help of intelligent algorithms. In fact, this is also a requirement if we want to create future smart cities", says Shiraz Farouq.

Licentiate exam facts
Title Towards large-scale monitoring of operationally diverse thermal energy systems with data-driven techniques
Author Shiraz Farouq
Supervisor Stefan Byttner, Mohamed-Rafik Bouguelia and Slawomir Nowaczyk, Halmstad University
Opponent: Ulf Johansson, Professor, Jönköping University
Examiner: Mark Dougherty, Professor, Halmstad University

The Reference Group

The CAISR Reference Group serves the very important function of being our critical friends. The group is designed to represent different perspectives: international and national industry, as well as international and national academic research, related to intelligent aware systems. In addition, Halmstad University has one member in the group, and the group has a Chairman: Christer Fernström. CAISR owes a lot to his excellent chairmanship.

Throughout the period 2012-2019, the Reference Group members have reviewed the CAISR achievements and activities 1-2 times per year, a total of 11 meetings over eight years, providing advice and feedback on the progress. Each meeting is two days long, and the last meeting was in November 2019. We thank the Reference Group very much for the service they have done to CAISR.

The importance of the Reference Group cannot be overstated. The meetings with them are a sharp deadline when progress is reviewed and results are reported; this helps to ensure that the pace is kept and the focus remains. Their advice has been sharp, and the CAISR researchers have followed up and discussed how to deal with improvement steps in annual CAISR workshops.

The Reference Group members have varied a bit over the years, but we have always been lucky to get excellent people. Christer Fernström and Charlotta Falvin are two members who have been in the Reference Group throughout the eight years, and they provide a personal reflection on CAISR development on the next page.

Members (from left)

Catarina Coquand

University Director at Halmstad University. PhD in Computer Science. Former Dean for the Faculty of Technology and Society at Malmö University. Before that head of the Department for Computer Science and Engineering at Chalmers University of Technology and University of Gothenburg (a shared department).

Fredrik Heintz

Associate Professor of Computer Science at Linköping University. Director of the Graduate School for the Wallenberg AI, President of the Swedish AI Society (SAIS), and a member of the European Commission High-Level Expert Group on AI.

Misha Pavel

Professor at Northeastern University, Boston, Massachusetts. Joint faculty appointment at Khoury College of Computer Sciences and Bouvé College of Health Sciences.

Robert Evans

Senior software engineer at Google, Mountain View, California.

Christer Fernström

Director and consultant at Fernstrom et Associates in Grenoble, France. Founder and director of Tekomatik. Chairman for the Reference Group.

Charlotta Falvin

Chairman of the board for the Faculty of Engineering at Lund University, and for the Lund research park Ideon. Member of the board for several companies.

Christer Fernström

It was with great interest I first heard about the plans for CAISR around 2011. What had been referred to as the "AI Winter" was slowly coming to an end, and a more general interest in the various fields of AI was on the rise with topics like data mining and machine learning, which had matured over more than a decade in academia, now started to attract a lot of attention in various industries. The CAISR team had a solid scientific background and a long-standing working relationship with industry, especially in the automotive sector and had now built a coherent and well-articulated research agenda with challenging research goals of both academic and industrial interest. The newly established Health Technology Centre at the University also helped to create new opportunities in the health sector.

Becoming a successful research centre with national and international recognition involves a large number of diverse challenges, of which the ability to attract new researchers is essential. I think that CAISR has been very successful in this aspect. The senior research team has shown excellent leadership and I have been pleased to see how many junior researchers have matured and managed to establish themselves in the research community with good publication track records.

While the funding from the KK-foundation was crucial to creating a critical mass at CAISR, the longer-term objective was of course to build up a capacity to attract funding from many different sources. CAISR has also been quite successful in this aspect, and it is both my hope and my conviction that, despite the KK-profile funding now coming to an end, a bright future lies ahead for the centre.

Charlotta Falvin

As a member of the CAISR reference group since its inception, it has been a great pleasure to share the development from a small team looking for a purpose and direction, exploring its way forward with enthusiasm and determination, learning some lessons the hard way and others smoothly, into a highly professional research group with well founded self-confidence and a clear view of its position in the universe of aware intelligent systems. With my primarily industrial background, I have particularly appreciated the efforts to collaborate with relevant industry partners and to build an entrepreneurial culture that has paid of both in terms of patents, formation of start-ups and co-production of valuable knowledge together with multinational corporations engaged in the project.

Over the years, as PhDs and professors have come and gone, much as the regular academic flow prescribes, I have greatly enjoyed getting to know such a wonderfully diverse team in terms of age, gender, personalities and ethnic background, all united by a common passion for intelligent systems and their applications in the real world. Jointly, these individuals have not only produced research results, papers and graduates, but also built a structure that will continue its contributions in this field, adding value, insight and solutions for society within a field that will most certainly grow in importance.

I look much forward to continue from a distance following the output from the CAISR program, and I take great pride in having been a part, albeit very small, in its construction.

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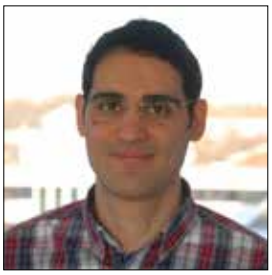

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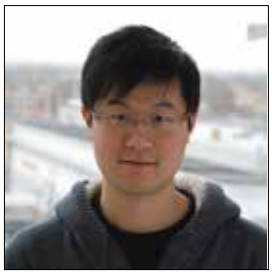

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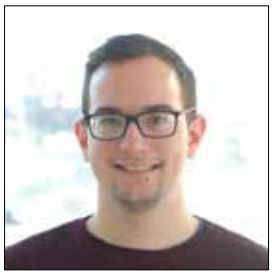

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CAISR Publications 2012–2019

JOURNAL PAPERS

2019

Abiri, N., Linse, B., Edén, P., & Ohlsson, M. (2019). Establishing strong imputation performance of a denoising autoencoder in a wide range of missing data problems. Neurocomputing, 365, 137-146. https://doi.org/10.1016/j.neucom.2019.07.065

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Pejner, M. N., de Morais, W. O., Lundström, J., Laurell, H., & Skärsäter, I. (2019). A Smart Home System for Information Sharing, Health Assessments, and Medication Self-Management for Older People: Protocol for a Mixed-Methods Study. JMIR research protocols, 8(4), e12447. https://doi.org/10.2196/12447

Miyasaka, H., Takeda, K., Ohnishi, H., Orand, A., & Sonoda, S. (2019). Effect of Sensory Loss on Improvements of Upper-Limb Paralysis Through Robot-Assisted Training: A Preliminary Case Series Study. Applied Sciences, 9(18), 3925. https://doi.org/10.3390/app9183925

Zarzoura, M., del Moral, P., Awad, M. I., & Tolbah, F. A. (2019). Investigation into reducing anthropomorphic hand degrees of freedom while maintaining human hand grasping functions. Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine, 233(2), 279-292. https://doi.org/10.1177/0954411918819114

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Ribeiro, E., Uhl, A., and Alonso-Fernandez, F. (2018) "Iris Super-Resolution using CNNs: is Photo-Realism Important to Iris Recognition?", IET Biometrics, Volume 8, Issue 1, January 2019, p. 69-78 (digital publication 2018).

Alonso-Fernandez, F., Farrugia, R.A., Bigun, J, Fierrez, J., and Gonzalez-Sosa, E. (2018), "A Survey of Super-Resolution in Iris Biometrics with Evaluation of Dictionary-Learning", IEEE Access, vol. 7, pp. 6519-6544, 2019. doi: 10.1109/ACCESS.2018.2889395 (digital publication 2018)

Krish, R.P., Fierrez, J., Ramos, D., Alonso-Fernandez, F., and Bigun, J. (2018), "Improving Automated Latent Fingerprint Identification using Extended Feature Sets", Information Fusion, Volume 50, p. 9-19, 2019. ISSN 1566-2535. doi: 10.1016/j.inffus.2018.10.001 (digital publication 2018)

Medved, D., Ohlsson, M., Höglund, P., Andersson, B., Nugues, P., and Nilsson, J. (2018), "Improving prediction of heart transplantation outcome using deep learning techniques", Scientific Reports 8, 3613 (2018)

Gholami Shahbandi, S., & Magnusson, M. (2018). 2D Map Alignment with Region Decomposition. Autonomous Robots. Epub ahead of print. https://doi.org/10.1007/s10514-018-9785-7

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Bouguelia, M.-R., Nowaczyk, S., & Payberah, A. H. (2018). An adaptive algorithm for anomaly and novelty detection in evolving data streams. Data Mining and Knowledge Discovery, 32(6), 1597–1633. https://doi.org/10.1007/s10618-018-0571-0

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Rimavicius, T., Gelžinis, A., Verikas, A., Vaiciukynas, E., Bacauskiene, M., & Šaškov, A. (2018). Automatic benthic imagery recognition using a hierarchical two-stage approach. Signal, Image and Video Processing, 12(6), 1107–1114. https://doi.org/10.1007/s11760-018-1262-4

Rothfuss, J., Ferreira, F., Aksoy, E., Zhou, Y., & Asfour, T. (2018). Deep Episodic Memory?: Encoding, Recalling, and Predicting Episodic Experiences for Robot Action Execution. IEEE Robotics and Automation Letters, 3(4), 4007–4014. https://doi.org/10.1109/LRA.2018.2860057

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Gonzalez-Sosa, E., Fierrez, J., Vera-Rodriguez, R., & Alonso-Fernandez, F. (2018). Facial Soft Biometrics for Recognition in the Wild?: Recent Works, Annotation and Evaluation. IEEE Transactions on Information Forensics and Security, 13(8), 2001–2014. https://doi.org/10.1109/TIFS.2018.2807791

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Muhammad, N., & Åstrand, B. (2018). Intention Estimation Using Set of Reference Trajectories as Behaviour Model. Sensors, 18(12). https://doi.org/10.3390/s18124423

Vaiciukynas, E., Ulicný, M., Pashami, S., & Nowaczyk, S. (2018). Learning Low-Dimensional Representation of Bivariate Histogram Data. IEEE Transactions on Intelligent Transportation Systems (Print), 19(11), 3723–3735. https://doi.org/10.1109/TITS.2018.2865103

Bouguelia, M.-R., Karlsson, A., Pashami, S., Nowaczyk, S., & Holst, A. (2018). Mode tracking using multiple data streams. Information Fusion, 43, 33–46. https://doi.org/10.1016/j.inffus.2017.11.011

Rosenstatter, T., & Englund, C. (2018). Modelling the Level of Trust in a Cooperative Automated Vehicle Control System. IEEE Transactions on Intelligent Transportation Systems (Print), 19(4), 1237–1247. https://doi.org/10.1109/TITS.2017.2749962

Gholami Shahbandi, S., Magnusson, M., & Iagnemma, K. (2018). Nonlinear Optimization of Multimodal Two-Dimensional Map Alignment with Application to Prior Knowledge Transfer. IEEE Robotics and Automation Letters, 3(3), 2040–2047. https://doi.org/10.1109/LRA.2018.2806439

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Calikus, E., Nowaczyk, S., Pinheiro Sant'Anna, A., & Byttner, S. (2018). Ranking Abnormal Substations by Power Signature Dispersion. Energy Procedia, 149, 345–353. https://doi.org/10.1016/j.egypro.2018.08.198

Rögnvaldsson, T., Nowaczyk, S., Byttner, S., Prytz, R., & Svensson, M. (2018). Self-monitoring for maintenance of vehicle fleets. Data Mining and Knowledge Discovery, 32(2), 344–384. https://doi.org/10.1007/s10618-017-0538-6

Mashad Nemati, H., Laso, A., Manana, M., Pinheiro Sant'Anna, A., & Nowaczyk, S. (2018). Stream Data Cleaning for Dynamic Line Rating Application. Energies, 11(8).

Parker, J., & Lundgren, L. (2018). Surfing the Waves of the CMJ?: Are There between-Sport Differences in the Waveform Data? Sports, 6(4), 1–12. https://doi.org/10.3390/sports6040168

Aramrattana, M., Detournay, J., Englund, C., Frimodig, V., Jansson, O. U., Larsson, T., Mostowski, W., Rodríguez, V.D., Rosenstatter, T., and Shahanoor, G. (2018). Team Halmstad Approach to Cooperative Driving in the Grand Cooperative Driving Challenge 2016. IEEE Transactions on Intelligent Transportation Systems (Print), 19(4), 1248–1261. https://doi.org/10.1109/TITS.2017.2752359

2017

Andersson, J., Habibovic, A., Klingegård, M., Englund, C. & Malmsten-Lundgren, V. (2017). Hello human, can you read my mind? ERCIM News. Sophia Antipolis Cedex: European Research Consortium for Informatics and Mathematics (ERCIM). Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:hh:diva-35488

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Knowledge Foundation

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.

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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