Development Plan

KTH School of Electrical Engineering and Computer Science 2018 – 2023

Revised version, July 10, 2020

Table of contents

0 Preface

The School of Electrical Engineering and Computer Science (EECS) was recently formed by merging the schools of Electrical Engineering (EES), Computer Science and Communication (CSC) and Information and Communication Technology (ICT). Digital transformation and sustainable energy are rightfully buzzwords on everybody's lips these days, and the strengths of our new School such as Information Technology, Electronics and Energy are right at the heart of these developments. The school merger provides excellent possibilities to form even stronger and unified research, and educational programmes in these areas that are of utmost importance to our country and planet.

The School of EECS stands strong on the international research arena, with top-100 ranking positions both in Electrical and Electronic Engineering as well as in Computer Science and Information Systems. The competition is fierce, though, and this development plan outlines strategies and activities to maintain and improve our positions.

The merger also provides an opportunity to reshape our educational programmes to meet the requirements of the future. Our investigation 'Curriculum 2025' addresses these issues. From having recruited most of our undergraduate and master students locally, EECS has been, since the last decade, more and more exposed to international competition. Excellence in education will thus be even more important in the future.

This development plan has two parts. The first part describes the changes in the surrounding world and discusses the continued relevance of our School (Chapter 1), outlines the School vision and shared values (Chapter 2) and finally provides some overarching strategies and measures to be used to quantify our success (Chapter 3). The second part of the document describes operational strategies and specific planned activities in the areas of education (Chapter 4) and departments (Chapter 5). Chapter 6 outlines EECS's organisational development. In chapter 7, we describe our professional support, while the final two chapters address our work environment and sustainability issues.

Welcome to EECS!

Professor Jens Zander Head of School

School of Electrical Engineering and Computer Science (EECS)

1 Introduction

This introduction is split into three parts. Section 1.1 presents the new School. Section 1.2 describes the outlook for the new School. Finally, section 1.3 places the School in the context of the university.

1.1 A new school

The School of Electrical Engineering and Computer Science (EECS) is the largest of KTH's 5 schools, with almost 1,000 employees (including employed doctoral students), around 2,700 students and a 1.1 BSEK annual turnover. It was formed in 2018 by combining the Schools of Computer Science and Communication (CSC), Electrical Engineering (EES) and Information and Communication Technology (ICT). The merged School encompasses a wide range of science and engineering subjects, from Electro Physics, via Low and High Power Electronics, Electric Power Systems, Communication Networks, Autonomous Systems, Data Science to Software Engineering (to name a few of the topics covered).

EECS offers academic activities at all levels in the fields of Computer Science and Electrical Engineering.

In this environment, EECS and its research partners conduct world-leading research, particularly in the areas of Electrical Power Engineering, Autonomous Systems, Social Robotics, Cloud Computing and Communication and Human Computer Interaction. The School's successful research has been internationally recognised. In subject-based university rankings, KTH has consistently ranked among the top 30 universities in the world in Electrical & Electronic Engineering and the top 100 in Computer Science and Information Systems.

The School is responsible for 22 educational programmes, both at the basic (1st cycle) level and the advanced (2nd cycle) levels. Moreover, these programmes are well connected to research and range from general engineering programmes in EE and CS to specialised Master's programmes in topics ranging from Electromagnetics, Embedded Systems, Communication System, Robotics, Machine Learning, Interactive Media Technology to Computer Science and Software Engineering.

Research is coupled with several successful doctoral programmes. Enrolling approximately 500 doctoral students, EECS is KTH's largest supplier of doctoral graduatesto Swedish society at KTH, with more than 80 graduates per year going into industry and academia.

The School has two main locations: the KTH main campus at Valhallavägen, where most of the staff and students work, and the Electrum campus, located in the middle of Kista, one of the leading industrial ICT clusters in the world. Kista is home to many of Sweden's IT-related companies (including Ericsson's headquarters) and research institutes, employing more than 10,000 engineers and researchers.

The School is responsible for two of KTH's largest research infrastructures. The first is the PDC – Centre for High-Performance Computing – which hosts what was until recently the most potent supercomputer in Sweden, the Beskow Cray XC40 machine, with a peak performance of 2.5 petaflops. In 2020, Beskow will reach end of life, and a new supercomputer is being procured to be put in operation during 2021.

EECS is also home to the Electrum Laboratory, one of Europe's most advanced cleanroom and semiconductor research facilities. This facility provides excellent environments not only for experimental research but also for the fabrication of prototypes and small runs of products and components. The school also hosts three additional KTH infrastructures, the Visualisation Studio (VIC), the Sustainable Power Lab (SPL) and the Talbanken database for voice recognition studies.

1.2 Outlook and continued relevance

The ongoing digitalisation of industry and society has the potential to create tremendous value. The lion's share of productivity increases in industry, and most of the increased quality of living in society, can be directly attributed to the digital transformation of businesses. However, at the same time this raises some of the largest scientific and technological challenges of our time. After the introduction of the mobile internet, ubiquitous sensing and cloud computing, cyber-physical systems (CPS) have now the potential of taking digitalisation to the next level. In these systems, the cyber infrastructure is tightly integrated with the physical environment through sensors and actuators. The 'things' around us will not only be monitored but also controlled in order to create benefits for society through improved efficiency, lower energy consumption and safer environments.

In parallel to this digital development, the global community has started to transform energy systems to a sustainable state. In regions all over the world, government policies and industry investments are turning away from fossil fuels to embrace renewable energy sources such as wind and solar power. The world is experiencing an energy revolution – this time focused on providing an energy-thirsty society with clean and reliable electricity from non-fossil sources that cannot be directly controlled (e.g., wind and solar energy sources). From a situation where the generation of electricity has adapted to meet demand from industry and society, we are moving towards a situation where demand must be flexible and based on the availability of energy generated from renewable sources. The same transition is taking place in the transportation sector, where fossil fuel vehicles are more and more questioned and the electric vehicle fleet is growing steadily.

The main challenge in the decade to come will be to apply technology, both digital and renewable, not just to the current handful of exclusive, high-value applications but also make it affordable and usable at a societal scale. EECS is uniquely situated to contribute to both of these revolutions. We need to create technologies that are scalable so they can be used everywhere and so everyone can benefit from them. What happens when billions and billions of users and 'things' communicate, compute and store information? How can this be used to manage energy needs and enable the necessary flexibility in energy use? Can we trust and rely on extremely large software systems? Can these planet-scale digital systems, perhaps what is needed to save the planet? Security as well as environmental and sustainability issues are taken into account in EECS research, as long with the possibilities and problems related to digitalisation in environmental and sustainability contexts. At the same time, almost 55000 technical staff at affiliates of the Association of Swedish Engineering Industries ("Teknikföretagen") will retire between 2016 and 2025. This could create a shortage of skills to fuel the growth of Swedish companies.

EECS has breadth in CS and EE, which offers unique opportunities to create knowledge and prepare its students for a sustainable digital future. Our research advances allow us to truly explore the enormous economic, environmental and social potential of 'smart societies'. They will contribute significantly to the vision of an autonomous transport system with electric vehicles communicating with each other and the infrastructure, a smart energy grid with a high penetration of renewable energy and flexible loads and the growing need for home healthcare for elderly. Our advances may also lead to completely new business opportunities and areas that are unknown today, similar to what we see happening with our earlier contributions to the mobile communication industry.

Because ICT is pervasive technology, it is hard to distinguish advances within the field itself from advances in those areas where ICT is being applied, such as energy and transportation. This has also caused the funding landscape to change. Computer science and electrical engineering are not distinct, separate disciplines in current governmental research funding nor in the European Commission's long-term work plans (Horizon 2020). One consequence is that less funding is likely to go to specific technology projects; rather, more funding is going to large, multidisciplinary endeavours such as the 'Digital Transformation of Society', where Electrical Engineering and Computer Science are critical components of the solution - but not necessarily the entire solution.

Research excellence is today mainly measured by bibliometric parameters that are primarily tailored to meet the demands of the natural sciences. One trend is that research output and societal/industry impact (rather than success in getting funding) will play a larger role in assessments in the future.

Increasingly, innovation has a critical role in funding decisions. Most funders of research (including the traditional Science Councils, e.g. VR) are looking for direct evidence of societal benefits from research results.

Despite strong recruiting efforts and a recent positive trend, Sweden as a country is incapable of providing sufficient talent to fill the needs of its still-growing domestic IT sector. The introduction of tuition fees and other barriers has hampered student recruitment in the past, but we are now making good progress in attracting more and more paying students. Our graduates are in high demand in the industry. Many are hired prior to graduation, which might be positive for society, but which has a negative impact on the throughput statistics of degree programmes.

Increasingly, universities are global actors that are actively promoting and exploiting their brands. Providing educational material online has been an important marketing strategy for well-known universities. Their goal is to increase visibility, attract students and improve their rankings. The increased availability of online educational material does not directly replace current education formats but will most likely transform it.

The support for the 'IT and Mobile Communications' area that was previously channelled through our Strategic Research area – ICT: The Next Generation – has been substantially increased. In addition, a new, KTH-wide centre/strategic area called 'KTH Digital Futures' has been formed. The centre is hosted by the EECS, and with its additional 78 MSEK/year in permanent faculty funding it provides significant new opportunities for collaborative projects, recruitment of top talent and exploration of new research fields.

1.3 The School's contribution to 'A leading KTH'

KTH has set a number of overarching visions for the 2018-2023 period in its development plan, titled 'A leading KTH'. The School of EECS will address these goals and provide the following contributions:

'A leading KTH'

In research, education and collaboration. The School seeks to further improve its research. Top-notch faculty, high international visibility and a clear demonstration of the impact our work will be of key importance. The School will reform its educational programmes in order to graduate top-level engineers who are ready to lead the digital transformation of society. Using the latest technologies to create successful learning environments is part of our creed.

'An integrated KTH'

The School creates a new organisational structure aimed at subject-wise organisation in order to better integrate research and education. In addition, operational processes are being streamlined to offer high-quality professional support to faculty and students alike.

'A visible KTH'

The School seeks to actively enhance KTH's brand recognition and university ranking in the areas that EECS covers. We also seek to create a significant and visible impact in industry and society.

'An open KTH'

The School will further strengthen collaboration with industry and research institutes by involving industry at the undergraduate level. The student environment at EECS should be characterised by creativity and sustainability. Open maker spaces attract students, and prospective students play an important role in this.

‘A KTH for a more digitalised world’

E-learning is a natural tool in EECS’s educational programmes. We will further improve our teaching methods and increase the use of top-tier online material. We will also selectively produce online material that can strengthen the KTH brand.

‘A KTH for a more sustainable world’

EECS covers sustainability development goals in a wide range of topics from energy supply to human-computer interaction in education, research and in collaboration with surrounding society.

‘A KTH in a global world’

EECS conducts many international collaboration projects through its many internationally recognised research groups. Our faculty recruitment occurs almost exclusively on the international scene in a highly competitive environment. In many groups, English is the working language, and the School has a bilingual policy. Our international student recruitment is strong and leads KTH in the recruitment of paying students.

‘An equal-opportunities KTH’

Further increasing the number of women among faculty and students is one of the school’s targets. Specific strategies are discussed in our faculty development plan and in section 4 on student recruitment. Equal opportunity is the baseline for the education and research that takes place at EECS.

2 Vision and core values

2.1 Vision 2023

In 2023, KTH School of Electrical Engineering and Computer Science will be the premiere research, education and innovation environment in the area of EE and CS in Sweden and one of the leading environments in Europe.

In 2023, the educational and scientific areas within the School of EECS will be of the utmost importance to our society, both locally and globally. The education at all levels will:

- be of the highest international quality,
- attract national and international students,
- attract a higher ratio of female students,
- attract a higher ratio of paying students,
- address important societal needs,
- be strongly integrated with our research and make full use of the faculty's areas of expertise,
- handle administrative processes even more efficiently.

EECS education will empower students with skills to improve society by designing, building and implementing electrical engineering and computer science technologies. The education will be broad and will include topics that serve as catalysts for change in industry and society, such as globalisation i.e. globalisation, digitalisation, sustainability and equality. Within these we will teach our students:

- basic mathematical, scientific and technical skills of engineering,
- current and upcoming technologies in EE and CS in areas where the teachers are scientific leaders, e.g., Communication, Intelligent Systems, Electronics, Energy Systems, Electrical Machines, Micro and Nano Systems, Interactive Systems and Computer Science,
- generic skills, including complex problem solving, creativity, ethical awareness, collaboration, leadership, abilities for life-long learning, and how to address openly formulated problems based on critical thinking and using scientific methodology,
- to understand and utilise current catalysts for change in industry and society, such as globalisation, digitalisation, sustainability and equality.

The domains that EECS encompasses change rapidly, and our students need to be able to learn new competencies and be open to life-long learning.

- The research quality of all divisions will be at the highest international level.
- We will study fundamental and relevant questions in our specific fields.
- We will publish in journals and conferences of the highest standard in our fields.
- We will be recognised leaders in our fields: the school's researchers will be highly visible and in demand as experts, as participants in multidisciplinary research programmes, as invited speakers; they will offer tutorials at international conferences and will serve on conference programme committees and as reviewers.
- Our impact on industry and society will be strong, and we will be highly visible. Innovation will play an important role in our research output. Researchers and students will start spin-offs on a regular basis, and entrepreneurship will be held in high regard.

The research environment at the School is dynamic and attractive to visitors and doctoral students. Guest researchers and post-docs will invigorate the research environment, create international bonds and form an important base for recruitment to faculty positions.

The EECS Professional Support is efficient, transparent and offers close-to-operations service. The division is a role model at KTH both when it comes to working environment and its outreach and cooperation. As with their academic colleagues, administrative staff will be encouraged to continuously develop their skills, improve the efficiency of the organisation and tackle new tasks.

2.2 Core values

KTH's shared values are democracy, equality and free and open discussion. KTH should contribute to a society characterised by peaceful co-existence – a society that is environmentally, economically and socially sustainable. In addition, EECS will promote the following:

Striving for excellence in all activities

KTH aspires to be a world leader in research and education. As a consequence, all activities in these areas must be of the highest quality in the international context – we always strive to attract the best faculty, we collaborate with internationally leading research groups, we publish in the top journals and conferences in the field, we use the best educational materials and teaching methods and we use the best administrative tools and routines. The common paradigm of 'not invented here' does not apply at EECS.

Contributing to the environment and the KTH brand

We expect all permanent faculty to actively contribute to the development of the School, sharing their enthusiasm in order to create a stimulating local environment and enhance the KTH brand. Visibility and actively working to build research groups, developing and conducting education and making a visible impact on society are seen as valuable contributions and are encouraged.

Promoting ethics in research and education

The School employs the highest standards in research ethics and expects the same from its students. We have zero tolerance for plagiarism, cheating and other forms of unethical behaviour.

Embracing diversity

EECS is a kaleidoscope of nationalities and ethnic groups, both men and women. This mixture is a natural consequence of looking for excellence in recruitment. We openly advertise our positions on the international level to attract the best possible candidates for our academic positions. Search committees are assembled for each new position. Their task is to actively search out top researchers appropriate for the announced positions, providing equal opportunities regardless of gender and origin.

An attractive workplace – a sustainable faculty

EECS should strive to provide good working conditions for all employees in all categories and stable base funding for our faculty.

Transparent and rule-based management

All important decisions at the School should be based on widely agreed and communicated rules in order to ensure predictable outcomes. Decisions should be well motivated and openly communicated.

3 Strategies and key performance indicators

3.1 Visibility and promoting the KTH brand

In external communication, besides one's own research group, the focus should be on promoting the KTH brand. This is of mutual benefit to all KTH faculty and researchers. The School as an internal organisation, will play an increasingly more limited role to outside observers. Most research areas at our school are already recognised as world leaders in the scientific community. However, many research groups still need to improve their impact on society, while others need to improve their scientific impact in terms of bibliometric performance. Many research groups perceive themselves as strong in applied science, innovation and industrial/societal impact but fail to deliver their message in research assessments. Our analysis shows that we do have a significant impact, but we have not been very good at demonstrating it. We must improve the visibility of our research output – not only in the form of publications but also in the form of research impact and innovations. In addition to traditional channels for scientific announcements, we should make extensive use of websites, the 'popular science' press, TV and radio. We need to change our traditional focus from only reporting when funding, grants, and so on are received (input) to reporting when important and useful results are achieved (output). Since industrial impact is a significant strength of many of our research groups, we should also establish a better way to assess research and innovation impacts for future research assessments.

3.2 Integrating research and education

In order to fully benefit from the top-notch international research that is conducted at the School, education has to be better integrated with our research programmes. Today, student interaction with researchers may in some cases occur first in during the student's master's thesis project, if at all (if the student chooses to conduct the project in industry). The School will aim to involve more students in research earlier in their programmes of studies, such as through bachelor's thesis projects, research-related project courses and research internships. We also expect the active involvement of research leaders and full professors in courses in the early parts of our programmes. In the long run, our educational programmes must reasonably match the research profiles and competences of our faculty such that our courses can be staffed using our faculty.

3.3 Research management

Shaping the research and education portfolio of the future

It is important for the School to determine and develop new areas for research, which in turn will lead to new educational subjects and courses. Which areas to develop and which to close down, cannot solely be a school management issue. This process must be driven from "below" by the divisions, by research teams and individual researchers that put forward proposals. The mechanisms that can be used are

Strategic initiatives

- Each year the departments and divisions are invited to propose strategic initiatives. Strategic initiatives funded by the School should in general benefit the School as a whole, and not only specific divisions or research groups. Strategic initiatives for specific departments and research groups and divisions can be funded by department or division equity ("myndighetskapital", MK).

Strategic positions

- In the school's reorganisation phase, 3-4 start-up grants have been available for assistant professors in strategic areas to revitalise and bind together divisions and research groups out of different existing schools and research environments. A majority of new positions will be opened at the assistant professor level, targeting broad research topics, in order to attract as much top talent as possible. Research profiles will not be dictated in a detailed manner.

3.3.1 Proactive research management

Researchers, research groups and divisions are encouraged not only to participate in project phases but also to engage in research programme design activities. This includes but is not limited to international research platforms, research agendas and consultation activities. The aim is to volunteer our expertise to influence research programmes during their design phases. As research programmes tend to be more application-oriented rather than focused by discipline, it is of critical importance that our EECS-related subjects become integral and important parts of these future programmes.

3.4 Faculty recruitment

Our faculty is one of our most important assets, and recruitment is probably the most important strategic task for a university striving to be an international leader. Faculty recruitment should be driven by the teaching needs of our programmes within the context of our departments. Newly recruited junior faculty should receive attractive start-up packages. Department MK can be used to partially finance those parts of the start-up package that are related to the pedagogic development of the faculty. In areas where the teacher shortage is significant and where this problem cannot be resolved by internal redistribution of teaching assignments, the School or department may provide additional start-up funding for junior faculty to support the divisions and departments. To provide sustainable funding for faculty, i.e. so that all faculty is funded from the basic funding within education and research – the faculty is not expected to grow from the present size of approximately 215 individuals in the coming period. Exceptions are those areas with substantial needs in first- and second-cycle education and retirements of faculty in strategic subjects for the School are anticipated.

The School's recruitment efforts target top talent. The question that needs to be answered in every faculty hiring instance is 'can this person add to our competence and improve the position of KTH?' If the answer is no, we should refrain from hiring. The School needs to employ active search committees to find the best possible candidates on the international market. The goal is to have at least 10 candidates for each faculty position, of which the majority should be international candidates. Proactive measures to attract more female candidates are to be taken. Candidates must have teaching experience in relation to what can be expected at the level of the position, that is related to our educational programmes is seen as required. Ability to teach first-cycle and basic second-cycle courses will be an important criterion for new recruitments.

3.5 Faculty development

The School employs deliberate career planning and mentoring for junior faculty and for aspiring tenured researchers, according to the KTH Future Faculty programme. Career planning and coaching efforts are also mandatory for post-docs in order to make such positions attractive to researchers with academic career ambitions. The school is also working hard to make conditions for junior faculty equal across the school and to provide clarity and transparency in requirements for promotion. This is done both by creating lists of good practices and examples and by educating division heads and other managers in career coaching, including aspects of gender equality.

The School encourages and may provide co-funding to host top-notch visiting senior researchers.

In the long term, all teachers at the School will participate in some form of university teaching that addresses environmental issues and sustainable development. This will, in the longer term, be a condition for career advancement at the School.

Promotion to associate professor (*lektor*) is seen as the target for all assistant professors, and they are coached in this process. Appointment to 'docent' is encouraged for all full-time faculty, with a focus on those research areas with a shortage of main advisors for doctoral students.

The school endorses promotion to full professor only for candidates that effectively drive their own independent research agenda: e.g., those who already manage research groups of several researchers, post-docs and doctoral students. Such individuals shall have demonstrated that they are able to sustain themselves over several years – beyond isolated project funding. There should be a clear need for promotion: e.g., that the candidate is opening a new research area that is sufficiently distinct from the area of the parent group. Candidates should also have taken an active part in administration, development and/or operation of first-cycle, second-cycle and third-cycle educational programmes.

3.6 Resource allocation

In the longer term, the school's ambition is that government allocation of resources for research (FoFU) and education (GRU) will cover the costs of all employed faculty. Due to the expansion of the university sector the recent years and prior principles for resource allocation, we are not at this stage yet. One important step towards this goal is fair and transparent principles for the allocation of resources that support achieving the goals outlined in this development plan. It is also important that the allocation of resources for research and education be well-coordinated and predictable over a number of years.

Allocation of resources for research, which goes to the division level, is based on two principles: first, a basic allocation related to the number and seniority of the faculty at the division; and second, an incentive-based principle which allocates resource in relation to the divisions' success in attracting external funds. These two principles are in line with the allocation models used at KTH and will be the basis for the model within EECS.

Allocation of resources for education (GRU), which goes to the department level, is based on the following principles: course reimbursement for the department should be performance-oriented (HST/HPR) and follow a transparent and easy-to-understand standardised cost-sharing model for division fees. A majority of GRU funds will be allocated to departments, while a small part will be maintained at the school level for development and joint ventures (GA, PA), programme development and pedagogical development. All course responsible teachers should have the required 15 hp of pedagogical courses. Full funding of costs will be received by the divisions in charge of a course when the course analyses are presented online.

3.7 Outreach, cooperation and impact

It is important to leverage the possibilities for collaboration with RISE (Research Institutes of Sweden), and in particular RISE-SICS (formerly the Swedish Institute of Computer Science). There is a long tradition of collaboration with SICS, with several of the School faculty currently holding part-time positions at SICS, and numerous doctoral students who have been involved in projects at SICS over many years. This collaboration is now being intensified by exploring new organisational structures similar to those found in the German Fraunhofer institutes. Such a model would simplify joint research projects and staff mobility between KTH and RISE-SICS.

Whereas collaboration with actors in the local research environment is already substantial, the School plans to leverage its contacts in the education domain as well. This involves collaboration in undergraduate and master programmes, not only at the strategic (programme content) level but also in the practical execution of courses. The involvement of industry in master thesis projects, which is already a strength, needs to be extended into all facets of undergraduate and master programmes: e.g., bachelor theses, project courses, motivational guest lectures, and so on.

3.8 Benchmarking and key performance indicators

The School of EECS will compare its performance with similar schools and departments at our closest international competitors – universities that have similar economies and similar subject rankings and with whom KTH already has agreements and good relations. The following universities have been chosen for benchmarking (figures in parentheses are QS subject rankings in Electrical & Electronic Engineering and Computer Science 2018/**2020**).

- Delft University (32/**16** EEE, 51-100/**51-100** CS)
- Technical University of Munich (37/**20** EEE, 42/**36** CS)
- University College London (32/**17** CS, 51-100/**48** EEE)
- KAIST – Korea Advanced Institute of Science and Technology (17/**17** EEE, 34/**36** CS)
- University of Illinois at Urbana-Champaign (22/**25** EEE, 28/**33** CS)

As a reference, KTH ranged 28/**17** in EEE and 51-100/**43** in CS. In subsequent revisions and follow-ups of the development plan, the development of ranking parameters, as well as relative strengths and weaknesses of these schools and universities in relation to the EECS, will be monitored.

3.8.1 Key performance indicators

EECS will include the performance indicators developed by the Swedish Research Council (VR) together with the Swedish Higher Education Authority (UKÄ) amongst its chosen key indicators. All indicators will be monitored at subsequent revisions of the development plan to spot improvements made.

Indicators: Research quality

- Number of highly cited publications: 106/12% top 10 cited publication, 283/37% in top 20% impact journals
- Proportion of funding from EU: 8% (2019)
- QS subject-wise university ranking in Electrical & Electronic Engineering/ Computer Science: 17/28

Indicators: Interaction with/impact on society

- Financial contributions from society **8% (2019)**
- Number of collaborating companies with innovation activities: **7** (2018-2019)
- Number of adjunct/affiliated professors, faculty **8/11** (2020)
- Number of industrial doctoral students **63/430 15%** (2020)
- Number of joint publications with industry/society **324/18%** (2016-2018)
- Number of open-access publications **521/46% (2018)**
- Number of participants in impact-related seminars and courses 250 (2019 estimate)
- Number of developed impact cases **23** (2018-2109)

Education-related KPIs

- Number of applicants/place 2019

Program	Number of applicants/place
CDATE	11.7
CELTE	12.0
CINTE	14.8
CMETE	10.8

- Throughput in civ ing programmes

Program	Andel avklarade	Andel Ej avklarade
CDATE	0.62	0.38
CELTE	0.55	0.45
CINTE	0.66	0.34
CMETE	0.68	0.32

- Average study time to doctoral degree

Doctoral Programme	Median programme time
Electrical Engineering	4.4
Computer Science	3.5
Information and Communication Technology	4.4
Mediated Communication	3.9

Gender equality KPIs

- Proportion of female faculty 12% (2018)

  Includes: Professor, Associate Professor, Assistant Professor, Adjunct Professor, Affiliated Professor, Affiliated Faculty, Visiting Professor, Nominated Professor, and Lecturer.

- Proportion of recruited female/male faculty 20%/80% (2018)

  Includes: Professor, Associate Professor, Assistant Professor and Lecturer.

- Proportion of female/ male faculty promoted to professor within 12 years: 19%/81% (2008-02-01 to 2019-12-01)

- Proportion of female/male doctoral graduates 24%/76% (2019)

- Proportion of female/male students in undergraduate and masters programmes

Programme	Female percentage (2020)
TIDAB	22.12%
TIEDB	15.00%
TIELA	11.94%
TCOMK	24.76%
CINTE	21.20%
CELTE	17.53%
CDATE	17.98%
CMETE (Civilingenjörsprogram i Medieteknik)	44.10%
TCSCM	19.26%
TMAIM	20.16%
TIMTM (Masterprogram i Interaktiv Medieteknik)	48.51%
TMMTM (Masterprogram i Media Management)	66.67%
TELPM	26.51%
TINNM	29.79%
TEFRM	10.00%
TSCRM	13.01%
TIETM (= fyra spår inom EIT InnoEnergy)	30.43%
TIVNM	23.33%
TCOMM (Masterprogram i Kommunikationssystem)	31.11%
TSEDM	11.32%
TEBSM	24.47%
TNTEM	27.08%
Doktorsprogram i Elektro- och systemteknik	19%
Doktorsprogram i Datalogi	27%
Doktorsprogram i Medierad kommunikation	22%
Doktorsprogram i Informations- och kommunikationsteknik	20%

Professional support KPIs

- Evaluation results for support (internal) vs overall support 4.74 (2020)
- Staff mobility 13% (2018)
- Staff who leave EECS but stay on in other positions at KTH: 25% (2018-2020)
- Percentage of internal applicants for each position: 7.8% (2018)

Work environment KPIs

- Results from the Employee Satisfaction Survey (MUS): Employee Index 67 (2018)

4 Education

The school offers programmes at all three cycles of higher education and is planning to organise programmes that support life-long learning. EECS uses the quality assurance model to increase the quality of its education, but also adds ‘impact of education’ to this model. This section includes a presentation of programme development in first-, second- and third-cycle education. This is followed by a description of the department perspective on subject-area strategy and development. The section ends with a description of the impact of education at EECS.

4.1 Programme development (first and second cycle)

The challenges of society require engineers with skills that span several traditional disciplines, such as system engineering, communication, human-computer interaction, energy engineering, electrical engineering and computer science. The EECS School has a unique combination of competences and will change its educational programmes to give students the opportunity to acquire the skills they need to take on these challenges. The School will augment its well-developed quality system with the new quality assurance tool that KTH recently introduced as it seeks to further improve the quality of its courses, programmes and educational environment.

A recent investigation (2018) focused on a review of our programmes with regard to future students (students that will graduate in 2025) and quality. We are committed to being leaders in modern educational and didactic methods. The areas represented at EECS are developing very quickly, and in order for our alumni to keep up to date, life-long learning programmes should be offered. Two of today’s challenges are a lack of a viable financial model for this type of education and a teacher shortage in popular subject areas. While these issues are being resolved, the School will need to focus on contract education and view it as a part of the school’s regular activities.

In order to facilitate the creation of broad educational programmes, programmes are owned and planned at the school level, while courses are owned and planned at the department level.

In short, it is a question of changing course offerings and programme content and establishing common planning for staffing that crosses divisions and departmental boundaries. We already know today that there are overlapping courses, as well as programmes competing for the same students.

Our programmes strength student contact with the labour market. Different ways to achieve this include letting students work on tasks in the industry in their bachelor’s and master’s theses, in different project assignments and by inviting representatives from industry to give motivational guest lectures.

In all EECS programmes, sustainability is included as a learning outcome, based on the UN’s Sustainable Development Goals. One way to work with the SDGs is to collaborate with industry via Challenge-Driven Education, where students work in groups on a challenge defined by an industrial partner.

Education is going through a transformation driven by digitalisation. Tools that support this transformation to e-learning and online education include flipped classrooms and streamed and recorded lectures. The goal is to offer excellence in teaching and to maximise learning by using tools such as digitalisation. Pedagogical seminars will be offered where scientific results, as well as proven experience, can be shared among faculty.

All students at KTH have access to ‘maker spaces’, and EECS offers a number of laboratories, experimental environments, mentor spaces and maker spaces.

Sustainable development means development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Sustainable development must be integrated into all education programmes at all levels so that students after graduation can contribute to sustainable social development. In all engineering and Master of Science engineering programmes should offer an opportunity to add a background in sustainability to students' education through elective courses or opportunities to choose a tailored master's programme or track that focuses on sustainability. Linked to environmental management systems, action programmes have been drawn up to strengthen the integration of sustainable development into education programmes. Sustainable development must be integrated into students' work in key assignments and in studies related to education. A teaching and learning course on Learning for Sustainable Development is offered at least annually. Seminars and networking meetings for teaching staff are organised. KTH will provide employees and students with knowledge and awareness about sustainable development in their daily work and academic lives. Future quality evaluations will include sustainable development. EECS will continue to integrate sustainability into programmes by offering progression, i.e. course packages that run from introductory material to more in-depth learning. Courses will have a sustainability classification.

At EECS, our educational activities will adhere to the Swedish government's goals for equality. Equality means providing the same opportunities to women and men to shape society and their own lives. In terms of education, all students – regardless of gender or their socio-economic background – must have the same opportunities and conditions in terms of education, study and personal development.

4.2 Programme development (third cycle)

During 2018, EECS targets the unification of administrative and academic procedures following the school merger between the CSC, EES and ICT schools.

For 2019 the focus was planned to shift towards the development of the course curriculum. The merger opens up opportunities for synergies between the old schools' doctoral programmes, giving them a broader base for existing courses and allowing them to be offered more frequently. However, this requires improving visibility and access to the courses. Modifications of its contents may also be required for a course to be attractive to other programmes. A systematic survey of our courses from this perspective, together with an action plan, will be a major effort. This project was delayed into 2020.

The School is involved in a number of large new research initiatives in the general area of digitalization, e.g. WASP, (Wallenberg Autonomous Systems and Software Programme), WASP-AI, SRA-TNG, CASTOR and the SweGrids programme. Renewal of the curriculum will be necessary to meet the challenges and opportunities associated with these initiatives. Follow-up of the objectives that have been set with respect to sustainability and equality is another activity that was planned for 2019. Resources are also to be devoted to improving the system for how student feedback is incorporated into course development. We are also interested in automating indicators for third-cycle education so that they can be tracked more easily: e.g., drop-out rates, throughput, and publication standards. For 2019, one focus for the doctoral programmes was psychosocial conditions for doctoral students.

In 2019 EECS decided on a plan for the implementation of the periodic review of third-cycle education. Two major milestones will be an internal review in 2022 and an external review in 2024. Follow-up on these reviews is an important component of programme development.

In 2020 an action plan for equality in third-cycle education will be put in place. One of the key components is a mentoring programme aimed at attracting women with master's degrees to our doctoral programmes.

Long-term plans for 2020 and beyond include reviewing the doctoral programmes and third-cycle subjects to ensure they meet the needs of the rapidly developing areas that make up electrical engineering and computer science. These plans also include activities to foster young faculty in supervision of doctoral students, as well as a renewed effort to improve the process of recruiting doctoral students.

5 Departments

5.1 Computer Science

5.1.1 Area Definition

The subject of Computer Science provides the technological basis for modern digitised societies, from public service to businesses and science. Education in computer science is at least as essential as mathematics is in all engineering disciplines.

The subject area covers all aspects of design, operation, and use of computer systems and software. We cover the field from its theoretical foundations to software and physical systems, using analytic as well as experimental methods. This includes formal methods, algorithms, computer architecture and networks, communication, parallel and distributed systems, computational science, data science and software engineering. We develop methods and tools for designing, verifying and evaluating computer-based systems and services with respect to application properties, such as performance, security, privacy and trust.

The communication area encompasses wired and wireless communication, computer communication (within a chip/SoC/board/data centre) and the modern view of network services implemented using open-source software running on commodity hardware, potentially geo-distributed across multiple cloud data centres.

5.1.2 Subject area strategy

Strategic outlook – societal/industry needs, student interest, expected impact:

It is a challenge to provide industries that increasingly rely on software adapted to their products and services with staff who can meet demands for developing reliable, secure, trustworthy systems.

There is a huge and growing need for students with knowledge of various aspects of software development, from traditional tasks such as programming, data processing and user-oriented services to newer skills.

In Europe alone, one million programmers are needed in the coming decade, according to recent press figures. In Sweden, and particularly in the Stockholm region, companies and public sector alike repeatedly express the need for trained staff with IT skills, mostly in software development, deployment and maintenance.

Today there are few individuals who do not make use of some communications technology during the course of their day, whether it be internet browsing, social media, streaming media, IP TV, IP telephony/multimedia conferencing, online shopping, cloud computing, RFID/NFC payments/tickets, big-data analytics on distributed data, electronic trading, or cryptocurrencies. At the same time, there is an increasing deployment of technologies for the Internet of Things. Industry 4.0, aircraft/bridge/building/traffic and more, monitoring and management systems, and other efforts that rely on communications between sensors and actuators and remote systems that make decisions based on sensor data and then act on the world. As a result, all of today's architecture and engineering students need to understand the fundamental concepts underlying communication systems. Software has become one of those fundamental, pervasive artefacts, and the efficient transfer and processing of information are as important as energy for the infrastructure of society.

5.1.3 Objective and strategies

5.1.3.1 Basic Education

Novel modelling and programming methods, as well as providing good environments for developing and maintaining software, remains a need where our education and research is and will be of crucial importance. Due to digitalisation and technology development, growth is expected to be particularly strong in Software development, Security and privacy, Data Science, Machine learning, and Artificial

Intelligence. The combination of big-data analytics with powerful and flexible platforms for processing real-time or almost real-time data in new ways is important. High-performance computation using distributed systems is increasingly important.

Area 'course package' description

A total of 14 course packages are included in this area. Current suggested areas are: (1) Computer Science Education, (2) Software Engineering, (3) Project and technology management, (4) Enterprise IT modelling and computing, (5) Computational complexity, (6) Software construction and analysis, (7) Model-based Computing Systems, (8) System design, analysis, performance, resource management, (9) System security, network security and privacy, (10) Scientific computing, (11) Distributed and Parallel Systems, (12) Data Science and applied AI, (13) computer engineering and computer systems and (14) communication.

We structure the communications area as four closely linked main sub-areas: internetworking, wireless communication and networks, communication theory, and communication software and services.

Course package development plan (new courses, cancelled courses)

A modernised package of mandatory courses in programming should be provided. A modernised curriculum for courses in computer engineering should cover new systems. There is an ongoing effort to launch a master programme in software technology and a new master programme and specialisations within certain existing programmes on Data Science, development of a programme in autonomous systems. We also wish to develop new courses on Network Science, System design: Performance of computing systems, Security, Project and technology management, Game theory, and Network Optimization.

There is also an urgent need to expand the education in Communication security due to the increasingly critical natures of modern cyber-physical systems and networked systems handling sensitive data.

We will try to achieve better exposure to research in our courses.

Strategic investments (MK)

We propose new development of courses/course packages as a result of the structural reform of the school's educational programmes and in order to further digitalise our course offering as a result of the COVID-19 pandemic, and also to invest in infrastructure/computing platform for Data Science and AI-related education and research. We also propose an IOT hacking lab, investment in support for MOOCs and various educational projects.

5.1.3.2 Research (Divisions)

The Department of Computer Science (CS) consists of five divisions:

5.1.3.3 Computational Science and Technology (CST)

Research in the CST division is aimed at understanding and modelling the dynamics and behaviour of complex physical systems (e.g., climate, turbulence in airflow), biological systems (e.g., the brain, heart, cancer genomics) and social systems (e.g., crowd behaviour). Most of the pertinent research questions associated with these systems are not amenable to conventional approaches and require high-performance computing and numerical simulations. Therefore, to advance the study of these complex systems we are not only addressing the scientific questions per se but also developing new analytical methods, simulation tools, high-performance computing tools and algorithms to visualise high-dimensional and multi-scale data.

CST comprises five research groups, all of them national and international leaders in their fields.

The primary methodology of the Computational Biology and Machine Learning in Biomedicine group is machine learning, where cancer is perhaps the current dominant application domain. Within machine learning, probabilistic approaches focused on modelling and inference algorithms are employed, as well as deep learning methodology, applied particularly to medical image analysis. Another line of research is modelling and inference in the context of somatic evolution, both in healthy tissue and in cancer research.

The Computational Brain Science group uses mathematical modelling and quantitative analysis to generate an understanding of brain functions over different scales of organisation (molecular, cellular, network, functional, systems) and to extract general principles for brain functions.

The research of the Numerical Methods group is focused on the development of numerical methods for partial differential equations and adaptive algorithms for massively parallel computing systems, with a particular focus on computational mechanics and in silico medicine. The group includes founders and developers of the widely used open-source software project FEniCS.

The Parallel Computing group focuses on programming environments and tools for exascale computing. It works on extensions to the Message Passing Interface for data-intensive applications exploiting novel memory/storage technologies, performance tools and the convergence of HPC and BigData environments.

The Visualisation group's research is focused on feature-based methods and their application in very large data sets. The Visualisation and HPC areas leverage their synergies in this regard and work closely together. The current focus of the Visualisation group is in-situ visualisation, interactive exploration of data using VR/AR technology and the simulation of crowd behaviour.

Research action plan of CST in summary

Biology and medicine are perhaps the richest application domains for machine learning. The Computational Biology and Machine Learning in Biomedicine group will continue to strengthen and build on collaborations with biotechnology developers, physicians and biomedical researchers who are at the forefront of applying experimental techniques. Currently, the most strategic areas are analysis of single-cell data and biomedical image analysis, but in the longer term there will be several opportunities for expansion, driven by the urgency of being able to analyse gigantic biomedical data sets. The long-term vision of the Computational Brain Science group is to continue to contribute to a deeper understanding of the computational mechanisms underlying biological brain function, in addition to working towards a strategic partnership with the Stockholm University Brain Imaging Centre. We play an active role in building the Swedish research community at the crossroads of brain science and ICT, including the development of neuromorphic hardware in collaboration with other EECS groups. Within Numerical methods, we will continue our engagement in the open-source community FEniCS and the H2020 e-infrastructure project MSO4SC for HPC/cloud computing, and we will further develop our interdisciplinary research collaborations with the H2020 ITN programme ENABLE for advanced manufacturing, the VPH Institute for in-silico medicine, and the OES programme for ocean energy. At the national level, the team collaborates with KI, LiU and UU and is engaged with SeRC, the Swedish Network for Mathematics in Industry, and the Swedish Biomechanics Society. In Parallel Computing, the efforts towards exascale are propelling novel hardware developments, which require appropriate programming and tool support. In addition, an increase focus on data calls for novel approaches and opens collaboration opportunities with other groups in the school. In Visualization research, we will explore machine learning and how visualization can help shed light onto automatically generated decisions.

5.1.3.4 Software and Computer Systems (SCS)

The SCS division conducts research and offers education on fundamental aspects of software technology and computer systems, focusing on cloud computing, service computing, social networks, time-aware systems, data science and applied AI, as well as software engineering.

Its research concerns fundamental principles of engineering and analysis of Systems and Services. The division contributes to systems that deliver high performance and reliability with cost and resource efficiency.

In the area of Software construction and analysis, we work with Software technology for DevOps, advanced software testing, and novel techniques for automatic software diversification. We research new methods and systems for software and services analysis and development. These include semantics-based and machine learning–based approaches, new architectures for data analysis systems, autonomous software systems, and privacy and trust-enabled software and services. We work with the automation of system-specific modelling languages and are involved in the Heterogeneous Model Compilers for Uncertain Environments project. We also work with software engineering, software testing, software diversity, cyber-physical systems, and compilers.

The Distributed Systems area focuses on systems research, algorithms and software technologies for distributed and parallel computer systems. This research group has been working on many specific relevant programming systems involving large-scale distribution, scalability, autonomy, and fault-tolerance, including cloud computing, and large-scale peer-to-peer and edge computing. Data-intensive computing applications of interest include systems for scalable, advanced streaming analytics and deep learning.

The Data Science and Applied Artificial Intelligence area is developing methods and technology for collecting, organising, and analysing data in order to generate new knowledge. It focuses on the two latter aspects: systems for large-scale distributed, decentralised machine learning, algorithms for enabling trust in machine-learning models through interpretability and statistical guarantees, and analysis of complex data such as sequences and graphs using with information-network analytics, graph mining, gossip learning, multi-agent systems and knowledge management**.** The research is applied in several different domains, including health care and medicine, drug discovery, computational epidemiology, climate research, predictive maintenance and social networks. The division has internationally competitive competences in the areas of conformal prediction and graph learning and an extensive presence on editorial boards and programme committees at several of the most prominent institutions in the area.

Research action plan for SCS in summary

Supported by WASP, we build up new activities in the area of Data Science and Applied Artificial Intelligence. In addition to an extensive international network, the researchers within this group have close, ongoing collaborations with researchers at the national level, both in academia (primarily at KI, SU, and JU) and industry (primarily at AstraZeneca and Scania). The plan is to expand these collaborations through additional joint projects. Especially in the area Software construction and analysis, we are actively participating in the CASTOR centre and the SRA ICT TNG consortium, both representing significant research initiatives that are taking place within the EECS area. We have an ongoing cooperation agreement with Software Competence Centre Hagenberg (SCCH), in Linz, Austria on Computational Models for Data Analysis systems. The Distributed Systems area continues to work on new challenges in data-intensive computing: most recently on continuous deep analytics systems for real-time decision-making in the CDA project, supported by SSF. We are also partners in other SSF projects.

5.1.3.5 Theoretical Computer Science (TCS)

The TCS division is responsible for teaching and research in areas of fundamental computer science. The division performs research on the core topics of computer science, including data and network security, software construction and analysis, foundations of data science, and computer science education. Research within TCS includes programming and programming languages, software engineering, embedded and distributed systems, formal methods, computer security, cryptography and privacy, data science and computer science education.

In the Computational Complexity area, we are particularly interested in understanding different combinatorial optimisation problems and algorithmic and complexity-theory techniques for designing efficient graph algorithms with provable guarantees. We study algorithms for NP-hard problems, analytic methods in algorithms and complexity, hardness of approximation, General Algorithm Theory, Algorithms for Matching Problems, Algorithms in Game Theory, graph algorithms, distributed algorithms, dynamic algorithms, optimisation, fine-grained complexity.

In the Computer Security area we perform research into Analysis of Networked Software, Intelligence and Security Informatics, Privacy, Provably Secure Systems, Secure Networks and Systems, and

Practical and Provably Secure Cryptography. Software Security, Web and IoT Application Security, Foundations of Computer Security, privacy-enhancing technologies, applied cryptography, decentralized systems security, Intelligence and security informatics, high assurance, low level security, security models, security verification, Security of low-level SW, Security of HW Architecture, virtualization, cryptography, and quantum computation.

In the Computer Science Education area we conduct interdisciplinary research aiming at improving the understanding of how students learn computer science and how the teaching and assessment of computer science could be improved. We study learning analytics, technology-enhanced learning, programme coherence, assessment, theoretical computer science education, project-based learning, narrative intelligence, AI and creativity and applied AI.

In Foundations of Data Science we study the theoretical foundations of data science and machine learning, with an emphasis on developing underlying theories, designing novel computational methods and exploring applications in software engineering, language technology, natural sciences and social network analysis, among others. Some methods include repository mining, machine learning for software engineering, visual analytics, synthetic data generation, privacy-preserving data analysis, adversarial learning, combinatorial optimisation, knowledge discovery, graph mining, social network analysis, natural language quality analysis, language policy, terminology, programming models for data science, large-scale distributed programming, automaton learning, machine learning for software engineering, machine learning for digital pathology, massive graph algorithms and mining, learning-based online and dynamic algorithms and autonomous systems.

In Software Construction and Analysis we perform research on the production of software systems that behave in a reliable and predictable manner: i.e., that deliver a trustworthy service in a timely manner without causing harm or significant malfunction. Currently active fields include programming and type systems, software evolution, virtualisation, formal verification, software testing, automatic programme repair and dependable autonomous systems.

Research action plan for TCS in summary

Responding to local industry calls for increased research and student production in software engineering, TCS is heavily engaged in the CASTOR centre, a software technology research centre at KTH. TCS is also actively involved in the WASP programme. Foundations of Data Science is one new direction for this research. Another direction is chaos engineering. TCS academic staff are coordinating two new WASP clusters: Security for Autonomous Systems and Software Technology for Autonomous Systems. In parallel activities, we are researching the software engineering aspects of automotive research with Swedish manufacturers. Security is a strategic area of growth for TCS. In the coming years the Complexity group plans to have more interaction with the mathematics division. In parallel with this, research on applied algorithms for NP-hard problems continues. In the short term, the TCS development plan is to consolidate the computer security and safety and complexity theory areas. We will also expand the new Foundations of Data Science research cluster.

5.1.3.6 Network and Systems Engineering (NSE)

The NSE division conducts research and provides education and service to society on key aspects of networked systems. The primary research focus is on system design, architecture and management; system security and privacy; enterprise IT modelling and computing; and project technology management. The core methods for conducting the research are stochastic modelling, queuing theory, game theory, optimisation, distributed systems, data analysis and machine learning, software design, prototyping and experimentation.

The division performs research in the areas of networked system design and optimisation, wireless and computing resource management, system security and privacy, enterprise IT modelling and project technology management.

The areas of network and systems engineering look at mobile services, quality of service, educational technologies, network management, distributed systems, machine learning, stochastic modelling, communication networks, distributed systems, optimisation, wireless networks and systems, Internet of Things, machine learning over networks, game theory, mobile edge computing, cyber/physical systems security and resilience.

Cybersecurity and enterprise computing addresses cybersecurity, enterprise computing, probabilistic modelling, information and cybersecurity, software architecture, industrial control systems, secure enterprise architecture, threat modelling and attack simulations and software system complexity

Project and technology management covers project management, product development, project management, quality management and product development.

Future wireless networks for the society at large will require extremely high data rates, low latency communications and massive access for IoT services. To address this, NSE has contributed pioneering, seminal research. For instance, we have devised fundamentally novel methods for centralised and distributed coordination schemes that allow the optimal operation of networks, avoiding interference while still balancing the computational complexity of the communication protocols and procedures.

Cybersecurity is an increasing concern with the digitalisation of society. ICT infrastructures are interconnected and underpin virtually all parts of society, including critical infrastructure, self-driving vehicles, advanced healthcare, business administration and national security. We see a flood of reported cyberattacks: power grid shutdowns, bank heists, election interference, and billions of personal records leaked. In order to staunch this trend, we are developing secure ICT components and ensuring security on the system-of-systems.

The division’s research in opportunistic communication provides both a novel direct device-to-device communication mode for which several use cases have been demonstrated and a resilient form of communication in the absence of infrastructure. It will be further studied in the cyber defence area.

Research action plan for NSE in summary

At KTH and on the national level, NSE faculty will contribute to research centres, including CASTOR and SRA-TNG, as well as to the WASP and WASP-AI doctoral programmes. On the European stage, the focus will be on collaborative EU projects and ERC grants. Globally, NSE plans to strengthen and possibly extend our collaborations with academic groups at MIT, Harvard, Berkeley, UIUC, KAIST, and HKUST, as well as with industry partners such as Cisco, IBM Research, and KDDI.us.

5.1.3.7 Communication Systems (COS)

Modern communication considers the whole networking stack, because the desired performance, reliability and power-consumption goals cannot be achieved in an isolated manner. Traditionally, the division is particularly strong in wired and wireless communication via its Network Systems and Radio Systems labs. The division is visible nationally, and especially internationally, via its past ERC Starting Grant and newly received ERC Consolidator Grant ULTRA, which will provide ultra-low latency network services that are implemented using open-source software running on commodity hardware, while being potentially geo-distributed across multiple cloud data centres. The division continues to be present as part of EU’s Horizon 2020 through the recently granted ‘PriMO-5G’ project to develop and demonstrate high-data-rate mmWave systems with fast mobility.

The CoS division consists of the following groups:

Network Systems, Networked Systems Security and Radio Systems.

CoS members work in the broad area of Communication Systems with an emphasis on the scalability, performance, reliability and security of vital societal systems. These systems are proving to be key in allowing society to function during the COVID-19 pandemic. Below are details on the research areas at COS:

Network Systems:

Distributed learning, IoT radio resource management, energy-efficient networking, virtualisation, IoT sensor networking, data centres, geo-distributed storage systems, software-defined networking, network functions virtualisation, secure routing, secure communication, credential management and

IoT security.

Internetworking:

Internet routing, software-defined networking, network resilience and network performance.

Security and Privacy:

Networked systems security and privacy-enhancing technologies.

Mobile Computing and Communication Systems:

Radio access virtualisation, joint communication and computation, edge computing, energy efficiency, autonomous management, security and privacy for large-scale mobile systems.

Wireless Networks:

mmWave systems, radar and sensing, spectrum sharing and co-existence, edge-cloud radio access networks, aerospace networks, satellite networks, UAV communications, autonomous network management, efficient and affordable spectrum sharing, performance evaluation of ultra-dense networks (UDN), energy efficiency, Internet of Things, information-theory and physical-layer security and secure localisation.

Research action plan for COS in summary:

A major aim at COS is developing ultra-low latency internet services. As witnessed in the COVID-19 pandemic, it is crucial for internet services to be able to quickly scale up tenfold or more, while maintaining excellent levels of efficiency that keep energy consumption under control. All this has to be done while maintaining tight control over the latency of packet processing within mobile networks, data centres and geo-distributed storage systems.

A second major goal is to develop the building blocks for a trustworthy, secure, privacy-preserving Internet of Things. Security and privacy are fundamental to the acceptance and deployment of emerging IoT technologies. This is even more true in a post–COVID-19 environment that necessitates rich and reliable data collection without eroding privacy. A wide range of our systems already addresses this multifaceted challenge. In the broad area of cybersecurity and privacy, CoS academic staff will continue contributing to centre activities, notably SecurityLink, ICES and SRA ICT TNG and Digital Futures; moreover, they can further contribute to other existing or emerging centres.

Networked systems will play a highly important role in our societies' further digitalisation efforts. In particular, distributed ledgers (aka blockchains) are likely to play a prominent role. Development of high-performance, efficient blockchains will require network support. Classic internetworking has evolved into high-speed, low-latency network services provided using open-source software on commodity hardware. Classic internetworking problems (such as congestion control and event scheduling) are as important as ever but are becoming much harder to solve due to the increase in bandwidth delay and the vast differences in deployment scenarios (ultra-low latency requirements, latency variance, etc.). Meeting the requirements for timely, high bandwidth communication requires the application of evolving AI techniques to solve these longstanding problems.

Network security will play a prominent role in digitalisation efforts. For example, in ongoing Internet of Things deployments it becomes crucial to fundamentally address network security concerns. Several recent exploits have taken advantage of IoT devices (such as cameras) to obtain sensitive information. A closely related issue is privacy, which has been recently thrust into the spotlight and is likely to remain a difficult issue to address.

5.1.4 Strategic investments (MK)

- Strengthened start-up packages for new and recently recruited assistant professors.
- Strengthened funding for faculty such as post-doc and PhD student positions.
- Investment in multiprocessors for education and research (GRU, CST, SCS).
- Cybersecurity lab (NSE).
- AI for networked systems (NSE).

5.2 Electrical Engineering

5.2.1 The subject, today and tomorrow

The transition of society to mitigate climate change involves electrification of several sectors of society and transitioning the electric power system to use sustainable sources of energy. In light of this overall trend, many activities throughout Electrical Engineering are per definition critical for leading and shaping the sustainable development of society.

The long-term trend of electrification of society has implied long-term investments in lab infrastructure, such as the Electrum Laboratory (also part of Myfab) for nanoscale electronics and the electric power engineering laboratories. The strong societal focus on sustainable energy has implied a recent reorganisation of our electric power lab facilities into a new infrastructure, in the form of the Sustainable Power Lab (SPL).

Fusion power has the potential to become a new sustainable energy source offering several advantages compared to present-day ones: for example, an almost limitless supply of fuel. The possibility of realizing fusion reactors is the driving force for a large international research programme that is currently centred around the ITER experimental facility in France. The research at the Division of Fusion Plasma Physics is part of a coordinated European research effort in this area.

The department is presently organised into five divisions covering different educational subjects and with research themes in common.

- Electronics and Embedded Systems (EES)
- Electromagnetic Engineering (EME)
- Electric Power and Energy Systems (EPE)
- Fusion Plasma Physics (FPP)
- Space and Plasma Physics (SPP)

The staff of 210 includes 27 professors, 16 associate professors, 3 assistant professors (1 contracted to start September 2020), 13 researchers and 94 PhD students.

Research questions in the field of electrical engineering can be formulated on many levels and are influenced by societal change and findings at the research front. Some areas are self-sustained on ideas, semiconductors, embedded systems, fusion and space plasma. Research in other areas follows from technological paradigm shifts: e.g., electrification in the automotive sector, policy shifts or changes in societal needs or trends. This applies to electric power systems, integration of renewable power sources with a lack of mechanical inertia, wind and solar power, electricity market deregulation and new materials applications. Research on antennas and metamaterials is largely driven by the search for new solutions for future communications systems for both civil and military purposes. Technologies that have their roots in all fields of electrical engineering have enormous impacts today. The evolution of electronic devices has enabled applications in so many fields that it is almost infinite. The sustainable-energy future on earth will largely rely on the electric power system. The integration of renewable power production and transitions in the transportation sector from fossil fuels to battery-based electric propulsion systems creates new challenges to address. In the near future, the focus will be on the ability of the electric power system to handle all the requirements and changes that must be implemented. In the longer term, research on fusion plasma physics may again transform the picture in the energy area.

5.2.2 Subject area strategy

The Electrical and Electronics Engineering area at KTH is currently (2020) ranked number 17 in the QS ranking. One main goal is to contribute to maintain this position and, if possible, move up.

Each specific educational subject and field of research has specific emerging areas to develop, but a number of common aims and synergies have been identified and are listed below. The aim is to develop them further during the coming years:

- There is an identified need to strengthen research on devices for high-frequency electronics in the radiofrequency area. This will also be developed in conjunction with the SCI course in microwave theory.
- The interface between semiconductor electronics and applied power electronics will be strengthened: for example, by developing joint masters- and PhD-level courses and joint funding applications – possibly at the centre level – as well as exploring possibilities for new academic staff positions.
- There are a number of partly overlapping fundamental level courses – e.g., electric circuit theory. The integration of courses from the engineering programme (Hing) in related fields opens up the possibility of creating a more efficient structure that uses team teaching and pedagogic development within the course, aiming for digitalisation and joint use of laboratory facilities. This includes a focused effort to increase the sustainability profile of these basic-level courses.
- We will work to enhance the visibility of the subject of Electrical Engineering in society. This includes working toward better participation in daily news reporting, debates, technical magazines and popular science activities directed towards schools. One key strategy is to encourage academic staff to volunteer at the many events being organised across KTH and within industry as a whole, rather than taking responsibility for the logistics of organising our own event
- We will strengthen activities within Mentor Space in Kista and the Creative Electrical Engineering Lab (CrEE Lab, student workshop) at Teknikringen in order to share knowledge and equipment.
- We will work to develop the Sustainable Power Lab into a highly regarded facility, increasing its internal visibility and openness but also emphasising the international importance of the facility through collaboration in interaction programs related to infrastructure for power engineering research (eg. ERILAB) and). We will also encourage our faculty to increase promotion of their use of the facilities in their research papers and presentations

5.2.3 Basic education

5.2.3.1 Subject area development

The education provided by the Department of Electrical Engineering ranges from fundamental electric circuit courses (which are of fundamental importance for many higher courses) and electromagnetic field theory to advanced courses in the five subject areas of the department: Electronics and Embedded Systems, Electromagnetic Engineering, Electric Power and Energy Systems, Fusion Plasma Physics, and Space and Plasma Physics.

Electrical Engineering is the key technology for a sustainable world. The education area encompasses fundamental courses related to semiconductor devices, physics and electromagnetism, up to many courses with a high degree of complexity covering cutting-edge research and state-of-the-art applications. Of utmost importance is the contribution of new and improved technologies and systems to a reduction of CO_2 emissions. This implies the transformation of the energy field from the use of fossil fuels like carbon and oil towards renewable forms of energy like solar, wind and waves, all of which involves the step of converting the primary energy form to electrical energy. In the long term, fusion power generation may also be realised. Moreover, our electrical power system is being transformed through digitalisation, which requires, among other things, high-frequency electromagnetic devices for efficient communication.

The Electronics and Embedded Systems (EES) area covers courses in what would typically be called electronics system design, including the design of both hardware and its embedded software. This area offers basic courses in circuit theory, analogue and digital electronics, circuit design at various levels of system complexity, embedded system architectures, embedded real-time systems, embedded software, hardware security, system design, system verification and system modelling. Practical courses cover printed circuit board design, product realisation and sensor systems. Courses in semiconductor devices and physics, including design, simulation, fabrication and characterisation, are also included. These courses are prerequisites for many courses in Intelligent Systems, Computer Science, Communication and Computer Engineering.

One example of an emerging field is the transportation sector and its transition towards electrified solutions. Automotive technologies are pursuing both battery-operated systems for cars as well as galvanic connected vehicles that target the heavy transportation sector, with several demonstration projects are underway in Sweden and Europe. Other examples can be found under the umbrella of "Smart Grid" projects that include any change in the electric power sector, from new market models, microgrids, demand response, and system changes due to distributed generation up to visions of worldwide high-voltage direct current (HVDC) super grids.

5.2.3.2 Subject area strategy: Strategic outlook. Societal/industry needs, student interest and expected impact

Electrical Engineering is behind the technical evolution that is transforming society and industry in many ways. Electronics and embedded systems are key enabling technologies for a large part of Swedish industry. It has been estimated that 28% of Swedish industry is in electronics, and more than 11% of Swedish exports relies on advanced electronics production.

Electromagnetism is also the key enabler for communication systems. In particular, the antenna is a crucial component in a wide range of applications such as space communication, 5G and 6G communications and self-driving cars.

The sustainability of energy production and consumption affects all areas related to electric power engineering. The impact of electric power technologies influences the whole chain – from electricity production using 100% renewable energy sources in the form of hydro, wind and solar power to energy consumption where the electrification of the transport sector in the form of electric vehicles is a rapidly developing area of electric power applications. Between power production and consumption we have the high-voltage power grid, which has to handle power transmission and distribution in a stable, reliable, efficient, flexible and economical way. This requirement has led to a long-term focus on smart grid solutions. Another recent trend here is the focus on energy storage solutions in the form of large-scale batteries that can help balance out short-term power fluctuations.

Long-term needs for energy supply lead to a continuous focus on fusion plasma physics and fundamental plasma physics, which also involves space plasma physics. The security and reliability of electric power systems are affected by many things. Among the disturbances of physical origin, it is worth mentioning geomagnetic-induced currents in near-earth plasmas. The functioning of our society is more and more dependent on space infrastructure; illustrative examples include navigation, communication and rescue. Some of our on-ground infrastructure may be also directly affected by space weather conditions: for example, geomagnetically induced currents in power supply networks. With expanding space exploration, we also need to consider space infrastructure in other parts of our solar system, such as planets and moons. The need for experts in space-related areas is expected to grow, and there is a continuous need to update courses so they are at the cutting edge of this fast-developing area.

Our education serves to provide the Swedish industry with highly skilled engineers. Our graduates pursue careers at KTH Partners ABB, Bombardier, Ellevio, Ericsson, Saab, Scania, Svk and Vattenfall. These employers have a continuous need for electrical engineers from all subfields, including electronics, embedded systems, electric power, electromagnetics and plasma science. It is important that this educational area grow and that our education be world-leading.

The demand for engineers specialising in electronics, embedded systems, electric power and electromagnetics is expected to be high and growing for the coming decades. We see this in the fact that the Master's programme in Electric Power Engineering is among the most popular Master's programmes at KTH in terms of its number of international applicants.

One important goal for our programmes must be to increase the number of women applicants and graduates. This includes EECS and related engineering programmes at the bachelor's (TIEDB, TIDAB, TIELA), Master of Science in Engineering (CINTE, CELTE, CENMI) and international master (TEBSM, TNTEM, TEFRM, TELPM, TIETM). A further goal is to increase the share of more advanced students drawn from our own bachelor's programmes.

In the area of space-related education, there are two important developments where we expect significant updates in the next decade. First, rapid expansion into the solar system will lead to a major expansion of our knowledge of the different space environments in our solar system, particularly with respect to planetary environments. Second, space technology is undergoing a new phase of development, with advances in electronics and sensor miniaturisation, growth of the 'New Space' sector and its multiple new actors, easier access to space and a paradigm shift in viewing space systems as part of new services.

5.2.3.3 Area course package description

At the first-cycle level, the department provides courses on vector analysis, engineering science, circuit analysis and simulations, basic electronics, digital design, analogue electronics, measurement technology, embedded systems, practical electronics and sensor-based systems, semiconductor devices and integrated electronics; project courses in electrical engineering, the global impact of electrical engineering, electric power systems and different variants of , adapted to the programme the students are following.

In addition, several project courses are offered to students, as well as first-cycle degree projects in all the department's subject areas.

The course packages are dominated by second-cycle courses, where the subjects reflect the different areas and sub-areas of the divisions. Courses range from fundamental courses for each subject area to more specialised courses that interface each subject with ongoing research in different fields. The course Sustainable Electric Power Engineering is an example of a course where many teachers are involved in providing students with insights into how electric power engineering contributes to the development of society in the direction of sustainability.

5.2.3.4 Course package development plan (new courses, cancelled course, etc.)

The needs are mainly to ensure a high quality of courses in order to ensure that appropriate pedagogical and didactical methods are used. There is a general need for upgrades in laboratory infrastructures to provide undergraduate and graduate students with state-of-the-art equipment for advanced scientific studies and access to labs where they can develop creative ideas that can then lead to new innovations. There is a need for coordination of courses in the third cycle with courses at the master's level, and there is a need for better planning of the third-cycle course packages. In order to strengthen the learning-by-doing process and the implementation part within the subject area, the department is hosting a Mentor Space on the Kista Campus. In 2019 a process was started to enhance the student workshop at Teknikringen, turning it into a better-developed maker space in the broad area of electrical engineering. This project is currently being referred to as the CrEE Lab (Creative Electrical Engineering Laboratory). Engagement within EIT/InnoEnergy and the SENSE programme will be strengthened and developed in line with the thematic field of smart grids and in connection with the programme's desired overarching learning outcomes in the areas of innovation, entrepreneurship and business creation. Initiatives will be taken to engage other sub-areas within EE to be part of pan-European educational programmes.

The classic topics of electronics and embedded systems are currently being revised by newly instated course teams. Prerequisites between courses will be followed up, and basic electronics labs and pedagogy are being modernised. Planned changes in basic electronics include new pedagogical theories: student recitations (*Studenträkneövningar*), peer instruction and home labs in digital design. Planned changes in embedded systems include the formation of a course team and the repackaging of course material. Planned changes in Practical electronics and Semiconductor devices include an increased focus on environment and sustainability and adapted learning outcomes that reflect this.

We are planning to start a new course on solar system physics, with a focus on planetary and other minor-body space environments, including observational methods and exploration. The course has grown out of a very successful STINT-financed international summer course given by the division at KTH 2019. The expansion of the space technology track for both MSc programmes and growing demands of industry for cross-disciplinary skills in our graduates have led to a need to develop two new courses in the near future: one with a focus on space avionics, electronics and data handling; and the second on space operations and communication.

5.2.3.5 Strategic investments (MK)

- New positions in the form of four new associate professors
- Two newly recruited assistant professors
- One ongoing recruitment for a new assistant professor
- A need to recruit female faculty
- New faculty will be recruited to replace retirees
- Strong efforts to apply for a new competence centre in the area of electric power engineering that can replace SweGrids, which expires in 2021. The focus will be on electric power research, with a focus on the leading edge of the technical evolution in the area, and in particular utilizing developments in other areas, such as semiconductor physics, artificial intelligence, advanced measurement techniques, information communication techniques and other emerging fields that are important to the electric power system in general. Such a competence centre will imply new knowledge, new courses and positions in relevant areas.

5.2.4 Research (divisions)

5.2.4.1 Electronics and Embedded Systems (EES)

Current state:

The division has a profile that covers a very broad range of basic topics in electronics, ranging from semiconductor device technology and circuits to systems integration and the implementation of embedded systems in industrial applications. Within device and circuit fabrication, research ranges from nanometre-scaled silicon and germanium MOSFETs to high-voltage silicon carbide (SiC) devices and photonic devices such as lasers and UV detectors. We can fabricate and characterise state-of-the-art devices and circuits in-house, using one of the leading university cleanrooms in Europe. High-temperature integrated SiC circuits operating at 600°C have been demonstrated, as have 15 kV SiC power switches. Research on integrated circuits and systems focuses on bio-medical analogue/mixed-signal ASICs covering a wide range of applications, such as ultra-low power implantable/wearable biosensors, brain interfaces and multi-source energy harvesters. The world's smallest bio-impedance spectrometer has been demonstrated. This research has a strong background in VLSI design and design automation, as well as in mixed-signal and RF integration. In addition, fundamental innovations in VLSI/SoC architecture have been achieved: for example, network-on-chip, clocking and power management and high-performance massively parallel architectures. Similar contributions have been made in the area of high-level system-level synthesis and formal design methods for such systems. Advanced embedded systems perform an increasing number of vital functions in areas such as transport, communications and healthcare. Embedded computer systems are integrated into physical or electrical environments and react continuously with those environments while having to satisfy different requirements such as real-time interaction, power, size or costs.

This design process is inherently complex. Ongoing research projects in emerging devices include printed and flexible electronics, integrated photonics and quantum communication, as well as spintronic devices and circuits. On the system level, neural network accelerators and neuromorphic brain-like computing are being investigated as techniques for machine learning, with applications in embedded systems, computational neuroscience and bioinformatics.

Future research action plan in summary (EES):

The research plans couple tightly with the EU ECS-SRA for Electronic Components and Systems. At the national level, we target Swedish industrial innovations in smarter electronic systems and autonomous systems. This includes areas of development such as 3D heterogeneous integration with Ge CMOS, high voltage SiC devices with ABB, high-temperature SiC integrated circuits with Sandvik (Vinnova proposal) and high voltage SiC integrated circuits (with the Swedish space industry). In terms of integrated circuits and systems, plans include energy harvesting interfaces, low-power electronics for self-powered devices, ultra-low power implantable/wearable wireless biomedical sensors, efficient software development methodology rooted in formal methods and multi-core architectures, network-on-chip architecture and design methodology, formal methods for network dimensioning to guarantee quality of service, structured VLSI Design Methodology and massively parallel reconfigurable architectures. Within Embedded Systems the plans include formal design of embedded real-time systems (with Saab – the addition of an adjunct professor is planned), collaboration with the CASTOR centre on embedded systems (Saab, Ericsson and EECS), design of heterogeneous safety-critical avionics and automotive systems (with Scania and Saab), massively parallel customisable reconfigurable architecture and synthesis framework, sustainable embedded computing for energy efficiency, intelligence and dependability, many-core architectures and systems, hardware security and network-on-chip system generator. Within emerging technologies, the following topics will be explored: printed supercapacitors for green energy, modelling of variability in spintronic applications, spin-torque oscillator (STO) modelling and STO-based electronic systems, electronic-photonics integration for optical data communication, photonics and quantum information, brain-like computing and neural networks-on-chip.

5.2.4.2 Electromagnetic Engineering (EME)

Description of current research:

Our current research deals with the theory, models and methods for the design, construction, operation and maintenance of devices intended for the generation, transmission and receipt of electromagnetic power at frequencies ranging from a few hertz to hundreds of gigahertz, employing a unique combination of methods in Electromagnetics, Physics, and Power Engineering. High-voltage engineering has renewed importance in the development of ultra-high-voltage AC and DC transmission systems in emerging markets, and in the importance of reliability, cost and efficiency at lower voltage levels. Its research includes properties of nanomaterials, streamer development in oil/paper systems, HVDC cable insulation and optimised characterisation of dielectrics, involving cross-disciplinary research between material science and engineering. Power system protection and safety has increased in importance due to changing conditions for renewable generation and electric vehicles. Our research includes physical modelling, measurements and inference to improve detection, fault location, and safety assessments and spans from extra-low-voltage microgrids to extra-high-voltage transmission. Power System Reliability and Asset Management include both system and component levels. Diagnostics and Monitoring are important for reliable maintenance and efficient operation of power components in grids, generators and industrial plants, and new needs are being created due to higher demand for reliability and component loading, along with ageing infrastructure. New possibilities are opening up thanks to better and cheaper sensors, communications and data processing. Research in energy storage for smart grids focuses on modelling, optimisation and suitability analysis of storage systems, including hybrid energy storage systems that are achieved by combining smaller types of storage. In Electromagnetic Compatibility the emphasis is on modelling the effects of high-power electromagnetic (HPEM) disturbances, both natural and manmade, on complex distributed infrastructure systems, with the goal of developing cost-effective mitigation strategies. Research on antennas and metamaterials looks to develop new analytic and numerical methods, including mode matching, circuit models, higher symmetries and transformation optics. The focus is on the design and optimisation of devices for the new generation of millimetre-wave devices, including array antennas, lens antennas and metasurfaces.

Future research action plan in summary (EME):

The division is uniquely qualified in the fundamentals of communications and sustainable energy in a way that enables new robust technical development. The SweGRIDS centre is a substantial part of electric power research at KTH, and the continuation of activities within the centre is a key challenge. In the area of power system reliability and asset management, the recruitment of an associate professor has been initiated. In addition, an affiliated professor from ABB is being recruited. This will further expand the work of this well-regarded group, with its large international network for collaboration and exchange, in the search for solutions for power grid technologies. Reliability issues are researched from the point of view of protection systems, where new conditions of grid operation put new demands on fault protection and localisation. Condition-based maintenance and reliable grid operation requires improved diagnostic and monitoring tools, and the focus here is on new methods that will be able to detect material ageing – for example, related to different transient stresses imposed on the power grid. An associate professor recruitment process has been initiated to address this need. Energy storage research aims at deepening the cross-disciplinary approach to include aspects such as life-cycle analysis and long-term losses. Research on electromagnetic inverse problems aims at diagnosing components and infrastructure for electric power transmission, utilizing guided and/or scattered waves for remote measurements and the detection of adverse structural changes. An assistant professor has been recruited to start in September 2020. Antenna research seeks to develop innovative front ends for 5G communications and beyond, as well as sensors. Goals in this area include lower energy consumption and better antenna performance. In the area of antenna limitations, goals include extending the limits and creating antennas and scatters whose performance approaches these bounds. The formation of a competence centre for antenna research is also planned.

5.2.4.3 Electric Power and Energy Systems (EPE)

Description of current research:

Research and education at the Division of Electric Power and Energy Systems covers areas including electricity markets, facilitating renewable electricity generation and its integration into the system, power system dynamics, operation and control, power electronics and its application in grids, electric drives and machines and their applications in electric transportation, and resilient communication and control systems. Researchers at the division are highly ranked internationally within several of these fields, and as a whole, the division is among the best-ranked at KTH. A key strength is its tight collaboration with Swedish industry. We participate in international projects and conferences, and we have also regularly organised internationally well-regarded conferences at KTH. A majority of our research activities involve collaboration with industrial actors, including industrial doctoral students. The main research focus on electric drives and machines is put towards targeting further improvement in industrial and automotive applications. Power electronics focuses on two different fields: wide bandgap semiconductors and high-power electronics for power system applications. Within WBG semiconductors, the focus is on integration, packaging and gate drivers. In high-power electronics, the emphasis has been on modular multilevel converters, but the emphasis is gradually shifting to HVDC grids. Power system operation and planning has a strong focus on efficient methods for balancing the increasing volumes of continuously varying electrical generation sources, such as wind and solar. Our research reflects strong collaborations with Nordic actors, and thereby we have a keen interest in systems receiving a high share of hydropower. One important line of research within this high share of variable power is the development of models, methods, tools and control strategies to maintain the secure and reliable operation of power systems. In the area of electricity markets, research topics include but are not limited to electricity market operation, analysis and design; market power detection and mitigation, Transmission investment and competition analysis, Generation-Transmission investment coordination and Distribution network pricing.

Future research action plan in summary (EPE):

In the area of electric machines, one important goal is to further increase engagement within the Swedish Electromobility Centre (SEC). This will be enabled by an increase in the volume of research at SEC in its upcoming phase, which will entail even more active involvement from Scania CV and other industrial actors. In the area of power systems operation and planning, including the integration of variable renewable power, we have well-established cooperation on the topic of power system operation and planning involving several other universities in Europe. Individual PhD students are also developing contacts in North America and other parts of the world. The division has previously been involved in cooperation with universities in Africa, and we are currently in the final phases of a cooperative project with Addis Ababa University in Ethiopia. In the area of power system stability, we are currently increasing research collaboration with Nordic national power system operators, as well as with universities in Nordic countries, along with projects involving Chinese and European universities via EU projects. On the academic staff side, the division has just recruited a new associate professor in the area of electric machines. There is also a plan to announce a new position in the area of smart grids, whom we hope will closely link interaction between the instant demands in power system balancing and the instant reaction of system components, an area where there is currently a significant need for instruction. There is a continued ambition in all research areas to increase international collaboration through European projects and others, and we continue to increase our efforts in this regard. The division has historically not had a significant funding share from the Swedish Research Council and has mainly depended on the availability of other funding. However, the research area is certainly on a level that should make it possible to secure such funding, and the plan is to increase the amount of funding from these sources.

5.2.4.4 Fusion Plasma Physics (FPP)

Description of current research:

The ultimate goal of fusion research is to construct and operate a demonstration power-generating system which can be developed as an energy source for future generations. The European contribution to ITER construction is provided by Fusion for Energy (F4E). The programme areas where the Fusion Plasma Physics Division is most active are: Magnetohydrodynamics, confinement and diagnostics. The experimental research programme on magneto-hydrodynamics is mainly carried out on EXTRAP T2R, and in a joint project at ASDEX

Upgrade. In the area of confinement studies, the group is actively involved at JET in the area of H-mode pedestal confinement. The theoretical programme aims at understanding improved confinement and developing new numerical tools. On the diagnostic development side, work is mainly carried out on JET in areas of high-resolution Thomson scattering and spectroscopy in support of ITER-like wall (ILW). Within Plasma wall interaction and first-wall materials, our research is concentrated on issues relevant to reactor-class devices, with the central goal of providing the best data for producing material behaviour under reactor conditions. The current research involves a broad characterisation of PFC from present-day tokamaks and testing of materials (beryllium, carbon-based composites and high-Z metals), and also includes the development of wall materials and diagnostics for JET-ILW. Within plasma theory, specifically wave-particle interactions, RF heating and current drive, the focus is on the modelling and development of RF heating as a tool to control plasma. The division has a strong involvement in the exploitation of JET and in coordinated work on Integrated Tokamak Modelling. Codes developed to model RF heating are validated against JET; three codes for self-consistent modelling of heating and current drive have been developed in collaboration with JET.

Future research action plan in summary (FPP):

The European fusion programme is focused on the international project ITER. Currently, the device is under construction, and it is expected to come into operation with the first plasma in 2025. After the start of operation, research is expected to be carried out for a period of at least twenty years. Since the EU is a leading partner in this international collaboration, this is a great opportunity for Swedish fusion researchers. Leaders of the European fusion programme have recently emphasised that the research carried out in Swedish fusion laboratories – the so-called accompanying programme – is of crucial importance to ensure the continuity of Europe's leadership in the scientific exploitation phase of ITER. Research at the ITER facility will rely on collaboration with Swedish research institutes. It is likely that the Swedish fusion research community will still be based primarily at Swedish universities, and the universities will be the main foundation for successful Swedish participation. Preparation for effective exploitation is provided by the coordinated Euratom programme. The Fusion Plasma Physics Division has a high impact in the following areas: plasma-wall interaction (PWI), where the selection of materials for the first wall –i.e. plasma-facing components (PFC) – is the key issue. This wall is vital for safe and economic reactor operation. The shift from carbon PFC to an all-metal wall is the topic of a case study. ITER will require advanced modelling for its operation, both for preparation for the pulses and for analysing achieved pulses. This requires integrated modelling in which the codes are already validated against current experiments –JET in particular. Another areas is Active feedback control of MHD stability; the development and implementation of advanced control methodologies for magnetic confinement. The in-house EXTRAP T2R experiment is being used as the testbed for the implementation of advanced control techniques, in collaboration with the RFX experiment in Italy. Control of instabilities is vital for the safety of the experiment and for economically feasible operation at high power densities. The design of the ITER MHD control system is now underway.

5.2.4.5 Space and Plasma Physics (SPP)

Description of current research:

Research at the Division of Space and Plasma Physics deals with space plasma physics in near-earth, planetary, cometary and solar wind space environments, as well as fundamental plasma physics, plasma-wall interactions in tokamaks, dusty plasmas and magnetron sputtering. The division is involved in building instrument hardware for large international space missions (ESA, NASA, JAXA) and national missions (MATS). The division has a strong rocket programme. The division is a part of the EUROfusion Consortium and is also contributing to the design and implementation of various international tokamak experiments. Space plasma physics explores various fundamental plasma physical processes associated with the interaction between solar wind and the earth's magnetosphere, and with the space plasma of other planets and bodies in the solar system. Examples include the formation of magnetosheath jets, auroral physics, the physics of Mercury's and Jupiter's magnetospheres and the space environments of Jupiter's moons Io and Europa. Measurements of electromagnetic fields and charged particles are taken in situ by satellites, space probes and sounding rockets and are taken remotely by ground-based or space-based imaging and spectroscopy instruments. Our activity spans the stages from mission initiation and design, instrument hardware development and production, and testing, operation and data archiving and processing on up to data interpretation, assisted by theory and numeric simulations. The focus of plasma-surface interactions lies in plasma-surface interactions in dense, strongly magnetised plasmas that are of relevance to the ITER fusion reactor. Two world-leading numerical simulation tools have been developed that model dust transport (MIGRAINe) and macroscopic melt motion (MEMOS-U). MEMOS-U is currently being employed as the main prediction tool for ITER wall deformation. Ongoing theoretical investigations are studying the influence of thermionic emission on the fusion plasma boundary. The topic of complex plasma covers theoretical efforts to describe structural and dynamic properties of strongly coupled non-ideal plasmas, as well as model validation through participation in the design and analysis of microgravity experiments for the International Space Station. In Applied Plasma Physics, the focus is on magnetron sputtering discharge, nanoparticle growth in hollow cathode discharge and simulations of capacitive coupled discharges of complex chemistry. High-power impulse magnetron sputtering (HiPIMS) is studied both experimentally and through modelling, and its application to thin film deposition is being explored.

Future research action plan in summary (FPP):

The Space Plasma Physics division will continue its exploration of fundamental plasma physical processes such as shocks, jets and reconnection, using MMS and other data. The recently launched ESA Solar Orbiter and NASA Parker Solar Probe missions will allow deeper studies of solar wind physics. To prepare for the arrival of BepiColombo to Mercury in 2025 numerical and in situ data studies of its plasma environment will continue. The Rosetta data will be further explored to understand cometary plasma interactions. Work will continue on the Jupiter system, looking to further use the capabilities of the Hubble Space Telescope, NASA's Juno mission, the upcoming James Webb Space Telescope and new ground-based facilities. Preparations are being made for the JUICE (ESA) and Europa Clipper (NASA) spacecraft's arrival to the Jupiter system. With EISCAT3D's start of operations, this powerful new generation of incoherent scatter radar will open a new window to space and enable a better understanding of auroral electrodynamics. We are actively contributing to the Daedalus mission through the study of Joule heating in the ionosphere, as part of the ESA Earth Observation programme. We plan to continue our participation in the Swedish sounding rocket and balloon programme. In addition, we will further explore data from our recently launched SPIDER and SPIDER-2 rockets. Within plasma-surface interactions we plan to benchmark the two new simulation codes against recent dedicated experiments and to intensify our predictive work for ITER and DEMO, benefitting from our active involvement in EUROfusion. We will focus on two relatively unexplored plasma-surface interactions of significance for reactors: (i) emissive sheaths and the transition from space-charge-limited to inverted regimes; (ii) vapour shielding phenomena and their consequences for ITER and DEMO. We have also started to develop a numerical code capable of modelling nonlinear free-surface deformations and melt ejections in order to address scenarios of melting-induced droplet and dust generation. In complex plasmas, we will focus on proving the connection between isomorph invariance and the quasi-universality of bridge functions and use this to develop a first-principle theory of the liquid state. In applied plasma physics, work on discharge physics and applications will continue. Retaining the focus on HiPIMS, we will also address fundamental issues in DC magnetron discharge: electron heating, the effect of the magnetic field and the recycling of species.

5.2.5 Competence development plan

At the Department of Electrical Engineering, the basic education course load is a relatively evenly distributed across the faculty, with a large number of smaller courses (in terms of the number of students) at the advanced level. The faculty consists of a relatively large number of professors who will retire over a relatively short medium-term time frame, which will entail a generational shift and which will also open the possibility for a rebalancing of the gender distribution. Since the department's last reorganisation, it has identified a need to strengthen teaching resources and educational leadership, and we plan to recruit a number of associate professors during the next year. The imminent retirement of several professors and the assignment of others to administrative roles further shape this need. In addition to planned recruitments at the associate professor level, the long-term plan is to recruit assistant professors. There is still time to identify new areas that complement our existing ones and that will enable a balance between renewal and continuity until we reach the crest of the retirement wave. The department has relatively few assistant professors and associate professors, which will mean few promotions in the near future.

5.2.6 Conclusion – Strategic investments (MK)

- Strategic development of educational activities:
- New positions in the form of four new associate professors (ongoing)
- Two newly recruited assistant professors (recent)
- One ongoing recruitment for a new assistant professor in the area of EPE, and tentatively a second recruitment
- A need for the recruitment of female faculty in general.
- New faculty recruitment will, in general, occur during the phase of replacing retirees in order to achieve a stable faculty situation. These new positions will be focused on identified interesting areas, as described in section 2. For example, the areas of electronics for harsh environments such as in space research applications, with high radiation or high temperature, high-frequency electronics and interfacing antenna systems, power electronics and semiconductor electronics, as well as important new fields that are emerging due to the increasing electrification of society and the achievement of a sustainable energy supply system.
- Laboratory investments in the area of the Sustainable Power Lab (ongoing)

5.3 Human-Centred Technologies

5.3.1 Current status of the subject area and future development

The Department of Human-Centred Technologies (HCT) consists of a single division – Media Technology and Interaction Design (MID). Faculty from other divisions, including Computational Science and Technology (CST) and Speech, Music and Hearing (TMH), are heavily involved in delivering undergraduate courses with a human-centred component related to aspects of human perception, cognition and expression, as well as sound and machine learning for media technology.

During the recent reorganisation, the MID-faculty actively chose to form their own department rather than to join the Department of Computer Science. This was due to the interdisciplinary nature of the research and education within that department, which has a strong focus on human interaction with digital media technologies. The department positions itself at the intersection between computer science, psychology, media and communication studies, design and sound and music computing.

HCT's objective is to create and study new technological opportunities that improve and develop current practices and quality of life. The starting point is an understanding of technology and human experience as mutually and perpetually influencing one another. This means that knowledge of how to shape and study these interactions is of key importance to society, industry and users. The interactive technologies we develop shape people's interactions with information, society, organisations, policies, and other humans – socially, intellectually and collaboratively. HCT expects to grow in size in order to pursue research and offer instruction on the many different areas that KTH is expected to contribute to. Internationally, there is a growing interest in this subject area, as indicated by the increasing number of researchers attending major international conferences and increasing national demand for interaction design competence within the IT business sector. There has also been growing interest in the combination of sustainability and digitally mediated communications, and HCT has several research projects in this area, focusing on ethical, accessible, educational and ecological sustainability. Finally, visualisation is a strong research and teaching area that is a much-appreciated specialisation among students. Internationally and nationally, most major universities have a Human-Computer Interaction (HCI) department. The topic of media technology is less common at universities, but during the 2010s several academic institutions established educational programmes that are similar to the one offered by KTH's Media Technology programme.

5.3.2 Overall objectives and strategies

HCT's overall objective is to conduct research and teaching on how to create and study new technological opportunities that improve and develop our practices and quality of life. In order to further strengthen the connection between research and education, the department's long-term goal is to increasingly involve students in research projects.

HCT will recruit an assistant professor that combines AI and design competence in order to strengthen the engineering perspective in HCI. HCT will also focus on supporting newly appointed academic staff with post-docs, as well as creating opportunities for individual research groups and the entire department to develop in a positive and forward-looking way: for instance, by organizing writing camps and supporting projects. HCT expects to have four assistant professors promoted to associate professor during 2021, and it expects at least one further promotion to associate professor within the coming years. We expect that some associate professors will be promoted to full professor during the upcoming period. Educational areas where we currently have a staff deficit are physical interaction design, interaction programming (including VR and AR), media management and general design orientation.

5.3.3 Basic education

5.3.3.1 Subject area development

EECS offers one of the most popular — and most gender-balanced (48% female) — 5-year engineering programmes at KTH: Media Technology, which HCT is heavily involved in. Over the last ten years the media industry has become increasingly digitalised with respect to both production and distribution of media content. This shift is reflected in our research and teaching. During this time, HCI has undergone a shift from mainly focusing on work-based effectiveness and screen-based interfaces to teaching and researching a media environment that has become pervasive in every aspect of daily life. As a whole, there is an increasing interest in physical interfaces with novel forms of media formats. Courses at the masters level tend to be more research-oriented and aim to develop students' expertise and understanding of contemporary research topics. At the bachelor level, the focus is on providing a broad basis in engineering in media technology. The department has ample facilities including a maker space, visualisation studio, multisensory studio, and a haptics lab. All of these are extensively used for teaching and research purposes.

The department's long-term goal is to further strengthen the connection between research and education by involving students in research projects to a greater extent. This is done by research projects formulating research subtopics that students work with within the framework of courses and degree projects.

The department provides most of the education in two masters programmes, Interactive Media Technology (TIMTM) and Media Management (TMMTM) respectively. The former is the most popular option for students in the 5-year Media Technology programme, while the latter is a freestanding 2-year programme not connected to a 5-year Master of Science in Engineering track.

The TIMTM programme admits around 80 students per year, of which around 20 are recruited internationally and from other universities in Sweden. The rest come from programmes at KTH. The programme currently has three technical specialisations: graphics and visualisation, sound and music computing and physical interaction design. The programme responsible teachers at EECS are currently investigating alternative structures for the programme that would allow for a broader range of specialisations and a larger degree of freedom for students to tailor their own education. The most radical solution would be to do away with specialisations altogether and instead provide a curated pool of conditionally elective courses from which students could craft their own specialisation. A more moderate approach would be to cover a broader range of technologies in the mandatory courses and to provide specialisations geared towards application areas rather than specific technologies. This would effectively flip the roles of required courses (traditionally targeting breadth) and specialisation courses (traditionally targeting depth) in the programme.

The TMMTM programme is a smaller programme that recruits around 20 students each year, mostly from external institutions. During 2019 the EECS programme responsible teacher worked on adding aspects of sustainability to several programme courses and identified a need to continue this work going forward.

Currently, the department does not have a professor of Media Management, which means that core courses are taught by external staff. One alternative to hiring personnel with the required competence would be to establish closer connections to schools at KTH that teach related topics (e.g., the Department of Industrial Economy and Management) or even move the programme to a new department. We have initiated such discussions, but so far they have not resulted in actionable outcomes. A second alternative being discussed would be to discontinue the programme based on its lack of fit with the department's profile.

5.3.3.2 Strategic development

To ensure long-term and continuous student influence over, and involvement in, programme development, we are suggesting that the school should create a paid position for a student assistant on the programme board. The assistant will be in charge of certain aspects of the annual review and development work within the programme and will serve as a link to the general student body, thus making programme development a more student-led activity than it currently is. We believe there are many advantages to be gained from this move, such as continuous dialogue with student representatives and increased student participation in programme development. We suggest that the concept will be tested out for the 5-year Media Technology Programme and the masters in Interactive Media Technology. If it is successful, it could be implemented in other programmes.

5.3.3.2 Summary

HCT will recruit an assistant professor who combines AI and design competence in order to strengthen the engineering perspective in HCI. HCT will also focus on supporting newly appointed academic staff with post-docs, as well as creating opportunities for both individual research groups and the entire department to develop in a positive and forward-looking way: for instance, by organizing writing camps and supporting projects. HCT expects to have four assistant professors promoted to associate professor during 2021 and at least one further promotion to associate professor within the coming years. We expect that some associate professors will be promoted to professor during the upcoming period. Educational areas where we currently have a staff deficit are physical interaction design, interaction programming (including VR and AR), media management and general design. As a whole, these developments will decrease our agency capital.

5.3.4 Research

5.3.4.1 Current research areas

Media Technology and Interaction Design (MID) is an interdisciplinary division researching the design and use of digital media in systems for mediated communication. MID is a globally recognised research hub owing to its longstanding expertise in the areas of Human-Computer Interaction, Computer Supported Collaborative Work, and Sound and Music Computing, alongside a growing standing in fields of design for sustainability, learning and immersive technologies.

MID is currently organised into four formal research teams. The Interaction Design team approaches digital technologies through design research, with novel design and aesthetic angles, to understand and design for deeply engaging, human needs–driven activities. Topics include arts and crafts, somaesthetic design, aesthetic, smart implicit interaction and addressing the impermanence of interactive technology. The vision of the Sound and Music Computing team (SMC) is to understand human communication and interaction at the intersections of different perceptual and interaction modalities across sound, music and haptics, to make them a natural part of everyday technology. The Sustainability team (MID4S) has research interests that span aspects of environmental, social and economic sustainability, with the aim of decreasing the environmental footprint of all sectors in society. The Technology-Enhanced Learning team develops and evaluates socio-technical support for learning; its research topics include learning analytics, mobile learning, integration of formal and informal learning environments, and collaborative and self-regulated learning. Beyond these established research teams, MID also conducts research on novel interaction techniques based on AI and big data, combining advanced engineering with ideas from the humanities in general and philosophy in particular. Furthermore, within MID there is a growing interest in Inclusive Design as a means to support people with a wide range of functional variations in their inclusion in today's society.

MID's research is published in the high-quality venues of the fields, particularly conferences and open access journals.

5.3.4.2 Future research areas

We foresee that areas such as interaction design for leisure and fun, work practices, sustainability, and learning support technologies will continue to grow and require deep knowledge pertaining to HCI and media technology topics. We aim to grow to meet those needs advancing the design of interactive digital systems.

As part of those efforts researchers at MID have been active in forming research centres and participating in their operation. For example, MID has been involved in financing and organising a centre for Arts, Technology and Design —NAVET headed by Roberto Bresin. The overarching goal for NAVET is to be a meeting place for research and projects, with the purpose of facilitating and creating opportunities for exchange and collaboration among artists, designers, engineers, humanists, natural and social scientists, leading to innovation through collaboration. A central task for the centre will be to support the subject area art, technology and design as a field of research, as well as develop knowledge of cross-cultural management in order to facilitate the inter- and transdisciplinary culture the centre seeks to establish. We are also involved in the Digital Futures centre, comprising 117 MSEK annually, aiming to do basic research on computer science topics as well as the general digital transformation of society, industry and everyday life. Kristina Höök is leading one of the themes, Rich and Healthy life, and acts in the management group of the centre.

5.3.4.3 Strategic development

We aim to continue the successful work in our research areas, and further strengthen the quality of our work through implementing strategies to increase the production of high-quality journal and conference publications, within- and cross-team grant applications, high quality recruitment, and support for individual researchers through increased faculty funding. We will continue to support newly appointed associate professors with post-docs. We are in the process of hiring a new assistant professor in Interaction Design and Artificial Intelligence in order to strategically advance new areas within Interaction Design and Media Technology. A long term objective is to hire more faculty in newly developing areas such as inclusive design, technology-enhanced learning and interaction technologies and programming. Providing support for expert evaluation of research and support for grant writing has yielded early successes and will continue to be a key activity.

5.4 Intelligent Systems

5.4.1 The Area Today and Tomorrow

5.4.1.1 Area Definition

An Intelligent System is an engineered or naturally occurring system, usually in interaction with its environment via sensors and actuators, that operates based on data and signals that are collected, sensed or perceived from the environment. The system performs one or more overarching tasks, where its actuation on the environment is usually a crucial component. The operation of the system can be passive, supervised, actively controlled or fully autonomous. Central to its operation is decision-making based on signals and information flowing between different parts of the system and its environment, often in feedback mode. Engineered intelligent systems are usually implemented through a combination of software and hardware, and can be of nano-, micro-, or macro scale, virtual or physical, and contain mechanical, electrical and biological elements. The design often strives to optimise the operation of the system, based on various metrics and subject to constraints and cost. In modern systems, learning in interaction with the environment is a key component. When these systems share space with humans, they should ideally communicate using human speech and language and understand human actions and the significance of items that occupy the common environment. When they are physically integrated with humans or other biological systems, they must be biocompatible.

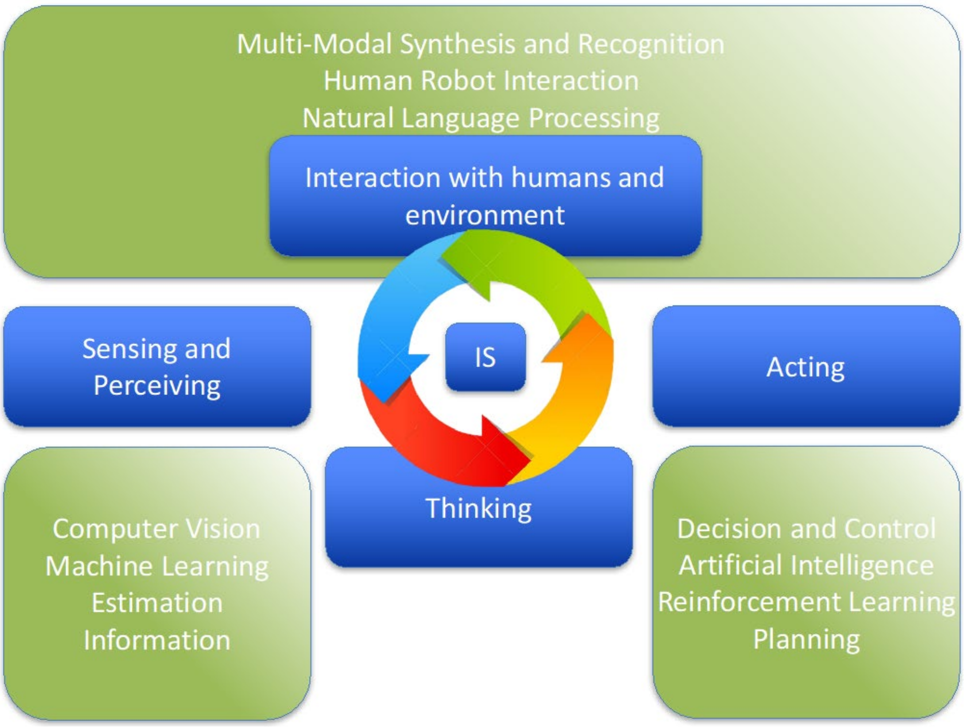


Figure 1: Illustration of the area of Intelligent Systems. The Perception-Thinking-Action-Interaction loop is a central concept.

5.4.2 Overarching goals and strategies

5.4.2.1 Strategic outlook - societal/industry needs, student interest, expected impact

Intelligent systems are the enabler for societal, industrial and personal digitalisation. Software technology and algorithm development are the primary drivers in the development of future Intelligent Systems. Thus, previous advances in computational power are now facilitating a paradigm shift, where intelligence is key. Our society relies on very complex systems, ranging from micro and nanosystems to large infrastructure systems. These systems are increasingly digitalised, automated and self-organizing, with the possibility of making intelligent decisions on the basis of continuous, heterogeneous, multi-source data. We expect these systems to be safe, efficient and reliable. Key challenges involve scalability, resilience and safety for heterogonous autonomous systems.

During the past few years, society at large has begun to respond proactively to the increased importance of intelligent systems. Important Swedish research programmes include the Wallenberg AI, Autonomous Systems and Software Programme (WASP) and the KTH Digital Futures (DF) initiative. As Sweden's major university environment in these areas, Intelligent Systems at KTH/EECS has a crucial role to play, and our strategic duty is to stay at the forefront of these developments.

Society and industry are currently experiencing an unprecedented shortage of engineers skilled in the design of the intelligent systems that are needed in order to capitalise on recent breakthroughs in this domain and to facilitate the transition into the service economy fuelled by increased digitalisation. Students clearly see these needs and respond to advances in the field, as evidenced by the rapidly increasing interest in course offerings in areas such as machine learning, reinforcement learning and AI, as well as areas such as signal processing, decision and control. As these subject areas also currently undergoing rapid development, KTH/EECS has a responsibility to provide students with a strong theoretical foundation in order to ensure the long-term viability and competitiveness of their knowledge, and to best facilitate their future development. A strong theoretical background is also needed for those who select a research career and will thus facilitate the next set of breakthroughs.

5.4.2.2 Area development

The area is progressing on four major fronts: 1) the application of intelligent systems in new technological and societal areas, such as healthcare and life sciences, energy systems, transportation systems and education, including the development of new techniques and algorithms for decision-making, control, learning, perception and interaction tailored to these new areas. Here the interaction between humans and algorithms is often at the centre; 2) progress in terms of our fundamental understanding and analysis of information flows, processing and machine intelligence, including decision and control; 3) the distribution and integration of intelligence and computation in large networked systems, such as intelligent transportation systems; 4) the use of intelligent systems to enable self-driving vehicles and other autonomous robots. These systems integrate concepts from decision-making, control, information fusion, perception, learning and interaction. Autonomous or semi-autonomous systems that have humans 'in the loop' will inevitably need to interpret and learn from increasingly large quantities of sensor data and auxiliary information in order to take informed decisions and actions. This is closely related to the area of intelligence augmentation. One challenge is real-time verification and decision-making in order to develop safe intelligent systems.

One set of topics of crucial societal importance that cuts across the four fronts is security, privacy reliability, resilience and trust in the context of intelligent systems. There is a need for new courses in this area.

Additional or modified courses are also needed in the new areas that are emerging with the spread of machine learning and AI applications. For KTH academic staff and students in the area of intelligent systems, it will be important to learn more about and continuously reflect upon the future role of AI in relation to humans and society.

Another development we see is the application of state-of-the-art machine learning tools to solving problems that were traditionally handled by tailored algorithms: for example, in communications and control. One example is reinforcement learning that builds on dynamic programming and adaptive control.

The Intelligent Systems Department currently provides a large number of course offerings in machine learning, ranging from traditional approaches such as decision trees and support vector machines, currently favoured data-driven machine learning methods such as deep neural networks, and model-based approaches such as hidden Markov models and Gaussian processes. Aspects of these methods are covered in many courses, but greater coherence at EECS would help focus pedagogical efforts and to aid students in selecting from among courses. This is further exacerbated by the pace of development in the field and the rush to include it. EECS and its students would benefit from a logical division of the fundamental content and different methodologies into separate courses, which may also lead to a reduction in the sheer number of courses. It would also benefit from the creation of overview courses with less technical depth offered at the bachelor's level. Such courses would help students select specialisations within the fields of systems, control and robotics, machine learning, AI and intelligent systems.

5.4.3 Education

5.4.3.1 Area description

Courses are organised in packages according to research subject areas.

Each course has a specific division that assumes primary responsibility for it, which means that the Director of Study for that division coordinates staffing for this course. This is what we mean below when we say that a course is *offered* by a division. The course is most often staffed with teachers from that division, but many courses have teachers from several different divisions. Formally, the course is offered by the department.

Course package development plan

Here we provide a higher-level overview of our long-term course development plans (2021-2023).

We are aware that this list is very long, and so there might not be time and resources for all suggestions. We have only suggested courses where we have indications of student interest. Many of the new courses are in machine learning and related areas, which have become increasingly important in recent years, and where both industry and students themselves are requesting more education. We have also noted interest from a wider group of students, from Engineering Physics, Engineering Mathematics, Biology via Solid State Physics to Financial Mathematics.

From a longer-term perspective, we are interested in developing teaching activity in the following areas, which we believe are crucial parts of a complete education in intelligent systems:

The theoretical foundations of Artificial Intelligence, Machine Learning, and Information Science

- Continuing education in AI (and possibly other areas in Intelligent Systems) for graduated Master of Science in Engineering. Life-long learning will be a crucial part of engineering education as development in this area is accelerating.
- Experimental design and analysis. One current gap in engineering education is proper training in data collection, which is becoming increasingly important as data-driven methodologies become more commonplace.
- Ethical and societal aspects of AI. Technical development within AI is changing 'the rules of the game' and affecting certain aspects of how society works. It is extremely important that modern engineers are initiated into these developments.
- AI applications in Healthcare, Education, Society. We need to broaden our scope and connect to research and education in AI application areas.
- New paradigms in AI and machine learning. One example is Quantum Computing, an area in the intersection of Computer Science, Theoretical Physics and Information Science. Another is Neurocomputing, in the intersection of Computer Science, Brain Science and Information

Science.

- Autonomous Systems, in the intersection of Artificial Intelligence, Machine Learning, Information Science, Decision and Control, Robotics and Autonomous Systems, Computational Brain Science and Micro System Technology

- Decision Making, Learning and Adaptation. Such cross-area courses would give our engineers training in combining knowledge from different Intelligent Systems areas in building intelligent autonomous systems.
- Real-Time Decision and Control Systems. Such cross-area courses would give our engineers training in combining knowledge from different Intelligent Systems areas in building intelligent autonomous systems.
- Bio-Inspired Autonomous Systems. Here we can draw from the experience of MST and CST in bio-inspired computing and modeling. Such inter-disciplinary courses would give our engineers training in combining knowledge from biology as well as different Intelligent Systems areas in building intelligent autonomous systems.
- Applications of Autonomous Systems in Biotech and Life Science. We need to broaden our scope and connect to research and education in application areas of Autonomous Systems.

- Active Perception and Interaction, in the intersection of Robotics and Autonomous Systems, Computer Vision and Image Analysis, Computational Brain Science, and Speech Technology and Processing

- Behavior Production. This would give our students training in developing data-driven methods for generation of speech, facial gestures and other communicative behaviors.
- Behavior Understanding and Social Signal Processing. This would give our students training in developing data-driven methods for perception of human speech, facial gestures and other communicative behaviors.
- Intelligent Interactive Systems. This would give our students training in building systems (Virtual Characters and Social Robots) perceiving and producing behavior.
- Computational Cognitive Science. This would give our students training in developing methods that incorporate high-level reasoning.

5.4.3.2 Strategic investments (MK)

We will invest the MK in a fund for course development, where teachers can apply on a rolling basis for funding to do larger-scale pedagogical development such as changing an examination form for a course or adopting flipped-classroom teaching.

We will adapt to the higher yearly income by directing more funding for master's project examination and supervision. This is currently highly underfunded, with around 3% of an annual full-time equivalent for examiner and supervisor together. We will also revise the quite strict timeshares for course teaching and preparation.

5.4.4 Research

5.4.4.1 RPL

Present research areas

RPL is an internationally competitive division with a uniquely comprehensive research environment in robotics and autonomous systems, computer vision and other types of perception, and machine learning and artificial intelligence.

The largest subfield in robotics at RPL is manipulation and grasping, with a focus on highly deformable objects such as fabrics, in order to address some of the unfilled needs in domestic and industrial applications. We also explore how to enable learning of robotic behaviours for problems where both action and sensing are uncertain and highly dynamic. Furthermore, we explore how to transfer solutions generated in simulated environments to the real world, given that the simulation is typically a crude approximation of the real world. A central question in robotics is that of interaction with humans. We study the challenges connected to enabling robots that can handle efficient and engaging long-term interaction with people in real-world situations. This means that the robots must be able to capture, learn from and respond appropriately to subtle dynamics.

Mobile robotics activities have recently been expanded to research on indoor drones. The main focus is on methods for localisation and mapping and safe navigation and exploration. With the establishment of the new Swedish Maritime Robotics Centre (SMaRC) in 2017, RPL has also built up a significant amount of activity in the area of autonomous underwater vehicles (AUV). Here we target several of the core SD questions, but again at a longer horizon than 2030. We provide basic functions such as underwater navigation and planning that will then enable the target applications. Three examples are SEAFARM's algae cultivation project, surveying for offshore industrial applications such as wind farms and support oceanographic teams that are using AUVs to collect data to model the melting effects of ocean currents under the Antarctic ice to better predict ocean level rise.

We are working on correct-by-design planning, motion planning and control for autonomous systems to enable their safer, more effective, efficient and socially acceptable movement. Related to this, we use behaviour trees as a way to model switching between tasks in an autonomous agent, with tools for formal analysis of robustness and safety.

In the intersection between computer vision and machine learning, we work on recognition and interpretation of human and animal nonverbal behaviour. Tight collaborations with researchers in speech communication and interaction design complement this.

Deep learning has become a standard tool in most fields of research. It is powerful but not yet well understood theoretically. We contribute work on several key challenges. We work on explainability in deep learning decision-making processes and propose to represent human-interpretable explanations as part of the process. This will ensure that in that representation space we have an interpretable explanation that caused the decision.

We also develop methods to accompany deep network predictions with uncertainty estimates in an efficient manner and to deal with overconfident network predictions. In addition, we work on deep transform learning and domain adaptation. In another strand of work within machine learning, we study geometric-topological machine learning methods. This allows for reliable, hierarchical and efficient mechanisms for reasoning about problems such as motion. In particular, we study the gap between low-level geometric reasoning and hierarchical abstraction.

Future research areas

Two of our currently announced positions are tightly connected to RPL, one in machine learning and one in autonomous systems. If either of these positions is connected to RPL, the corresponding faculty will bring on board a research area that adds to RPL. It is not currently possible to state which specific area this will cover.

We also advocate using broad recruitment announcements for future positions at RPL. This will help us maintain our current favourable gender balance by being able to draw from a much larger pool of strong female candidates. We see continued growth in the machine learning area in general throughout all dimensions of our work: education, research and interaction with society. In terms of research, we predict that this expansion will take place in two main directions: application-specific machine learning and general-purpose machine learning, with a focus on explainability and developing a deeper understanding of models.

Strategic investments (MK)

RPL has decided on a number of initiatives funded by MK in the coming years aimed at making RPL an even better work place. The largest initiative short-term is moving RPL into one building (Lv24), which is estimated to cost roughly 5.5 MSEK. Another large initiative is to hire an administrator at RPL to provide a more local and customised support for the staff.

5.4.4.2 TMH

Current research areas

Research and teaching at TMH aim at understanding how humans communicate through speech, music and gestures. Rooted in an engineering modelling approach, our research forms a solid base for developing multimodal human-computer interaction systems in which speech, music and gestures are used to create human-like communication. The research field is truly interdisciplinary and is based on data collection, analysis and generation of human communicative behaviour. Central methods are obtained from speech technology, signal processing, machine learning, computer animation and robotics, and combined with knowledge from linguistics, phonetics, cognition and experimental psychology. TMH is a world-renowned research department, as evidenced by its participation in more than 25 EU projects and its high ratings in the KTH International Research Assessment Exercises: RAE2008 'This is an outstanding, world-leading research group – among the top and most respected (a national asset)', and the KTH RAE2012 states 'Research output is internationally excellent in all fields, with a substantial number of units reaching the level of world-leading quality. Another sign of its international reputation is that it organised Interspeech 2017, one of the largest international speech conferences (800 papers, 2,100 participants), as well as six of its satellite workshops.

TMH contributes to the advancement of the state of the art within the following research fields:

- Spontaneous conversational speech synthesis
- Modelling multimodal, multiparty interaction
- Modelling turn-taking in interaction
- Modelling co-speech gestures
- Development of spoken dialogue frameworks
- Social robotics, e.g., development of the Furhat robot
- Development of scientific clinical instrumentation for voice analysis
- Critical perspectives on the ethics of AI applied to music
- Modelling music perception

Future research areas

The Speech, Music and Hearing division has a 70-year tradition of research in speech technology and communication, where our aim has been to describe, explain and model human communicative behaviours and to improve the technologies and methodologies that allow us to do so. We also investigate how humans behave when using speech and social robotics applications, which is a multidisciplinary effort. Since we have a focus on situated, face-to-face interaction, comprehensive also takes into account visual input (using motion capture and computer vision) and output generation includes generation of lip movements, facial gestures, communicative gestures and body postures. In general, our goal is to further develop core speech technologies so they are able to deal with naturally occurring, real-world conversational speech and can be useful in real-world situations and real applications. Our conversational systems research aims at making interactions with these systems more fluent and making the systems more human-like. Our goal is to further develop our incremental multimodal dialogue models using machine learning that allows them to learn directly both from human-human conversation and from their own behaviours in conversations with humans. Social robotics envisions a future where robots and people co-exist, collaborate and communicate on human terms, alongside each other in the same environments. The methods explored in social robotics differ sharply from traditional robot research and focus on human interaction, collaboration and social behaviours as applied to robots. Our goal is to explore social robotics applications in a broad range of areas: for example, the intersection of the manufacturing industry and robotics, health care and teaching/tutoring.

Analysing and modelling the human voice apparatus brings us into contact with a wide range of disciplines, including acoustics, continuum mechanics, biomechanics, psychoacoustics, phonetics, phoniatrics, speech-language pathology, and the related signal processing. Our goal is to set up a voice research centre where we harness the long-term collaboration we have with the Logopedics Department at KI. The centre would share infrastructure, data and voice analysis methods, increasing our knowledge of human speech production and improving clinical practice.

Other well-established domains of expertise at TMH centre around music: acoustics, modelling and informatics. Historically, research in music acoustics at KTH has contributed significantly to understanding the piano, bowed instruments such as the violin and the singing voice. Research on the modelling of expression in music performance continues. Recent research in music informatics from TMH has been recognised by major awards: a best paper award at the flagship conference of music informatics (ISMIR 2019) and an ERC Consolidator Grant (ERC-2019-COG No. 864189). The latter award provides €2 million for a five-year project (2020-2024) that will bring two post-doctoral students and three PhD students to TMH and further strengthen collaborations with the Royal Conservatory of Music in Stockholm. The goals of this project centre around uses for artificial intelligence in music practices, such as listening, composing and analysis. One goal is to facilitate the discussion of the ethics of AI in music and in the arts in general. Another is to improve the development and application of AI to music with reference to the ethical framework developed in the project. The outcomes of this project will facilitate the use of AI applications in music in robust and responsible ways, impacting a wide variety of stakeholders. It will not only prepare music practitioners and audiences of the present (human and artificial) for new ways of listening, working, appraising and developing the art form but will also pave the way for analysing, criticizing and broadening the 'AI transformation' of other artforms.

In 2020-2021 TMH and RPL will build the Robotics and Interaction Labs (KTH IRL) on the ground floor of LV24, where we will co-locate the RPL robotics labs with the PMIL motion capture lab and the Språkbanken TAL perception lab. The Intelligence Augmentation Lab will be a joint RPL-TMH effort. Through this living lab we can explore the usefulness of augmented reality and social robots in a domestic setting. It will provide a physical setting with advanced technical infrastructure for unobtrusive real-time capture and processing of human motion and speech and for the data presentation (sensors, displays, robots and cloud-based and local software) required for true domestic-like situation-dependent human-machine interaction. The lab will serve as an important hub for integration and exploitation, where research results from different projects in social robotics and intelligent systems can be combined, matured and maintained as important showcases and used for demos, education and user studies. The KTH IRL infrastructure will be important for our research and development the next 5-10 years.

Organisational goals

1. We have long-term funding for scaled-up speech and language technology research
2. We have started a master programme for speech and language technology at KTH
3. We host speech technology infrastructure for both industry and the public sector
4. We have set up a strong speech technology forum for all kinds of stakeholders

Strategic investments (MK)

For 2020-2021 we have planned the following strategic investments:

- 3 MSEK start-up package for an assistant professor in intelligent systems with a specialisation in speech technology
- 3 MSEK building the Interaction and Robotic Labs at LV24

5.4.4.3 DCS

Current research areas

The Decision and Control Systems division comprises several strong research groups with complementary expertise and with a high degree of success in securing competitive external research funding. We have a strong publication record in terms of volume, impact and presence in prestigious venues. The academic staff, PhD students and postdocs are almost exclusively recruited from outside KTH, and the division has a good balance between Swedish and foreign participants. The division maintains a large national and international network in academia and industry.

DCS performs research in the broad area of automation, control, learning and decision-making. In particular, our expertise is centred around optimisation and control, networked control and robotics, machine learning, cybersecurity, intelligent transport systems, system identification, processing modelling and control. The division comprises an internationally recognised team of scientific excellence and proven leadership abilities. Their scientific production and impact are comparable with top research groups worldwide.

The main scientific contributions of DCS research groups are in the following areas.

Networked control

Wireless networked control systems emerged from the successful hardware and software developments of wireless sensor and communication networks. These control systems, with spatially distributed sensors and actuators, have the potential to drastically improve system robustness, performance and resource efficiency. Because the wireless communication medium imposes control loop imperfections, such as message delays and dropouts, appropriate modelling and analytical tools need to be developed, together with new control architectures and principles that are able to handle the uncertainty but also benefit from the additional flexibility. Several faculty members have contributed extensively to this area of research over the last 10-15 years and have received many prestigious awards and research grants for the work.

Cybersecurity

Cybersecurity in control systems is a new, rapidly evolving research field. The practical motivation comes from concerns about malicious cyberattacks against large-scale networked control systems, such as critical infrastructure (power systems, etc.). DCS has contributed to cyber-physical security metrics that localise inherent infrastructure weaknesses, and to methodologies for attack-resilient monitoring and controller design. Much of the division's cybersecurity work is conducted within the framework of the Centre for Resilient Critical Infrastructures (funded by the MSB, led by DCS), and within the Trust area of KTH Digital Futures.

Multi-robot systems

Robotics research involves theory and application for task planning and control of autonomous (multi-agent) systems in unknown and dynamic environments. The platforms considered include mobile robots (which may be also be equipped with manipulators), aerial vehicles and underwater robots. Further application domains include human-machine interaction and social networks. The theoretical results being developed involve elements from nonlinear and robust control, decentralised systems, hybrid control and formal methods for controller synthesis.

Optimisation and decision-making

With the growing ease of connecting devices that can sense, analyse and control the environment, there is an increased interest in developing technology for coordinating large distributed systems to conserve resources while guaranteeing the desired level of performance. It is natural to view this coordination as an optimisation problem and to develop coordination mechanisms based on principles from distributed optimisation. Examples include matching consumption and production in smart grids, managing radio resources over wireless networks and using machine learning on large distributed datasets. The academic staff at DCS has contributed to several fundamental aspects of multi-agent, distributed and large-scale optimisation, both in terms of new theory for asynchronous and communication-efficient computations and in terms of novel optimisation algorithms with strong performance guarantees.

Machine learning

The main activities at DCS in the area of machine learning concern the intersections of control and learning theories. Specifically, we develop theoretical tools that support the foundations of reinforcement learning (RL), including so-called bandit optimisation, and their application to iterative identification and control problems. A particular emphasis is on model-based RL, where a-priori knowledge of the dynamic systems to be learnt (e.g., through its structure) may considerably speed up the learning process. Most of our work deals with systems with large but finite state and action spaces, with applications such as the design of search engines or resource allocation over networks. However, recently we have been revisiting RL problems for more classical linear systems with continuous state and action spaces. Other important activities at DCS aim at deriving information-theory limits and efficient algorithms in clustering and change-point detection problems. One recent area of ML research is inverse decision and learning problems for Markov models.

Intelligent transport

Members of DCS study many applications for connected and automated vehicles and transport systems, where we apply methods from optimal and model predictive control, but also learning-based algorithms and graph-search planning methods. The research is applications-driven, and we collaborate extensively with the automotive and telecom industries (for example, Scania and Ericsson). Contributions include longitudinal and lateral control of self-driving vehicles, collaborative and coordinated control of vehicle platoons, motion planning, and routing and coordination of vehicle fleets. DCS has developed the KTH Smart Mobility Lab, which comprises a large set of heterogeneous autonomous miniature vehicles, a motion-capture system, wireless communication infrastructure, real-time integration of traffic data and a variety of user interfaces on both the vehicle and the operator levels. The lab is financially supported by KTH, Scania and Ericsson and is linked to the Integrated Transport Research Lab, which is co-directed by DCS faculty members. Our research in intelligent transport is supported by the KTH TRENoP (Research for novel transport solutions) strategic research area.

System identification and process modelling

System identification is a very strong research field within DCS, which has studied several subtopics intensely, including input and experiment design, estimation under sparsity and low-rank constraints (using convex and non-convex heuristics), kernel regularisation and continuous-time identification. In addition to the problem of estimating linear and nonlinear dynamic models, at DCS we have also developed tools for the efficient estimation and control of hidden Markov processes and for inverse filtering and control, where the goal is to reverse engineer an existing agent acting on a Markov decision process. We have also developed applications for system identification in several fields, including medical research, bio-production, and paper-making. DCS is leading NewLeads (New Directions in Learning Dynamical Systems), which is a strong environment research grant funded by the Swedish Research Council (VR). NewLeads is a collaboration with the Control & ML group at Uppsala University and concerns the intersection of automatic control, signal processing and machine learning.

Future research areas

We plan to continue to strengthen and enhance our signature research areas, including networked controls, robotics and autonomous systems, optimisation and control, machine learning, cyber-physical security, transportation and vehicular systems, and process modelling and control. In the near future, we see significant opportunities to expand our activities in cooperative autonomous systems, machine learning for control, and other core topics of digitalisation and automation in general. Part of this development will be done the recruitment of junior faculty and new cross-disciplinary collaborations in conjunction with the WASP and Digital Futures initiatives.

We see a strong convergence of our research disciplines under the umbrellas of AI, computing, digitalisation and autonomous systems. We also believe that future research will be even more motived in the direction of applications. We will also strengthen our industrial collaborations: for example, through more adjunct professors from industry. One example is the future electrification of transport systems.

Most of the DCS faculty are very experienced, and our strong research and education environment provides fertile ground for future faculty recruitments. We still have 5-10 years before our most senior faculty are retiring, and there is a strong need to hire complementary junior faculty who will be prepared to expand our future research agendas.

Strategic investments (MK).

DCS has a rather limited FoFu myndighetskapital (MK), given its research budget, and the division has decided to pursue a bottom-up process in which senior faculty obtain MK to invest in novel, high-risk research projects. We will use 3.5 MSEK per year over a four-year period for these strategic investments. Given the current situation, the timing is very good to invest in excellent PhD students and post-docs.

5.4.4.4 ISE

Current research areas

– What are the fundamental limits in communication, processing and learning?

We employ mathematical modelling and information-theoretic concepts to identify ultimate performance limits that govern communication, processing, and learning (e.g., capacity, complexity, uncertainty, and error). These limits are important benchmarks, and the underlying concepts guide us in how we can reach them. In the first half of the assessment period, the focus has been on communication systems, addressing topics like complexity, interference control, distributed systems and collaboration, storage and caching, automatic control over networks, and coordination, leading to roughly 15 graduated PhD students and more than five active PhD students and postdocs. In the second half of the assessment period, identifying fundamental limits in learning and processing has become a core activity of our research with more than 10 graduated, and more than five active PhD students.

– Which communication, processing and learning strategies allow for an efficient and (close-to) optimal utilisation of resources in achieving their task?

In several domains, we have contributed to closing the gaps between state-of-the-art performance and ultimate performance limits by providing coding techniques and communication protocols, signal processing and optimisation tools, and learning and processing algorithms. Our topics include massive multiple antenna systems, low-latency/ultra-high reliability protocols, and edge computing in 5G systems and beyond-5G systems, sensor fusion, compressed sensing, sparse signal processing, signal processing for biomedical data analysis and automated cell tracking. Overall, more than 15 PhD graduates and at least 10 active students and postdocs have contributed here.

–How and under which conditions can we guarantee security, privacy and trust through the design of communication, processing and learning techniques?

Our approach is based on concepts from information-theory security which lead to provably unconditional privacy and secrecy, as well as signal processing methods for intrusion detection and response. We have demonstrated the feasibility of these concepts and identified their fundamental limitations in a large number of contexts: e.g., secure communication, smart-meter privacy, privacy-preserving learning, privacy-preserving information retrieval and computing and biometric identification. At least PhD students have graduated in this area, and at least five PhD students and postdocs are currently active. In the future, we expect all three core research questions to maintain their relevance for our work, even though the underlying application domains will shift. An ongoing shift towards an emphasis on biological and medical systems is already visible.

Existing contributions to the advancement of the state of the art

Fundamental limits in communication, processing and learning.

We have contributed to **information-theoretic** bounds in relation to wireless communications, collaborative transmission over noisy wireless networks, cooperative interference management, approximations using deterministic models, multi-terminal relay networks, interference alignment, and wireless wideband networking.

We have also considered various source and channel coding scenarios, with novel extensions such as action-dependent side information and helper settings with security or privacy requirements. Furthermore, we investigated fundamental performance trade-offs relating to identification systems, considering multiple stages, uncertainty, and pre-screening.

We have developed necessary and sufficient conditions for stabilisation and control over noisy networks and have also contributed to networked coordination problems.

Some of our most recent work considers information-theory tools applied to machine learning, in particular in the information bottlenecks framework. We have also developed performance bounds for distributed optimisation algorithms for time-varying networks.

Algorithms for efficient communication, processing and learning.

Significant efforts have been made in considering transmission strategies for wireless communication. We have focused on techniques for large-scale MIMO (multiple-input/multiple-output) systems, such as low-complexity numerical processing for channel estimation, efficient algorithms for joint channel estimation, precoding with hybrid analogue/digital hardware, and machine-learning approaches for radio resource management. We have also contributed several results on modelling and mitigating the impact of imperfect radio frequency hardware. We have worked on ultra-reliable low-latency wireless networks and millimetre-wave communication.

We were also active in developing signal analysis methods of broad utility. A MIMO system identification method has been included in the MATLAB system identification toolbox since 2013, which makes it widely available to users. Very recently we have also advanced the understanding of information criteria for model selection.

Another important area has been provably optimal coding schemes based on practical, feasible coding techniques that allowed us to achieve the theoretical limits in problems like wiretap channels, cooperative relaying, and anytime communication.

We have also contributed to image processing with a focus on 3D/free-viewpoint communication. We advanced the state of the art in tracking 3D objects and real-time streaming of free-viewpoint content in a rate-distortion efficient manner, as well as achieving robust transmission over packet networks.

Additional work considers bioinformatics and medical data analysis. Together with colleagues at the Karolinska Institute and SciLifeLab, we worked on hidden Markov models for sepsis detection in preterm infants and for single-stranded DNA sequencing. A joint project with the Blau Lab at Stanford resulted in state-of-the-art multiple target tracking.

Security, privacy and trust.

We worked on physical layer authentication at the air interface of wireless networks. Significant contributions were also made in the area of privacy-by-design for cyber-physical systems. To enhance consumer privacy over smart grids, we worked on privacy-preserving energy flow control strategies. We have also considered privacy guarantees in various statistical inference problems. In addition, our work on network information theory has, in many cases, had a central goal of secure communication in the presence of wiretappers. More recently, we also contributed to the development of information-theoretic private information retrieval in scenarios with colluding servers and adversarial attackers, as well as passive eavesdroppers. Finally, we have contributed to the development of explainable AI, as exemplified by works on structured deep neural network dimensioning and training.

Future research areas

Our focus on fundamental research grounded in applied mathematics creates ample opportunity to contribute to a wide range of applications. Our solid base makes it easier for us to adapt to trends in what applications are 'hot' compared to more applied researchers, whose base is the application itself and not the foundations. In 5-10 years, our expertise and activities will reflect the full spectrum of information science, from machine learning and statistics, via biomedical data analytics, to networked societies. We will have established several new collaborations with societal partners in urgent need of expertise in data science and security/privacy for their research. We will always have sustainable development in mind when choosing which application areas to focus on.

In 5-10 years, we will have contributed significantly to the development of 6th generation wireless systems. We will also have established cyber-physical human systems, with humans as active decision-making agents in the network as one of our main fields of research. Our interest in information theory will, in addition, have contributed to the analysis and interpretation of various machine-learning techniques. A particular goal is that we will have established multiple results in the theoretical understanding of deep learning.

We believe that our existing faculty members represent the main directions we plan to explore, with one exception: quantum information. While the division already offers a PhD-level course in quantum information theory, we believe that an externally recruited faculty member will significantly strengthen our ability to compete for funding in this area.

The division conducts considerable research activities in the general area of wireless communications, while undergraduate and masters-level teaching in this area is coordinated by the Department of Computer Science (CS). In the longer term, it will be beneficial both for IS, ISE and CS to better coordinate both teaching and research activities in this area.

Strategic investments (MK)

We strongly advocate using savings to fund initiatives driven by our faculty members, either as individuals or on teams. Here, co-funding from savings for internationally recruited postdocs is an important investment to foster the division's international competitiveness. We will also use savings to co-fund initiatives driven by KTH Digital Futures.

5.4.4.5 MST

Current research areas

Biomedical Microsystems:

In many cases, the acceptable size of technology in medical applications is very limited. The Micro- and Nanosystems division develops miniaturised medical tools that enable new ways of performing diagnostics and therapy.

Micro- and Nanofluidics:

Micro- and nanofluidic systems, sometimes called labs-on-chip, are ultraminiaturized systems to control tiny amounts of fluids. Our research focus within micro- and nanofluidic systems is on developing integrated systems for healthcare applications. We develop novel technologies that enable powerful biomedical diagnostic and therapeutic procedures in new settings by simplifying their use and reducing their cost.

Microwave and Terahertz Microsystems:

RF (radiofrequency) MEMS (micro-electromechanical systems) are microdevices which interact with electrical signals by switching, modulating, filtering or tuning electrical circuits. The Microwave/THz research group within the Micro- and Nanosystems Division focuses on developing innovative micromachined devices and systems, including reconfigurable MEMS, for microwave and Terahertz applications. The frequency range we are primarily working with is 100 to 750 GHz. Major application fields are beam steering and remote sensing, in particular automotive radar and industrial radar sensors, telecommunication, radiometers for space and environmental sensing. The key research topic is to create complete THz systems on a micromachined silicon chip. The THz Microsystem group at KTH has already made some substantial achievements in this direction.

NEMS and Nanosystems:

Nanoelectromechanical systems (NEMS) and nanosystems have nanoscale features in at least one dimension and promise exciting applications for the Internet-of-Things (IoT) and biomedical devices. At the Micro and Nanosystems Division, we are researching novel graphene NEMS sensors, NEMS sensors for biomolecule detection, nanostructures structures made of biomaterials such as DNA and silk, and biohybrid nanostructuring of polymers.

Organ-on-a-Chip and Cell Models:

Microphysiological systems, also known as organ-on-a-chip, combine advances in microfluidics with biomimetic cell culture to emulate human organs or organ systems. They typically consist of two or more microfluidic compartments – allowing for the application of biochemical and biophysical cues – each hosting a specific type or mix of cells and separated by permeable barriers to facilitate cellular communication.

Photonics:

Light and optics are essential to many technical applications. Fibre optics has transformed communications, powerful lasers are used in industry to cut metal and optical measurements are common in the life sciences.

Sensors:

Sensors such as pressure sensors, accelerometers, gas sensors and biosensors are indispensable in modern society. At the Micro- and Nanosystems Division we are developing new sensor concepts, sensor packaging methods and 3D micro- and nano-manufacturing technologies, including micro 3D printing, for next-generation sensors in application areas such as medical, automotive, industrial, safety, aerospace, life sciences and IoT.

Soft Matter:

We research the manipulation of soft matter on the micro- and nanoscale. We engineer both synthetic materials (such as polymers, synthetic gels and granular materials) and biological and bioderived materials such as DNA, silk, and living cells. Soft matter structures, including biohybrid structures that integrate synthetic and biological matter, are being investigated as a way to study biological phenomena, to form biosensors and to create novel therapeutic formats.

Future research areas

Our plan is to reinforce and develop the position of MST as a world-leading micro- and nanosystem research group. To achieve this, we participate in multidisciplinary research collaborations with selected partners developing innovative micro- and nanosystem solutions for improving energy, healthcare and ICT applications. We are developing smaller, better-performing or lower-cost components and systems that address the major challenges of industry and society in these areas. We see the novelty and relevance of our research as our combined guiding principles. Our current partner network includes world-leading researchers from organisations such as MIT, Harvard University, EPFL, KI, Ericsson, etc. Whilst continuing collaborations with our partner network in existing and novel constellations, we plan to increase collaboration with healthcare professionals and industries and take a proactive role in the formation of new major researcher centres.

As a multidisciplinary division, we are uniquely positioned to leverage research collaborations with other academic groups and to cross-fertilise into new areas. The Micro- and Nanosystem Division therefore encourages visits from other divisions and schools, as well as faculty-initiated research relations with other universities.

We will continue our successful research in the six major application areas mentioned above but plan to expand further in the following new research areas: life science and medical technology, specifically biosensors, biohybrid systems and translational drug delivery; sensors, in particular, environmental sensors for sustainable societies; ICT and transport, specifically THz microsystems for telecommunication and radar applications, and advanced materials and nanotechnology, specifically micro and nano 3D printing, quantum technologies and programmable matter.

Strategic investments (MK)

Our plan for the upcoming years is to reduce the division equity line with instructions from KTH. This will be achieved through increased funding to our faculty and investments in new infrastructure and scientific equipment for the 2021-2025 period.

5.4.5 Competence Development

Based on the information in Sections 5.4.2 and our competence development plan, we envision the need for additional faculty recruitment in Artificial Intelligence, Real Time Autonomous Decision and Control Systems, Machine Learning, Robotics and Autonomous Systems, Language Technology and

Search Engines, Speech Technology, Computational Cognitive Science, and Intelligent systems in Medicine and Lifesciences

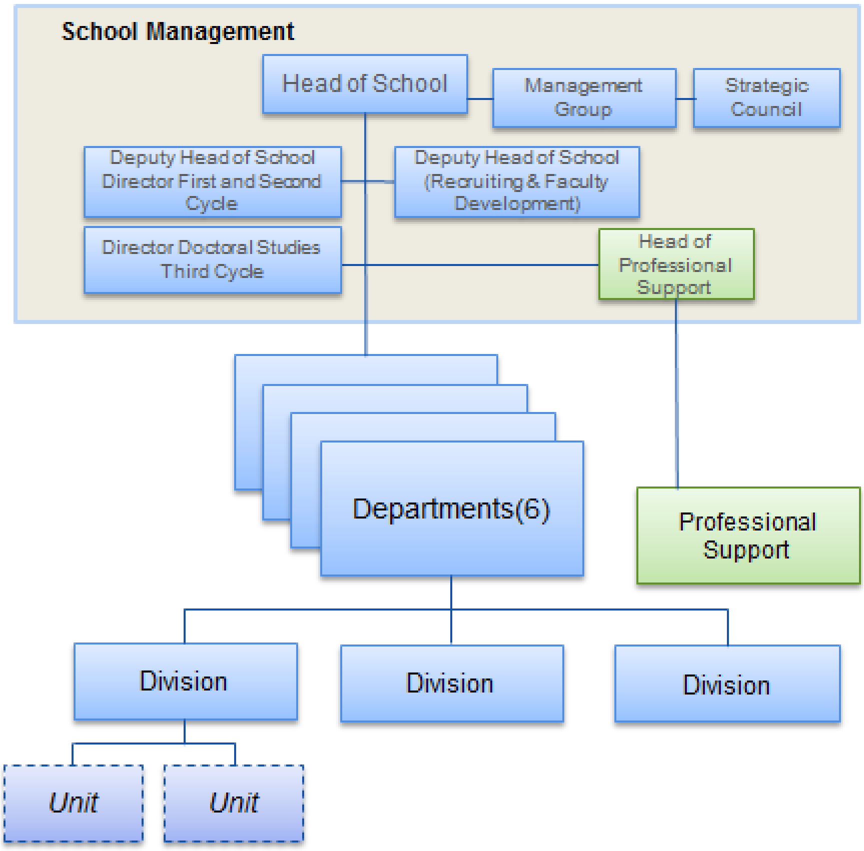
5.4.6 Strategic Investments and MK

As summarised in Sections 3.3 and 4.1-4.5, our MK is relatively large on both the education and the research sides. Moreover, the last financial summary showed that yearly revenues from education are 15-25% higher than expected in the budget for 2020, which implies that we have opportunity to make strategic efforts to expand our areas of research and education (see Section 3.2.13-3.2.15). We have therefore proposed the hiring of new assistant professors, in addition to the three ongoing recruitment processes.

6 Organisational development

6.1 School organisation 2023

The preferred organisational model for KTH schools is a strictly hierarchical line organisation model with five to six departments (*institutioner*) led by a department head, each consisting of a number of divisions (*avdelningar*). This organisational model has clear advantages from a management perspective, as it provides a clear division of responsibilities. It also allows for the delegation of many decisions to the department level (e.g., all temporary employment decisions).



6.2 Organisational development process

Moving from the current, flat organisational model with 16 divisions will require several steps in order to avoid major disruptions in school operations. A first step was taken in 2019 by introducing 'departments'. The departments will, during this intermediate step, focus on the operational aspects of undergraduate and masters-degree education and the long-term competence-development plan for each department's field. The divisions focus on the operational aspects of research. In research matters, division heads report to the Head of School.

In 2020, the second step was taken to reach the final organisational form, at least formally. Work remains yet to be completed, in particular in the new departments, in finding new and more-efficient ways of working that create both efficiency of operations (in particular with respect to education) while retaining the divisions' autonomy to conduct research in the way they feel is best.

7 Professional support

On January 1, 2018, the administrative units of the three former schools were merged into one Professional Support division for EECS. This organisational unit employs some 100 staff and is divided into six units (communication, finance, HR, student affairs, infrastructure & service and the school's administrative office). It supports 200+faculty, 500 doctoral students and 160 researchers/teaching staff across the school's 4 departments, 17 divisions and 8 centres, which are located at 10 different addresses. Some 5,300 students are enrolled at EECS and receive support from the Professional Support division.

To assist the School in delivering on the decided performance indicators and contributing to KTH's overarching focus areas (2018-2023), the division aims at providing efficient, transparent and close-to-operations support. All services offered should be relevant and lead to the development of the school's research, education and collaborative efforts.

To deliver on KTH's focus area, 'An Integrated KTH', EECS will work to provide one common 'entry point' for all services offered. The Service Centres are a major part of this solution and are both practically and digitally the natural place that the school's employees turn to for support. They are able to handle a variety of tasks and ensure that different processes are carried out in a lean and professional manner: e.g., practical arrangement for a doctoral thesis defence, low-cost procurement, travel planning, etc. They also act as a dispatch centre, forwarding tasks to the correct staff in the Professional Support division, always keeping the requestor updated about what is happening.

In order to ensure a close relationship with operations and know-how about the specifics of the research environment, EECS will further develop the concept of department and division teams. These will be the experts on specific research environments and will know the academic staff and the research projects, taking pro-active steps to make daily operations run smoothly. They will also be liaison officers to the rest of the support division and will, in most cases, have offices within the department or division.

The balance between keeping local know-how and providing efficient and professional centralised services will remain a main focus. One necessity to deliver on this will be a continuous and active dialogue between Professional Support and faculty to calibrate the support offered and the design of processes. Professional Support staff and academic staff need to cooperate even more closely in order to make the service lean and efficient. Mutual knowledge and understanding of conditions for each component will be key.

To keep the level of administrative costs down and to provide similar services to all faculty, a common support level for different areas will be established. This will be financed by all departments and divisions. The level will vary between areas and will be set during the budget process each year.

To ensure that the above goals are met, a second important strategy for Professional Support will be to strive to become one unit, by establishing common processes (such as budget routines, student services and recruitment processes), cooperating across unit boundaries and creating an inspiring and friendly work environment (see Chapter 8). Developing the staff's competences will be a core part of this ambition, along with using digitalisation to reach the established goals.

A third strategy is to intensify cooperation with the four other KTH schools, as well as the central administration (GVS), in order to benchmark, learn and form one cohesive KTH.

Strategy areas:

- The Professional Support Division will become a role model at KTH that is known for providing relevant, transparent, integrated high-quality support for research, education and collaborative efforts, which always is characterised by proactiveness.

- The Professional Support Division will become a role model at KTH known for its inspiring and creative work environment, where staff are encouraged to develop, take responsibility and challenge themselves.
- The Professional Support Division will become a role model at KTH known for its close cooperation with other KTH schools, as well as with the central administration (GVS).
- The Professional Support Division will have a specific focus on treating all students and all colleagues equally.

8 Work environment

The School of EECS should be an attractive employer, with a welcoming and inclusive work environment where employees thrive.

Preventive efforts, systematics and efficiency should permeate the management of the school's work environment issues. Transparency regarding work environment efforts is important, and the Head of School has through the School's delegation and rules of procedure distributed and delegated responsibility for staff and work environment to the Heads of Divisions/ Departments followings the school's delegation policies and rules of procedure.

KTH’s intranet, the School’s internal pages, workplace meetings (APT) and other informative meetings are the main communication channels for work environment issues.

The School will work in line with the President´s priority area for work environments – ‘Sustainable working life’ – and ensure that staff have an opportunity to reflect on KTH's personnel policy, including work environment policies, guidelines and routines on the matter and the KTH Code of Conduct.

The School merger has meant major changes, especially for the School's Professional Support Division. The process of creating a uniform Professional Support Division is ongoing and aimed at the goal of creating a work culture characterised by open dialogue between employees and management.

With regard to the organisational and social environment in the workplace, the School strives to ensure that employees experience a high degree of satisfaction at work thanks to a good work environment, employeeship, a healthy workload, continuing professional development and opportunities to influence.

An important factor for employee well-being is the physical work environment, which should be safe and ergonomic. In order to offer this, the School will ensure it is prepared for possible crisis situations and will have inventory procedures and risk assessments to prevent accidents and occupational diseases. It will employ properly trained personnel responsible for the various parts of the physical work environment.

Strategy areas:

- The EECS management (including Heads of Departments and Divisions) and the HR Unit will work on the employee-ship, and making the KTH Code of conduct well known and a natural guide for the employees.
- The EECS management (including Heads of Departments and Divisions) and the HR Unit will work to ensure that there is no inequality, discrimination, harassment or sexual harassment.
- The EECS management (including Heads of Departments and Divisions) and the HR Unit will work to ensure that the premises are functional, ergonomic and adapted to the organisation’s needs.
- The EECS management (including Heads of Departments and Divisions) and the HR Unit will work for a sustainable working life at the school and that all employees and students treat everyone with respect.

8.1 Work environment group

A work environment group, consisting of operational representatives, has been appointed to work with the school's systematic work environment and to serve as an advisory body for the Head of School on the issues of work environment and equality. The work environment group reports to the school management and supports the Heads of Departments and Divisions in work environment issues.

It is also important that there be good cooperation with the central university administration (GVS) regarding work environment laws and KTH guidelines and instructions. In addition, coordination of processes, processing and collaboration with the other KTH schools will be required.

9Sustainability

The sustainability work at the School of EECS is aimed primarily at environmental, economic and social sustainability. It is defined by continuous activities and high ambitions focused on contributing, in the best ways possible, to the sustainability goals of KTH (‘A KTH for a more sustainable world’). EECS aims to continuously identify and improve our sustainability performance through a step-by-step process, starting with the low-hanging fruit, with a general philosophy that no improvement is too small to neglect.

One long-term goal is for our sustainability work to influence all parts of the School. It should be well integrated, meaning it is applied to all parts and levels. It should also be carried out in close collaboration among groups/divisions/units within EECS, as well as in collaboration with the other schools at KTH and KTH’s central administration (KTH GVS). External partners will be essential contributors as well

Maintaining such integration, quality and ambition requires continuous work and monitoring. This will be driven by the Head of the School, coordinated by environmental representatives with the involvement of academics, staff and students.

At EECS, sustainability is pursued within the framework of an environmental management system. KTH holds ISO 14001:2015 certification for environmental sustainability.

Strategy areas:

- The pursuit of sustainability will influence all EECS processes and routines, as well as steering documents.
- The pursuit of sustainability will focus on delivering projects under the school’s local Sustainability Plan.
- The pursuit of sustainability will strive for the school’s campus environments to be characterised by sustainable solutions.
- The pursuit of sustainability will be carried out in close cooperation with other KTH units (schools and GVS) and with external actors.
- The pursuit of sustainability at EECS will satisfy the key performance indicators set by KTH centrally.