SELF-EVALUATION Research 2021 **Computer Science**

UNIVERSITY OF TWENTE.

SELF–EVALUATION
Research
2015-2020

COMPUTER SCIENCE
UNIVERSITY OF TWENTE

October 15, 2021

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This document was prepared in LaTeX in the overleaf.com environment, using the Carlito font.

Contents

Abbreviations and Acronyms

	Groups in Computer Science	Chair
AM	Applied Mathematics	
CAES	Computer Architecture for Embedded Systems	Prof.Dr.ir. Geert Heijenk (interim)
DACS	Design & Analysis of Communication Systems	Prof.Dr.ir. Geert Heijenk
DMB	Data Management & Biometrics	Dr.ir. Maurice van Keulen
FMT	Formal Methods and Tools	Prof.Dr. Marieke Huisman
HMI	Human Media Interaction	Prof.Dr. Dirk Heylen
PS	Pervasive Systems	Prof.Dr. Paul Havinga
SCS	Services and Cyber Security	Dr.ir. Marten van Sinderen

	Research Institutes
CTIT	Centre for Telematics and Information Technology
DSI	Digital Society Institute
TechMed	Technical Medical Centre

	Graduate Schools
ASCI	National research school: 'Advanced School for Computing and Imaging'
IPA	National research school: 'Institute for Programming research and Algorithmics'
SIKS	National research school: 'School for Information and Knowledge Systems'
TGS	Twente Graduate School

	Other
4TU	Federation of four technical universities: Delft, Eindhoven, Twente, Wageningen
BMS	Faculty of Behavioural, Management and Social Sciences
CEDICT	Centre of Excellence in Dependable ICT (aka 3TU.CEDICT)
CORE	Conference Ranking by the Australian Computing Research & Education
CPS	Cyber-Physical systems
CS	Department of Computer Science within EEMCS at the UT
CSS	Cyber-Social systems
DCPS	Dependable Cyber-Physical systems
DMB	Data Management & Biometrics
DMP	Data Management Plan
EC-CIS	Ethics Committee Computer & Information Science
EE	Electrical Engineering
EEMCS	Faculty of Electrical Engineering, Mathematics, and Computer Science at the UT
EIP	European Innovation Partnerships
EFRO	Europees Fonds voor Regionale Ontwikkeling
EIT	European Institute of Innovation & Technology
EIT 'Digital'	refers to the Knowledge Innovation Community, previously 'ICT Labs'
ETP	European Technology Platforms
FES	Fonds Economische Structuur versterking
FPGA	Field-programmable gate array
GDPR	General Data Protection Regulation
GPU	Graphics Processing Unit
ICT	Information and Communication Technology
IIP	Dutch ICT Innovation Platforms
IoT	Internet of Things
IPN	ICT-research Platform Netherlands
JTI	European Joint Technology Initiatives
KNAW	Royal Netherlands Academy of Arts and Sciences
LOWI	National Body for Academic Integrity
NESSIE	Centre for Networked Systems and Intelligence
NIRICT	Netherlands Institute on Research in ICT (also known as 3TU.NIRICT)
NWA	Dutch National Research Agenda (Nationale Wetenschaps Agenda)
NWO	Dutch Research Council (funding agency)
PPP	Public-Private Partnership
RDM	Research Data Management
SBD	Strategic Business Development
SEP	Dutch "Strategy Evaluation Protocol" by KNAW, VSNU, NWO
T&SP	Training and Supervision Plan for PhD candidates
TUCCR	Twente University Centre for Cyber-security Research
UT	University of Twente
VSNU	Association of Universities in the Netherlands
VU	Vrije Universiteit Amsterdam

Preface

We are happy to present to you the Self-Evaluation Research 2021 of the Department of Computer Science (CS) of the Faculty of Electrical Engineering, Mathematics and Computer Science (EEMCS) of the University of Twente (UT).

Looking back at the past six years, one thing becomes very clear: the future is unpredictable. At the start of the reporting period, the Computer Science department was still in the process of reducing research and supporting staff because of low student numbers, amongst other things. Six years later, we are struggling to find enough people for our research and teaching as the number of students has increased fivefold.

In the past six years, we have strengthened our focal areas of research in emphasising collaboration between the research groups, with other departments in the faculty and with other faculties.

We are proud of what we achieved in particular in a period when COVID-19 made our work more difficult. But we also noticed that there is still work to be done to improve some weaker points. With more financial means becoming available because of increased student numbers and both national and international investments in ICT, we are confident that the strategy that we are developing to take away the weaknesses and counteract the threats will be successful.

This self-evaluation was prepared under supervision of the head of the department. Several sessions with the chair holders of CS and the faculty board were held to discuss draft versions of the report with special attention to the SWOT analysis and the Key Performance Indicators. Thanks are due to the supporting staff who swiftly provided all the information on finances, human resources, publications and more.
Special thanks go to Floor Meijer for providing many suggestions on content and her contributions, to Anne van de Maat for assisting in many ways in organising the whole endeavour and to Job van Amerongen for his guidance, editing work and his encouragements.

Prof.dr. D.K.J. Heylen
Head of the CS department

Prof.dr. J.N. Kok
Dean EEMCS

The self-evaluation starts with a brief presentation of the research unit. Main characteristics, important organisational features and changes over the past years are presented.

1 Introduction

1.1 Introduction

Computer Science and computational thinking are transforming the world and influencing the way that research in other disciplines is conducted. The next generation of computer science is outward facing: bringing expertise in harnessing data and computing power for the outside world. The UT excels in bringing fundamental and applied research together. The Department of Computer Science is especially strong in people-centred, crossover research on smart, safe and sustainable information technology.

The department collaborates intensively with other research fields within and outside the faculty. Several groups within CS combine expertise in information technology and electrical engineering: physical systems such as sensor systems, robotics, the Internet of Things and embedded systems have become an integral part of the overall systems solution. There are also close connections to research in mathematics with data science and the joint initiatives on energy as examples. Furthermore, as a *People First University*, the collaboration with researchers that have a basis in the Humanities and Social Sciences is also very close. The research is firmly embedded in research institutes that have the goal to foster interdisciplinary research to make an impact on society. In particular the Digital Society Institute (DSI) and the Technical Medical Center (TechMed), with high involvement in the programmes on eHealth and robotics, amongst others, play a vital role. Through these initiatives there is a lot of collaborative research with groups of other departments including Engineering Technology and Behavioural and Management Science. The department is connected with the other technical universities through two 4TU research centres: NIRICT and Humans & Technology.

People First University

Computer Science at the UT is built on strong focal areas: *Cyber-Physical Systems*, *Cyber-Social Systems*, *Data Science*, *Software Science* and *Security*. The research is inspired and driven by real-life challenges. Scientific challenges concerning the core of software and data science, the integration of information technology in embedded systems and networks are fundamental, while also studying human-technology-interaction. Security in particular is a cross-cutting concern that receives special attention and which we therefore also identify as one of the focal areas.

Focal Areas:
Cyber-Physical Systems
Cyber-Social Systems
Data Science
Software Science
Security

For more details, see Section 2.2

1.2 Research environment and embedding

1.2.1 Faculty of Electrical Engineering, Mathematics and Computer Science

The University of Twente was founded in 1961 to innovate the manufacturing industry around Enschede. The motto of the UT in the period covered by this report was "*High Tech, Human Touch*" which translates in the current slogan to: "*The University of Twente is the ultimate people first university of technology. We empower society through sustainable solutions*". Central values of the UT are to be entrepreneurial, inclusive and open. The University has five faculties, and the Faculty of Electrical Engineering, Mathematics and Computer Science (EEMCS) is one of them.

High Tech, Human Touch

See Figure 1.1

Connecting themes of the faculty between the departments are the application areas energy, security, health and well-being but also robotics – with social robotics as a major domain of research in the Cyber-Social focal area.

The faculty opts for a certain autonomy within the three constituent disciplines, whereby substantive choices are made within the disciplines. The disciplines formulate their *research agendas* and partly

Research agendas

are given the space to align the distribution of research budgets to this agenda. The agenda is translated into the *annual plan* [3] of EEMCS.

Annual plan

Teaching

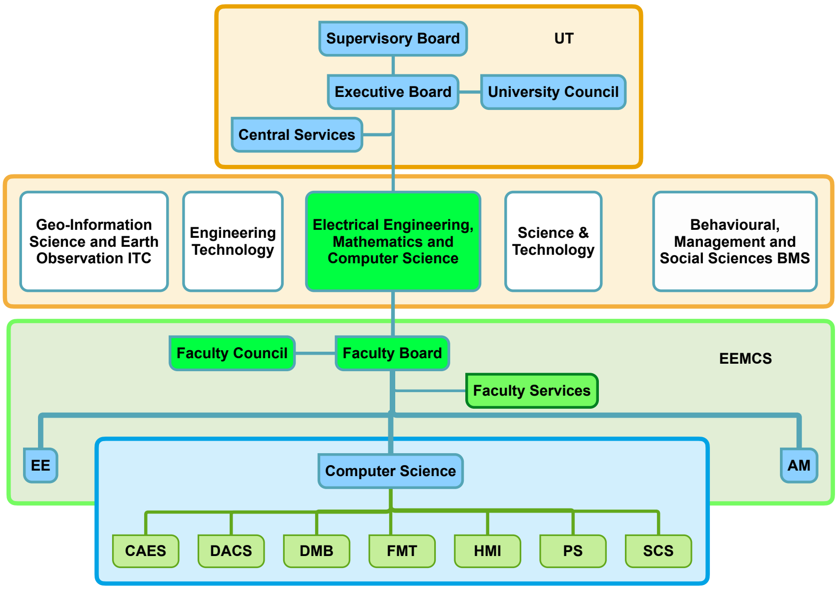
With respect to *teaching*, the Department of CS is either responsible or heavily involved in the BSc and MSc programmes of Technical Computer Science, Business Information Technology, the BSc programme Creative Technology and the MSc Interaction Technology. It also plays an important role in the MSc Embedded Systems and in the MSc Robotics currently being developed.

Figure 1.1
Organogram of CS in the UT

5 faculties

3 departments in EEMCS

7 groups in CS



1.2.2 Department of Computer Science

See Figure 1.1

The department of Computer Science consists of seven research groups. They work together in the focal areas mentioned above. These focal areas are described in the next chapter.

CAES [4]

The *Computer Architecture and Embedded Systems* group (CAES) studies energy-efficient architectures for dependable networked embedded systems. This includes design technology and efficient architectures for embedded, high-performance and cyber-physical systems and architectures for efficient energy management in Smart Grids.

DACS [5]

The *Design and Analysis of Communication Systems* (DACS) group studies the design and analysis of wired and wireless networked systems, focusing on their security, resilience and performance by means of measurements, modelling and simulations.

DMB [6]

The *Data Management and Biometrics* group (DMB) works on explainable data science by developing methods for autonomous, reliable and robust gathering, preparation, and analysis of data, to enable relevant, trustworthy and explainable results.

FMT [7]

The *Formal Methods and Tools* group (FMT) develops methods and techniques for verification, testing and synthesis of concurrent and distributed software, high-performance algorithms and data structures for (multicore) model checking, model-driven design and analysis, language design, predictive maintenance, and quantitative analysis.

HMI [8]

The *Human Media Interaction* group (HMI) investigates multimodal interaction: from brain computer interfaces to social robots. It is a multidisciplinary group in which computer science meets social science to investigate, design and evaluate novel forms of human-computer interaction.

PS [9]

The *Pervasive Systems* (PS) group studies systems that are composed of a network of collaborative sensing, computational, and reasoning components. These systems are highly embedded in and actively –yet unobtrusively– interact with the environment. The group studies how to optimise such systems considering such factors as energy-efficiency, transparency and scalability.

SCS [10]

The *Services and Cyber-Security* group (SCS) works on the design and analysis of trustworthy and secure services that are realised by the complex cooperation of human and software agents, focusing on semantic interoperability, context-awareness, security for data and data for security.

1.2.3 Research institutes

Before 2017, research was organised through scientific institutes. It was the prerogative of the institutes to develop strategic lines for research in close collaboration with the research groups. The 'Centre for Telematics and Information Technology' (CTIT) was fully dedicated to research related to computer science. In the reporting period (since 2017) this model was changed considerably: governance and financing of research were transferred to the faculties. The current institutes are responsible for setting up multidisciplinary projects across faculties, capitalising on the UT's strength in collaborating between the various disciplines. The relevant institutes for Computer Science are the Digital Society Institute and the Technical Medical Centre.

DSI

Data Science & AI,
Smart Industry,
eHealth,
Robotics and
Cyber security

The *Digital Society Institute* [11] (DSI) performs scientific research in technology that is essential for digitalisation, on methods and techniques for integrating digital technology into our environments, and in how we can come to intelligent, well-informed decision making. An important aspect of the mission of the institute is to conduct research that has a positive impact on society. As a partner in regional, national and international ecosystems, DSI offers the knowledge, education and infrastructure for the development of successful solutions and products. DSI focuses on five themes: Data Science & AI, Smart Industry, eHealth, Robotics and Cyber Security.

TechMed

TechMed offers access to clinical institutions and facilitates applications in real-world settings.

The *Technical Medical Centre* [12] (TechMed) is a leading Innovation Hub impacting healthcare by excellent research, innovation and educational programmes. TechMed collaborates with industry, hospitals, governments and insurance agencies on the development of new solutions for healthcare. It initiates common research proposals, builds a community through extensive health-related events (so-called TechMed events). TechMed facilitates small grass-roots initiatives through concerted actions with the regional hospitals and educational institutes. Examples are the Pioneers in Health Care (PiHc) vouchers for combined technical-medical research for one year projects in which many researchers of the Computer Science department participate. The Personalised EHealth Technology Project [13] is one of the multidisciplinary projects in which CS plays a prominent role.

1.3 Research Staff

In the previous review period, the Computer Science department went through a reorganisation, which resulted in a serious reduction of staff – including technical-support staff. This resulted, at the start of the review period, in a somewhat unbalanced staff population, with relatively many older staff members, including full professors, compared to the more junior functions. During the review period, the following strategy and trends resulted in a relatively large shift in the composition (see Table A.2 and Figure 1.2):

Senior staff members left

- Senior staff members who left (e.g., due to retirement or other career steps) have in several cases been replaced by more junior staff members resulting in a decrease in the number of full professors, compared to assistant professors.
- To some degree this has been counteracted by promotions from assistant to associate and from associate to full professorships. More such promotions are expected in the foreseeable future, filling up gaps in senior personnel in some research groups.

New academic staff

Lecturers/teachers

- We have also hired additional academic staff at the assistant and associate professor level, to deal with the strong growth in the student influx of our Computer Science programme (a factor of 5(!) over the review period). In addition, we have an increasing number of *lecturers/teachers*, only charged with educational duties. This number has grown from 2.2 FTE in 2015 to 7.5 FTE in 2020.

FES funds

- A 30% reduction in the number of PhD candidates can, besides to the reorganisation, be attributed to the more than 50% reduction in the research grants (see Figure 1.3 in Section 1.4). Also the expiring funding from the *FES funds* ('Fonds Economische Structuurversterking') had its impact.

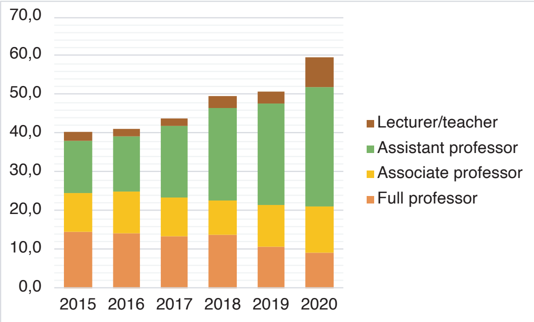
Sector plans

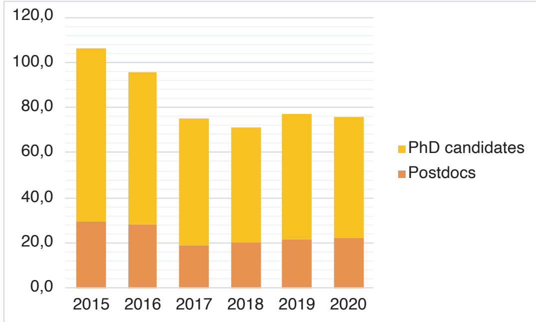
See Section 1.4

- In 2020/21, the '*Sector plans*' have allowed us to improve the balance between research and education capacity with 8 new positions. This is not yet visible in the graphs shown.

Figure 1.2
left:
Scientific Staff (fte)
and right:
Postdocs and PhDs
(fte),

Based on table A.2



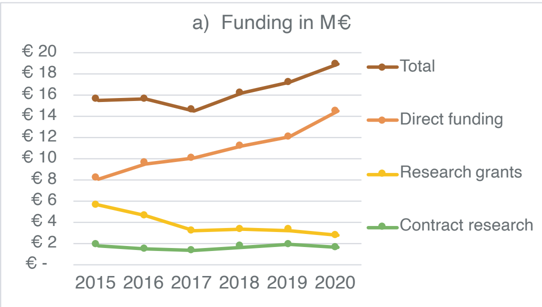


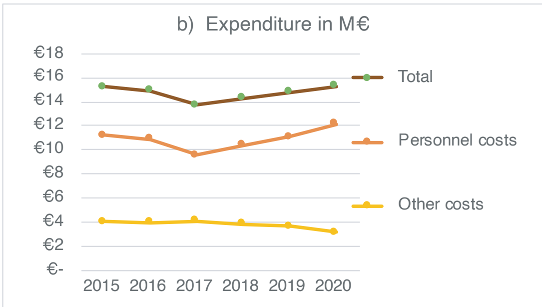
In Table A.2 and Figure 1.2 a full-time employed staff member is counted as 1 fte, thus also counting the time spent on teaching. Appointments ≤ 0.2 fte are not counted.

We regard the staff composition as healthy, leaving room for further growth and promotions, while noting that a significant part of the overall capacity is needed for, and financed by, education.

1.4 Financing

Figure 1.3
a) Funding and
b) Expenditures
in M€ , based on
Table A.5





- Direct funding = funding by government/university ('basisfinanciering')
- Research grants = grants obtained in national and international scientific competition e.g. grants from NWO and KNAW, and ERC. (Note: this deviates from SEP, where ERC grants are listed under Contract research)
- Contract research = funding for specific research projects obtained from external organisations, such as industry, government ministries, and charitable organisations.

Direct funding has considerably increased

As Figure 1.3 and Table A.5 show, the *direct funding has considerably increased* in recent years; from 15.5 to 18.8 M€. This can partly be attributed to the increase of the number of BSc and MSc students in the review period (see Figure 3.2). Figure 1.3 also shows that the expenditures rose slower than the funding, resulting in a positive balance of 3.5 M€. The reason for this is that hiring new qualified staff is difficult. This leads to a high teaching workload for the present staff. As a result there is less time available for writing research proposals, which can be observed in the *decreased funding from research grants* and in a decrease in the number of PhD candidates (see Figure 1.2). On the positive side: the money for new staff is available, which in the longer term will lead to a better balance between the time available for research and education.

Decreased funding from research grants

1.4.1 Sector plans

An important stimulus for our research was obtained from the *Sector plans*, [14], [15]. In November 2018 a document [14] was produced by the 'Bèta' disciplines in the Netherlands with plans to stimulate these disciplines with many new staff positions and start-up funds for the new staff members. This plan was elaborated on for the UT in a *Profiling plan: 'Impuls to Innovate'*, [15]. For CS at the UT this implied 6 new positions in the focal areas of CS (2 full professors and 4 assistant professors). Two additional requested, but not honoured, assistant-professor positions are funded by the UT (30% matching). As a result the 5 focal areas of CS got 8 new positions in total. The total budget from the Sector plans, including the 30% matching, is 6148 k€ for the period 2019-2024. This extra funding of more than 1000 k€ per year, significantly contributes to the rise in the total funding.

N.B. In the Sector-plan documents the five focal areas are referred to as 'Zwaartepunten' 1-5 (ZP1-ZP5).

In this chapter we describe our mission and the main strategic aims of the past six years. This description regards our contribution to scientific knowledge, as well as our contribution to society.

2 Mission and strategy during the assessment period

Seamless integration of ICT into our modern digital society

> The mission of Computer Science at the University of Twente is to establish a *seamless integration* of ICT into our modern digital society, by investigating the development of systems that one can justifiably rely on, and that people can effortlessly interact with.
> In collaboration with other disciplines, we aim to combine fundamental and applied research that addresses the needs of people and the world at large.

2.1 Strategy

Summarising the introduction in the previous chapter, research at the CS department at the UT is outward facing: we are inspired by real-world questions and place people at the centre. This means that we need to connect our fundamental research in the core of information technology – data science and software science – with a broader vision in building systems that can be applied and used by people. This then means two further things. First, we are also driven to build and to integrate: to make things work, to embed software into hardware (sensors, networks, smart environments; the Internet of Things). This integration we refer to with the term *Cyber-Physical*. Second, we need to make sure that people can use the systems we are building and that have the intelligence to interact with people. Therefore, we make investigating *Cyber-Social* systems part of our core business.

Cyber-Physical

Cyber-Social

To realise our mission, we need to collaborate both internally in the department but also with other disciplines. Within the research groups expertise is often mixed with people trained in computer science, mathematics, electrical engineering, and physics, but also biology, linguistics, and psychology. In the reviewing period we have continued to strengthen the collaboration between groups through various means. The aforementioned sector plans positions are one, as are the multidisciplinary projects from the research institutes that we collaborate in, such as the personalised e-health project and the robotics project. The latter two cases also showcase our goals to connect to industry and society as they are not just initiatives that connect research groups but also connect to the outside world.

We have set up more intensive collaboration with industry and external stakeholders through setting up research centres such as the Centre for Networked Systems and Intelligence (*NESSIE*) and the Twente University Centre for Cyber-security Research (*TUCCR*). Within the faculty we have intensified our connections with mathematics and electrical engineering thanks to special funding for collaborative research projects.

NESSIE

TUCCR

As the reorganisation in the previous period was mainly due to low student numbers, we also invested in study programmes to attract more – and in particular more international students. The investment in EIT programmes *Human Computer Interaction and Design* or *Cyber Security*, and the revision of the MSc programme *Interaction Technology* (before Human Media Interaction) have proven very successful. Another goal that we set out in this period is an increasing diversity in terms of gender and nationality.

Human Computer Interaction and Design

Cyber Security

Interaction Technology

In this chapter we will first present our research lines followed by a more general context in which we conduct this research and that characterises part of our academic culture.

2.2 Research lines and objectives, Focal Areas

Focal Areas

As we mentioned in the introduction, the research is organised in five *Focal Areas*. Here, we describe the aims of each of these.

Focal Area 1 Dependable Cyber-Physical Systems

CAES
DACS
PS
See for an example Twente47 at page 14.

Cyber-Physical Systems are systems composed of a network of collaborative sensing, computational and reasoning components that are highly embedded in the environment and actively interact with it. Within the three Cyber-Physical Systems groups (*CAES*, *DACS*, *PS*) we perform research on dependable connected and distributed embedded systems. Cyber-Physical Systems cooperate to support various applications as unobtrusively as possible (transparently and accurately), making efficient use of scarce resources independent of growth (scalability), in such a way that the system adapts to a dynamically changing environment (evolvability, adaptability), and operates and gives results that can be relied upon (trust). Mainly due to resource constraints, devices and connections are inherently unreliable, yet the system should be able to provide reliable services (quality, fault-tolerance).

Focal Area 2 Dependable Cyber-Social Systems

HMI
DMB
PS
SCS
See for an example the case study C.6.

Our human-centered computing research investigates the interaction loops between people and computers in both directions. On the one hand we study how people use and experience technology and on the other hand we develop and study technology that knows how to interact with people and that provides usable, useful, and pleasurable experiences enriching people's lives. In the past period, our research has been driven to a large extent by societal questions. Thus we have explored, amongst other things, haptic technology for children born deaf-blind, investigated how people with severe mental and physical disabilities can experience a sense of control with an interactive installation and built a robot that can help young children in the autism spectrum to learn social skills. The technology that we use, study and develop is very broad: conversational systems (built on speech technology and natural language processing), virtual and augmented reality, humanoid robots, brain-computer interfaces and haptics. We have many people with a mixed background that includes expertise in speech and natural language, psychology, and psychiatry. One of the usual approaches in this focal area is research through design and experiments with users.

Focal Area 3 Data Science and Engineering

DMB
HMI
DACS
PS
SCS
See for an example the case study C.1

Data Science is a rapidly growing interdisciplinary field aiming to develop technology for extracting knowledge and insights from voluminous noisy, structured, and unstructured data. This is used for decision making and smart services across a broad range of application domains. The field is related to machine learning, data mining, big data analytics, and data management. Our research on Data Science and Engineering (DSE) stretches from the *DMB* group into many other groups of computer science (such as *HMI*, *DACS*, *PS*, *SCS*) and other disciplines (departments such as Applied Mathematics, Electrical Engineering, Mechanical Engineering, Business Science, and institutes such as DSI and TechMed).
The challenges in DSE are, on the one hand found in data preparation, obtaining high quality data suitable for analytics from voluminous noisy distributed sources, and on the other hand in modelling, obtaining reliable, trustworthy and usable (predictive) models from this data. One can think of concepts such as fairness, data quality, robustness, privacy, and trust, and threats such as bias, morphs, energy consumption, and fake news that must be addressed.

Focal Area 4 Software Science and Engineering

FMT
SCS
See for an example the case studies C.2 and C.4

At the heart of all ICT systems is software that needs to be reliable, trustworthy and maintainable, in order to provide the required system functionality and services over prolonged periods of time. Both the Formal Methods and Tools (*FMT*) group and the Services and CyberSecurity (*SCS*) group work on Software Science and Engineering, focusing on the following two scientific challenges: (i) to support the development of robust and reliable software that can react and adapt to dynamically changing contexts and situations; and (ii) to handle the continuously growing complexity of software.
On the one hand we develop mathematical methods, high-performance data structures, and suitable

programming languages for software- and data-intensive systems. On the other hand we develop methods, models and languages for designing the coordination and semantic interoperability of software systems in their socio-cyber-physical context. The synergy between these complementary approaches for building complex software systems is also fostered through the investment of the Sector plans [14], [15] with two positions (each at one of the groups) that will work on the topic of Software Evolution: how to develop reliable software that can easily be maintained and extended and can be adapted to changing requirements and situations.

Sector plans

Focal Area 5 Security

DACS
SCS

Securing society against cyber threats is one of our core missions. Our research focuses on data and network security. We research advanced cryptographic protocols to provide security for data, both while stored and transmitted over networks and during data processing. We also study data for security and aim at AI-based fully automated systems that can identify, analyse, prevent, and respond to cyber threats. For network security, we focus on three challenges: imminent threats, for which we develop means to detect, mitigate and prevent existing attacks, the security evolution of networks, and finally, the design of future secure network systems.

See for an example the case study C.5

To achieve immediate impact for society, we collaborate closely with partners from industry and government. Over the past six years, we helped shape the national cyber-security research agenda, and were highly successful in attracting funding from calls related to this agenda [16]. Similarly, we are a partner in several large-scale Horizon 2020 projects, with strong industry participation, covering the entire cyber-security landscape. A key example is the CONCORDIA project in which the UT is a leading partner. This consortium not only performs groundbreaking research, but also trains the next generation of cyber-security specialists, with a strong focus on diversity (CONCORDIA Women in Cyber-security programme [17]).

See also the Women Cyber Manifesto [18]

2.3 Safeguarding Research Integrity

2.3.1 Code of conduct

House of Integrity

At the UT we have an integrated integrity programme called 'House of Integrity' [19] to structure and organise various integrity policies, regulations and practices. Our House of Integrity approach covers scientific, social and business integrity. With respect to scientific integrity, the UT has a code of conduct with general principles of integrity for everyone who is part of the UT community: employees, students and those representing the UT. This code of conduct entails the key values of the UT and general principles of integrity including scientific integrity for students and employees. All those involved with education and research bear responsibility regarding upholding scientific integrity as specified in the above-mentioned code of conduct. The UT stimulates an environment within which responsible research practices are stimulated and warranted. The UT offers dedicated facilities such as ethics assessment of research and innovation, scientific integrity education for PhD candidates and research data management support.

The University of Twente subscribes to the guidelines for scientific integrity, as specified in the VSNU policies and procedures in the Netherlands Code of Conduct for Research Integrity [20]. The European code of conduct [21] and the Singapore statement on research integrity [22] are also relevant as well as the advice of the KNAW about correct citations [23]. The UT website [24] and the links provided there, explain in detail how the UT deals with issues concerning scientific integrity. The department of Computer Science adheres to the university-wide policies and procedures for scientific integrity.

2.3.2 Ethics protocol

House of Integrity

As part of the 'House of Integrity' [19], the UT has a university-wide research ethics policy. Students, employees, and others involved in our research are expected to follow good scientific practices of ethical research.

When a project concerns medical research involving human subjects, a medical-ethical review may be mandated under the Medical Research Involving Human Subjects Act (WMO). For this, the UT

collaborates with an accredited MREC, the CMO Arnhem-Nijmegen, and support is offered by the UT TechMed centre.
When the research is non-medical, an ethical review of research plans is organised in four domain-specific committees: Humanities and Social Sciences, Natural Sciences and Engineering Sciences, Geo-Information Sciences and *Computer & Information Sciences*. Researchers submit their research to the domain-specific committee best suited to evaluate the ethics issues relevant to their research. A UT-wide ethics committee, finally, is responsible for handling complex, multi-disciplinary research proposals; moderation of complaints about domain reviews; and general quality assurance. Full details of the review process and procedures can be found on the UT website [24].

Ethics Committee Computer & Information Sciences

The faculty of EEMCS is responsible for the domain-specific Ethics Committee Computer & Information Sciences (EC-CIS) [25]. This committee focuses on the types of research typically carried out in the faculty, including AI and data science, cyber security, human-computer-interaction studies, and interaction design for (mostly) ICT based systems – although not exclusively, since internationally the field of ethics in computer & information science is still evolving. Ethical review in this domain is important; amongst other things, because

a) society demands accountability, as visible in high-profile media articles on failures of ethics in ICT companies and research projects,
b) journals and funders in the domain increasingly demand engagement with research ethics as precondition for publication or funding, and
c) Computer & Information Sciences often target transforming the world through building new applications of technology, which raises ethical questions of desirability and inclusivity of these designs.

To properly review research plans in the domain, the committee has a multidisciplinary composition including specialists in each of the above subjects and a general ethics expert (6 members in total, plus 2 support staff), and has access to specialist advice concerning medical research, legal matters, and aspects of data and privacy under the GDPR. Over the past few years, the number of review requests handled by EC-CIS has increased dramatically: from 20 reviews in 2015 to more than 150 in 2020. To streamline this increasing workload, EC-CIS invests in continuous improvement of the clarity and adequacy of the ethics review questionnaire. EC-CIS expects to benefit from the new web portal that is currently being developed centrally at the UT, which should streamline the submission, review, and administration of the research ethics review process. Finally, EC-CIS has started to develop extensive new training materials for staff and students to help them better understand the ethics review process, which should improve both their awareness and competence in this topic.

2.3.3 Data policy

Open data

Shaping 2030

In 2020, 67% of the CS publications was open access

Open data and related research-data policies are gaining importance in academia. In 2017, at the national level, a National Plan Open Science [36] was presented by all major Dutch research organisations. Already in 2015, an overall research-data management policy was established by the UT, updated in 2018. The UT policy statement Shaping 2030 [26] formulated that in support of the Open Science transition, 100% Open Access publication is the aim to be reached already in 2023. Preferably this should be immediate open access publications, and if necessary, after six months via the UT research-information website. In 2020, 67% of the CS publications was open access. Tools such as the UT Open Access website [27] help researchers in this process. Shaping 2030 also established FAIR data [28] as the new norm for UT researchers. The university-wide data-management policy serves as a starting point for tailored data policies of UT faculties, institutes, and research groups.

UT-wide RDM

Research Support Team

To further the implementation of the research data management (RDM) policy, a *UT-wide RDM* project was started in 2019. Within this project a data steward was hired to provide direct practical support on RDM for researchers within EEMCS. The data steward is a member of the *EEMCS Research Support Team* [29]. In 2021 the RDM project will result in the start of a Digital Competence Center (UT-DCC) at the UT, with funding from the Dutch Government. The goals for the UT-DCC are:

- coordination/organisation of Data Stewardship and ICT research services,
- to be a knowledge and advice centre for Open Science, FAIR data/software [28] within the UT,
- to be a knowledge and advice centre for digitisation of research and related ICT facilities,
- to be a node in a network for open science, data and digitisation of research and ICT facilities both inside and outside the institution.

EEMCS

In 2019, the Faculty of *EEMCS* formulated a tailored research data management policy, which is a refinement of the UT-wide policy. In turn, several individual groups already have or are in the process of formulating further refinements in the form of practical guidelines and workflows for the handling of research data. The guiding principles in all of these are scientific integrity and FAIR data.

We missed it during the pandemic, discussions at the coffee machine.

We present and explain our KPIs (Key Performance Indices) for products, use and marks of recognition for both quality domains (research quality and relevance to society). Appendix C presents some highlights of our research in the form of Case studies.

3 Quality and relevance

3.1 Introduction

Societal demand

Collaboration with external partners

In the previous research assessment of the discipline in the Netherlands, the position of Computer Science at the UT was characterised as excellent. In the past period we have tried to keep up this standard. We continue our path to have our research led by *societal demand*, to continue our *collaboration with external partners* not just through spin-offs but also by collaborating closely with companies and other stakeholders.

In this chapter we will first summarise the key goals and achievements of the past period in terms of the Key Performance Indicators. Next we will summarise the achievements per focal area.

3.2 Key Performance Indicators

Table 3.1
Key Performance Indicators (KPIs)

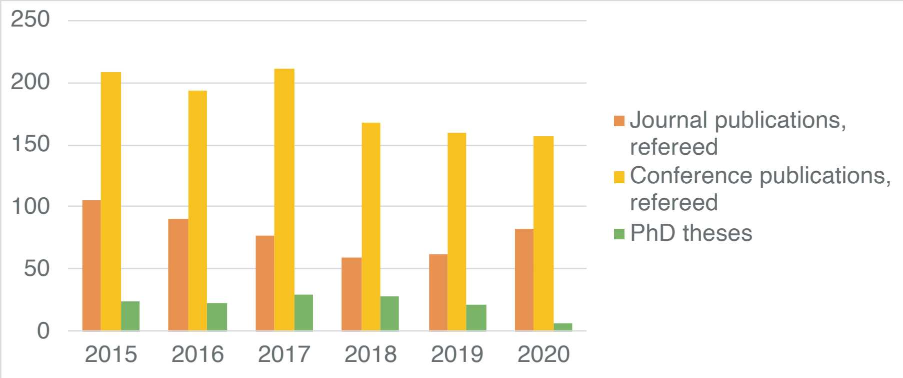
Assessment Dimensions	Quality domains: Research quality	Quality domains: Relevance to society
Demonstrable products	**1. Research products for peers** a. Publications: Articles in a selected set of main journals and conferences, PhD theses	**4. Research products for societal target groups** a. Well-educated Masters' and PhD graduates b. Media appearances
Demonstrable use of products	**2. Use of research products by peers** a. Use of data sets b. Use of software	**5. Use of research products by societal groups** a. Contract Research b. Spin-offs and Start-ups
Demonstrable marks of recognition	**3. Marks of recognition from peers** a. Major awards and grants b. Prizes	**6. Marks of recognition by societal groups/companies** a. Part-time positions financed by industry b. Ancillary positions

We have collected evidence for the KPIs (such as awards, software tools and data sets, grants, academic service) in a file with all the raw data [30] provided by the groups. A selection is presented in the next sections.

3.2.1 Research products for peers (Publications and PhD theses) KPI 1

Our data and publication policy has been described in Section 2.3.3. Figure 3.1 and Table A.7 show the numbers of journal and conference publications and the number of PhD theses in the last six years. Research groups have their own particular policy, which is dependent on the particular publication culture in the field. In general, we try to balance attending high-quality conferences with peer reviewed journal publications, leaving room to publish and meet international colleagues at workshops, for instance.

Figure 3.1
Publications
More details in table A.7



For most areas of Computer Science publications in conference proceedings are still highly valued. However, there is a clear shift in the field. This trend is visible in Figure 3.1 from 2018 onwards. During the first half of the reporting period there was a decrease in the number of publications. This was anticipated with the reorganisation taking effect also on the number of PhD candidates. Another reason was the heavily-increasing teaching load. We hope to remedy this by increasing teaching staff numbers in the years to come. In the last years of the reporting period, number of publications were on the rise again, especially in terms of journal publications.

Open Access journals
2020: 67%

Analysis of 1531 papers of the last six years shows that 44.5% of the papers were published in *Open Access journals*, with a provisional peak of 67% reached in 2020. The department supports the Open Access initiative of the UT but adds that in some cases it is beyond the control of CS whether open access publishing is possible. We leave the option open to publish in highly-valued publication venues such as IEEE journals. A total of 6328 (co-)authors were involved in the 1531 papers published during the review period, indicating our collaborative spirit with colleagues around the world.

A list of five selected key publications is available in Appendix B and on the website [31]–[35]. All publications in the review period of CS and of each of the groups are available on the website [36] as well.

3.2.2 Use of research products by peers KPI 2

Use of data sets and software

In all focal areas we contribute to building and maintaining data sets, software and tools that are made available for research and other uses. We mention a few in the results of the focal areas (Section 3.3) as well as in the case studies. But there are several more that can be found in the file with the raw KPI data [30]. A good example is OpenINTEL.

OpenINTEL

The DACS group designed, implemented and operates the OpenINTEL active DNS measurement system. This system performs daily measurements of over 65% of the global Internet name space. Initiated in 2015, the OpenINTEL project has collected almost 6 trillion data points to date.
Data from OpenINTEL has been used in over 40 scientific publications, written by both University of Twente authors and authors from other academic institutions across the globe. Where possible, OpenINTEL data is made available as open access data. If contractual obligations require us to restrict access to the data, free (of cost) access is provided to fellow academic researchers under contract.
In 2018, we received the Research Data Netherlands Prize, awarded by 4TU.Centre for Research Data, SURFsara and DANS, for our efforts in making OpenINTEL data accessible to the research community. The OpenINTEL project was jointly funded by the University of Twente, SURFnet and SIDN.

3.2.3 Marks of recognition from peers KPI 3

Best paper and poster prizes

Besides numerous best paper and poster prizes, there are also diverse awards for CS researchers.

- 2016: IFIP/IEEE "Salah Aidorous Award" 2016 (Aiko Pras)
- 2017: IRTF Applied Networking Research Prize 2017 (Roland van Rijswijk-Deij)
- 2017: Arne Jensen Lifetime Achievement Award, ITC 2017 (Hans van den Berg)
- 2018: Research Data NL Prize, awarded by 4TU.Centre for Research Data, SURFsara and DANS, for the OpenINTEL project (multiple DACS staff members)
- 2019: Rising Star in Computer Networking and Communications 2019 (Anna Sperotto)
- 2019: IRTF Applied Networking Research Prize 2019 (Roland van Rijswijk-Deij)
- 2020: KHMW Kees Schouwhamer Immink Prize (Roland van Rijswijk-Deij)
- 2020: IEEE TCI Rising Star Award (Roland van Rijswijk-Deij)

Major grants

In the last six years, members of CS submitted 24 VENI proposals, 3 VIDI proposals and 2 VICI proposals. 2 VENI projects and 1 VICI were granted (≈10%). This is slightly lower than the average score nationwide. In addition, 2 ERC consolidator grants were obtained.

Among the major research grants obtained by CS are

- CONCORDIA (EU Horizon 2020) (total budget 16 M€, UT 500 k€), UT is Research Coordinator
- INTERSECT (NWO NWA ORC)(total budget 8 M€, UT 1M€)

3.2.4 Research products for societal target groups (KPI 4)

Part of our mission is to connect to society. Our research is inspired and funded not only by national agencies such as the Dutch Research Council (NWO) or the European programmes, but also by organisations that look for solutions to real-world problems. This also means that we have a strong drive to communicate about our research endeavours and results.

Media Appearances

The CS groups had more than 120 media appearances in the review period, ranging from the UT digital newsletter U-today to Prof. Vanessa Evers (HMI) presenting her work internationally at many high profile events such as the World Economic Forum in Davos (2016) and the European Heads of State Digital Summit in Tallinn (2017). The FMT group alone [37] had more than 60 media appearances.

Well-educated Masters' and BSc graduates

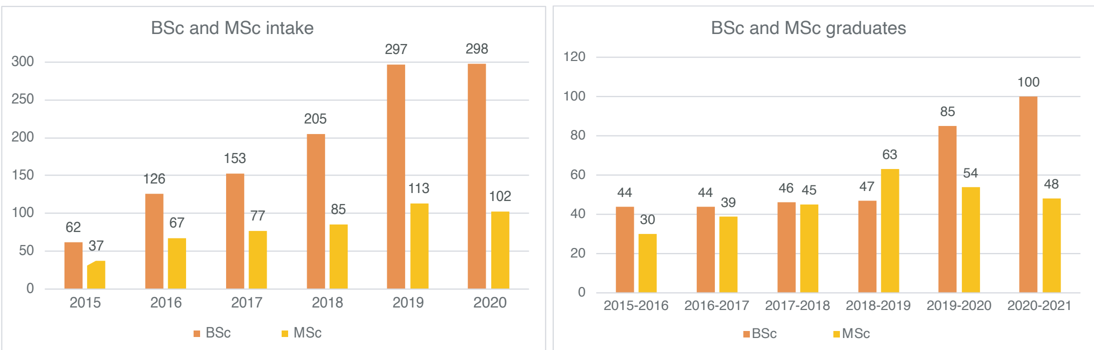
The intake of BSc and MSc students Computer Science is given in Table A.8 and Figure 3.2 (left); the number of MSc graduates in Figure 3.2 (right). The intake of BSc students has grown from 62 to 298 in the review period. As a result it may be expected that the intake of MSc students will also increase considerably in the coming years.
In addition to the BSc and MSc programmes Computer Science, we are also strongly involved in several other programmes where the intake grew considerably between 2015 and 2020: BSc programmes BIT (36 ⟶ 86) and Creative Technology (95 ⟶ 138), and the MSC programmes BIT (17 ⟶ 37), Embedded Systems (16 ⟶ 39) and Interaction Technology (iTech) (28 ⟶ 77).

Figure 3.2

left:
BSc and MSc intake Computer Science

right:
BSc and MSc graduates Computer Science

Based on Table A.8



Well-educated PhDs

Information on the intake and success rates of PhD candidates is given in Table A.6 in Appendix A and in Figure 4.1 in Chapter 4. The enrolment in the period 2018-2020 varied between 26 and 35.

3.2.5 Use of research products by societal groups KPI 5

Contract Research

As indicated in Table A.5, on average about 10% of the total funding comes from contract research.

Spin-offs and Start-ups

Spin-offs and Start-ups

In the review period the following Spin-off and Start-up companies were founded:

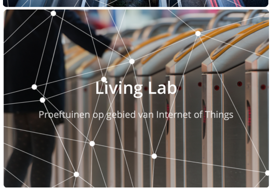
2016	QBayLogic	https://qbaylogic.com/
2017	Codesandbox	https://codesandbox.io
	20face	https://www.20face.com/en/
	Locus Positioning	https://locuspositioning.com/
	The Value Engineers	https://www.thevalueengineers.nl
2018	Westpulse	https://westpulse.com/

Creative Technology

Students of the BSc programme '*Creative Technology*' started two companies in the review period. In the curriculum of Creative Technology there is a course on entrepreneurship [38].

IMPULSE:	provides organisations with a cost-effective and visible Carbon Reduction Strategyservice .
Tiny Giants:	delivers visualisations of architectural projects, 2D and 3D animations, 3D printing, Virtual and Augmented Reality presentations.

Besides start-ups and spin-off we are active in setting up collaborations with industrial partners. The Twente/47 initiative is one of these, another one is TUCCR (Twente University Centre for Cybersecurity Research) described in case study C.5.



In 2017, to accommodate the demands of (regional) SMEs and industry in terms of the IoT the Pervasive Systems research group initiated the IoT accelerator Twente47 [39]. The combination of expertise on the IoT (University of Twente, Saxion), business development and legal aspects (Novel-T) turned out to be highly successful. Funded by the Province of Overijssel and EFRO, many projects have been established by Twente47, allowing many companies to explore and use the innovations.

The application domains are quite diverse and include smart domains such as city, industry, agriculture, biodiversity, health, transport and mobility, supply chain management, sports, asset management, and predictive maintenance.

Example projects include:

- Countdown [40] – enabling smart and sustainable logistics. This EFRO funded project was executed with 6 SME companies in the region, together with the UT.
- 'Kunstwerken' in control [41] – enabling efficient asset management of bridges.
- Living lab [42]– enabling various smart solutions in the domain of agriculture, city life, education, and biodiversity.

3.2.6 Marks of recognition by societal groups/companies KPI 6

Multiple CS groups have, or have had, part-time positions in collaboration with the industry. These positions, paid for by industry partners, lead to a fruitful exchange of ideas for both the university and the industry partners. Through these collaborations, our research can have a direct impact in industry, a key motivator to initiate and continue these collaborations for our industry partners. Equally, these part-time staff members act as a bridge to industry, feeding real-world challenges faced by our partners into novel research, and providing access to unique data sets from the operational reality of our industry partners. Over the past six years, we have enjoyed such collaborations with (among others) TNO, SIDN, NCSC, Nedap, Northwave, SURF and NLnet Labs.

3.3 Results in the Focal Areas

Dependable Cyber-Physical Systems

Over the last six years, research on Cyber Physical Systems has achieved validated designs of architectures, algorithms and protocols for several application areas. For connectivity, results have been achieved on the IoT and vehicular networking (e.g for reliable broadcasting and geocasting and for support of cooperative adaptive cruise control), measurement-based analysis and improvement of core functionality of the Internet (e.g. anycast, IPv6, and the domain name system). On computer architectures, results have been produced on methodologies, designs and tools for decentralised energy management and energy efficient computing, (e.g for data centres and SCADA systems). On distributed sensor data analytics, results have been obtained on methods, algorithms and designs for predictive maintenance (e.g. roads, bridges), unobtrusive sensing (using RF and acoustics), and on animal monitoring (e.g. horses and wildlife). The publications, many prizes, awards, and adopted solutions (see KPI data [30]) demonstrate the quality of the research.

Dependable Cyber-Social Systems

With respect to the technology, we have made advances in our work on embodied conversational interfaces (virtual humans and social robots), tele-presence applications, in the interaction using haptic/tactile input and feedback and in automatic means to sense activity and mental states of users (Affective Computing). We have designed a new framework to build dialogue systems that has been implemented for various applications. It is part of an international effort to provide tools for the research community to be used and extended. It has been integrated with modules from other partners as the Agents United platform [43]. It also resulted in a best paper award at the ACM Intelligent Virtual Agent's conference. Our work on tele-presence has taken two approaches. One is studying and improving the collaboration of people at a distance using a combination of augmented and virtual reality. The other involves tele-operating a robot where we study the feeling of embodiment. We started collaborations with fashion designers and experts into technologically enhanced fabric to investigate how smart clothes can sense information from the body and how haptic feedback can be used to provide information to the wearer. Traditional design methods such as focus groups and questionnaires do not work for children, elderly people with dementia or low literate persons. We have made progress in developing alternative approaches for these special groups.

Data Science and Engineering

Over the past six years, research on Data Science and Engineering made significant progress for addressing the challenges mentioned in Focal Area 3 in Section 2.2 in many application domains, like health care, cyber security, biometrics, networking, cyber-physical systems, human and animal activity recognition, predictive maintenance, logistics, indoor localisation, energy preservation, and robotics. To illustrate, we pioneered in the reconstruction of 3D facial images from 2D as well as the detection of manipulation of biometric data. In robotics, we worked on bringing the processing of artificial tasks, data and results from the cloud level to the physical system (embedded AI) as well as using deep learning, autoencoders and reinforcement learning for the navigation of real robots equipped with a lidar or camera sensor. And we recently pioneered a significantly different approach to explainable machine learning, called *ProtoTree* (See Case Study C.1), which is intrinsically explainable while being able to exploit the strengths of deep learning.

ProtoTree

Software Science and Engineering

Over the past six years, Software Science and Engineering have achieved important steps for addressing the challenges mentioned under Focal Area 4 in Section 2.2. For example, we developed the VerCors verifier [44], which supports the verification of concurrent and parallel software in many widely-used programming languages, including support for GPU applications. Furthermore, we have developed different quantitative analysis techniques, including fault trees and model based testing, to make maintenance of high-tech systems more predictable, and stochastic model-checking techniques to enable the analysis of systems with uncertainty. In order to facilitate the development

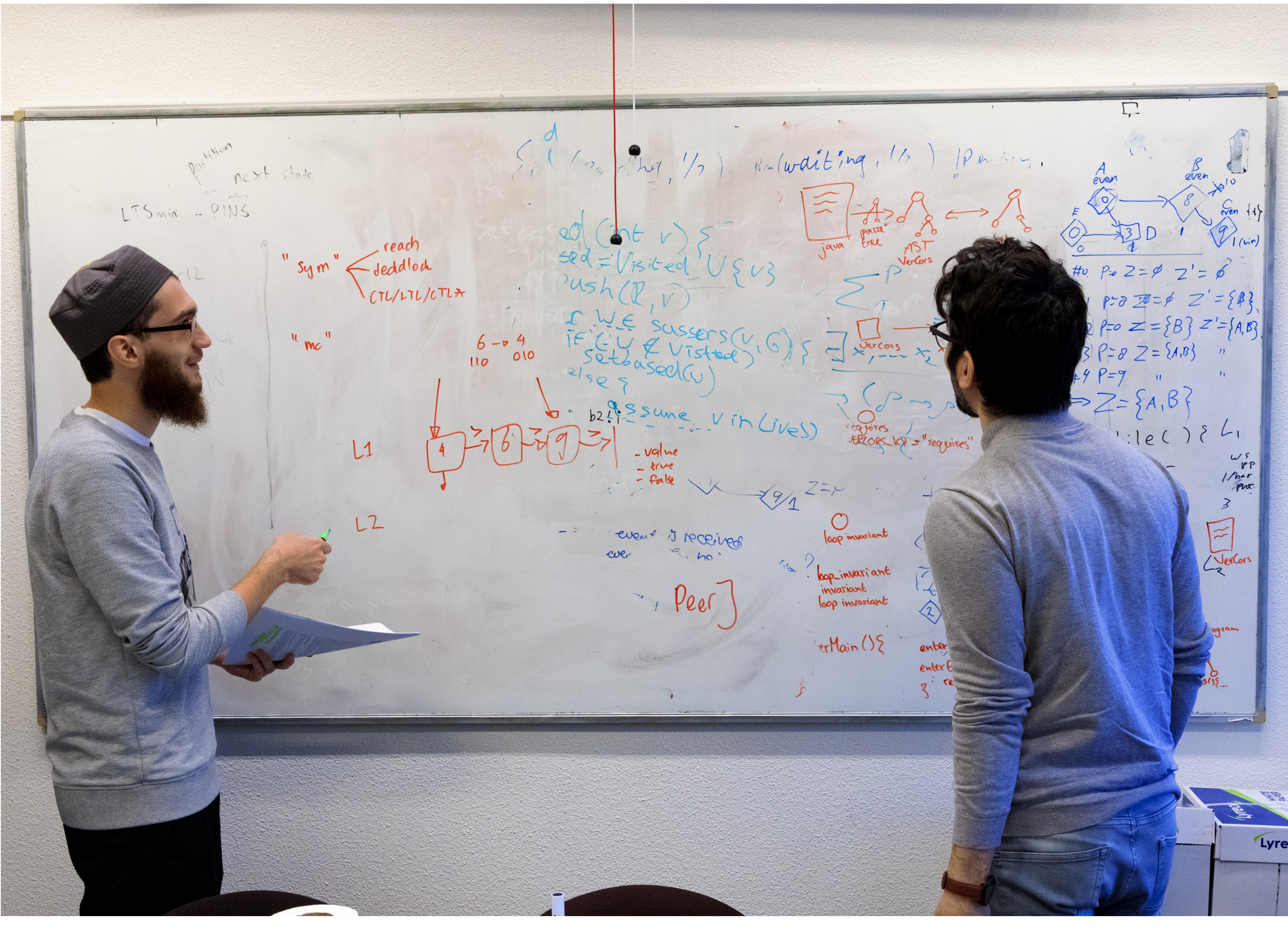
VerCors verifier

of IoT-based software systems, we defined, designed and validated the SEMIoTICS framework. This framework supports the model-driven, ontology-based development of distributed and decentralised software systems that use the IoT, focusing on early warning and emergency services. As final examples, we can mention the development of data-driven requirements-engineering techniques, for automated support of requirements-engineering activities, using user feedback and app change logs, and the empirical evaluation of quality requirements in agile practices.

Security

Research highlights from the last six years include the initiation of the National Anti-DDoS Coalition [45], the release of several open-source tools such as the industry-used rcATT tool for automated identification of tactics and techniques [46] in threat reports, and the development of the world's largest active DNS measurement platform, called OpenINTEL. This was picked up by the media [47], the National Cyber Threat report [48], and other researchers due to associated open datasets that we released.

Towards the end of the period covered by this report, our dedication to working with stakeholders in Dutch society culminated in an ambitious public-private partnership: TUCCR (See Section C.5 on page 43), which lays the foundation for strong future research on cybersecurity.



Chapter 4 presents our PhD policy as well as the success rates of the PhD candidates.

4
PhD policy and training

4.1 Training and Supervision

The training and mentoring of PhD candidates forms a crucial part of our scientific activities. We value an intensive coaching of our PhD candidates, for example, by having regular progress meetings. Through early attendance of conferences, participation in specific courses and other activities we aspire to educate and train the next generation of top scientists.

4.1.1 Twente Graduate School (TGS)

All PhD candidates participate in the *Twente Graduate School (TGS)* [49]. The TGS gives a clear framework for our PhD policies. Uniform procedures and rules now apply for all PhD candidates of the UT. This involves:

- central registration of all PhD candidates in the ProDoc system (now called Hora Finita)
- PhD charter [50].
- clear GO/NO-GO moment in the first year followed by formal appointment of the promotor
- Training and Supervision Plan(T&SP)
- forecast and drop-out registration.

4.1.2 Training and Supervision Plan (TSP)

The *Training and Supervision Plan (TSP)* [51] is obligatory for all PhD candidates. The TSP follows a strict format. It contains the summary of the research plan, the supervision plan (detailing, e.g., the frequency of the meetings with the supervisors and the role of each supervisor), and the educational programme to be followed by the PhD candidate. In principle this programme amounts to 30 ECs (European Credits), that is, a six-month study load. It is defined by the candidate and the supervisor, and should be approved by the Dean (especially when a deviation occurs from the targeted 30 ECs). This is delegated to the Director TGS, who can also approve exemptions up to 20ECs. The educational programme can contain courses offered by the university, national research schools and international programmes such as Summer Schools. The Training and Supervision plan further details the teaching obligations of the PhD candidate.

Formal 'qualifier'

The plan is first drawn up within three months after the start of the PhD candidate, and is periodically reviewed and updated if necessary. A formal 'qualifier' towards the end of the first PhD year, aims to determine a conclusive assessment whether or not to proceed with the remainder of the PhD project. In this way we hope that under-qualifying PhD candidates leave the university without delay.

4.1.3 Research Data Management

Twente Graduate School

Data management plan

Like all other PhD candidates at the UT, the PhDs of the Department of CS take a mandatory course on Data Management & Biometrics (DMB), offered by the *Twente Graduate School* [49]. The data stewards function as trainers. Subjects in the course are: management of data for verification and reuse, the value of research data as scientific output of one's research, awareness of legal issues in the handling of research data and writing a data management plan (DMP). The knowledge from this training is used as a basis for the *data management plan* that every PhD student has to hand in, in the first year. The DMP has to be reviewed and monitored regularly, in line with planning and progress of the research project.

4.1.4 National research schools

ASCI
IPA
SIKS

Several groups participate in *national research schools* like *ASCI* [52] (DACS, CAES), *IPA* [53] (FMT) or *SIKS* [54] (DMB, HMI, SCS). These schools offer, among other things, summer schools and lectures at a central location in the Netherlands. They have their own rules with respect to the educational programme.

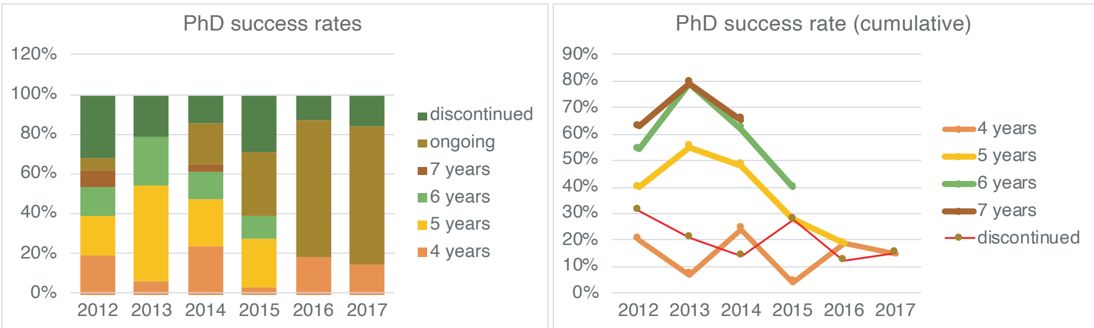
4.2 Intake and Success Rates

The intake of PhD students is given in In Table A.6 and summarised in Table 4.1. The success rates are given in Figure 4.1

Table 4.1
PhD intake

starting year	2015	2016	2017	2018	2019	2020
	25	16	20	35	26	29

Figure 4.1
PhD success rates
More details in table A.6



The success rate of PhD candidates appears to be quite low. For the recent period, the COVID19 pandemic played its role in that either they postponed their graduation in the hope to have a live defence, or their research was delayed because they could not execute their studies. The faculty has decided to support the latter group and extend their contracts. But the pandemic alone does not account for the low success rate. We also see a number of other factors that explain the slow progression of PhD candidates and high dropout rates.

- External PhD candidates (people with a job elsewhere) often only work part-time on their PhD.
- Some candidates have a combined appointment with teaching.
- Mental and physical health issues make up for a delaying factor.
- There is a rather big drop-out rate for several reasons: not all students pass their qualifier, (mental) health issues, external funding stops.
- There is a noticeable drop-out of external PhD candidates that have stipends. We have therefore decided on a more thorough screening before accepting them. Closer monitoring of success rates is on the agenda to be addressed.

This section discusses policies and accomplishments with respect to various aspects relating to academic culture within the unit. This includes diversity in terms of gender, nationality and age.

5 Working environment and personnel policies

5.1 Human Resources policy

Development

CS adheres to the HR policies of the Faculty of EEMCS. EEMCS wants to be a faculty where every employee has the opportunity to develop and use their talents in an optimal way. As a faculty, we choose to focus on the talents of all employees, based on the conviction that each individual has unique talents. We have taken steps forward, but realize that improvements are possible and that development requires continuous attention.

Talent

All chairholders have regular consultations with HR, in which the monitoring of the development and the stimulation of the development of employees is an important subject. To support the development of employee talents, the 9-grid tool [55] has been introduced. In preparation for the annual performance appraisal, the chairholder fills in the 9-grid with the potential and performance of each staff member. Subsequently, the chairholders of CS discuss the performance and potential of the staff with each other. After some initial doubts, it is now appreciated as a preparation for the annual appraisals. It is good to discuss the development potential of the academic staff with each other, precisely because of the different perspectives.

Recruitment

Recruitment is an important part of the HR policy within CS. When selecting new colleagues, we look at the talents of the applicants and how they fit into the team. Striving for more diverse teams is important to us. We are supported in this by HR. In addition to the support from HR, more recruitment tools are used, such as game-based assessments for PhDs and Textio, an instrument that supports in writing vacancy texts. More attention is also being paid to the onboarding of new employees by holding onboarding talks, in which, among other things, the possibilities within the UT in the field of training and coaching to support development are indicated.

Teaching Excellence

Employees have a wide range of talents. We want to appreciate that. That is why it is possible for employees who spend more time and effort on education to grow into associate professors and full professors with an emphasis on teaching. Because of the increased teaching tasks within CS, this is interesting for a number of employees who are very involved in education and regularly implement innovations. Meanwhile, two assistant professors within CS have been promoted to associate professors positions with an emphasis on education, and we expect to be able to appoint our first full professor with an emphasis on education soon.

Work-pressure

More generally we see that CS at UT forms no exception in terms of work-pressure and working hours as experienced by academics in the Netherlands. Especially the increasing administrative duties seem to take their toll in the efficiency of our work. Though this is a problem that should be addressed on a national scale, we feel that the size of our discipline and the open and the collegial atmosphere help in keeping things in check. We value this aspect of our collaboration and feel that, together with our attractive infrastructure, it also helps us to interest new talents to come to Twente.

5.2 Diversity

Gender

The goal of the faculty EEMCS is to employ 20% female full professors, 20% female associate and 35% female assistant professors in 2025. At present, these numbers for CS are : 19% full professors, 13% associate and 29% assistant professors. As indicated in Figure 5.1, the percentage of female full professors has grown, but with regard to associate and assistant professors, a decrease can be seen.

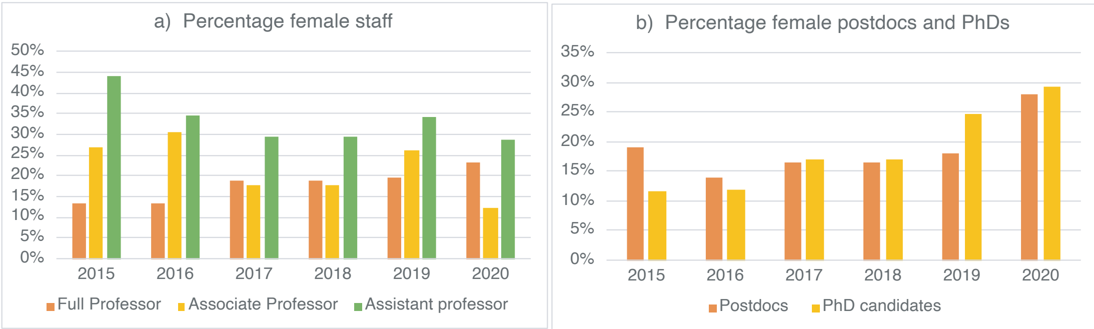


Figure 5.1
Percentages female employees, based on table A.3
a) Scientific staff,
b) Postdocs and PhDs

Given the age structure of all full professors within CS (see Figure 5.3), opportunities are coming. The pool of female PhDs and Postdocs is also growing. In order to effectively use these opportunities for women, a number of measures have been taken, such as a diverse composition of selection committees, gender bias training, and the use of Textio, which makes vacancy texts more attractive for female applicants. At the moment, the Faculty Board is in discussion with the Faculty Council to open up vacancies in the academic permanent staff to women first. We think that such measures are necessary to catch up.

Nationality

The percentage of international staff continues to grow. Given the Dutch labour market for CS, this is not surprising. At the moment, most chairholders are Dutch, but this will change in the future. More attention will have to be paid to intercultural awareness than is currently the case.

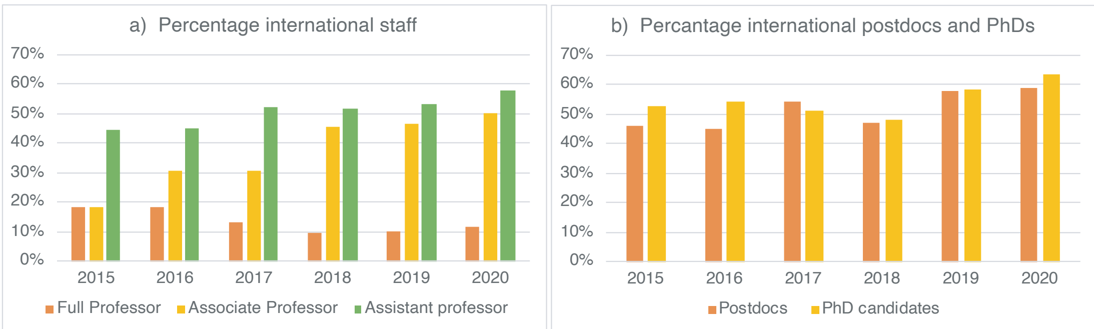


Figure 5.2
Percentages international employees, based on table A.3
a) Scientific staff,
b) Postdocs and PhDs

Age

The age distribution of CS (Figure 5.3) is particularly skewed at the level of full professors. This offers opportunities for women and also for younger staff members.

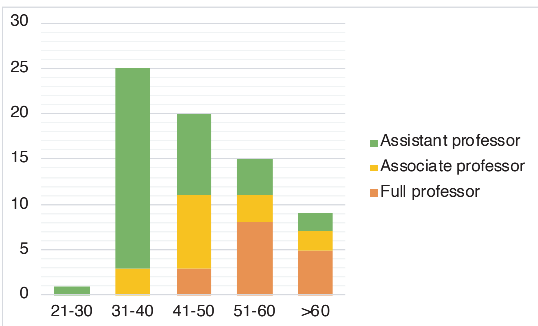


Figure 5.3
Age Distribution
Based on table A.4

Computer Science is active in stimulating women in computing:

Alice & Eve

The goal of *Alice & Eve* is to celebrate the achievements of women in computing, from Ada Lovelace to one of the first Dutch female full professors in computer science, Franciska de Jong. Alice & Eve started in January 2020 with an event at the University of Twente, consisting of a symposium, a poster competition, an exhibition portraying the achievements of 25 very diverse women in computer science, and an accompanying exhibition booklet. The event attracted over 80 participants. It was organised by Marieke Huisman, Niels van Huizen (exhibition text), Puck Kemper (design), Sophie Lathouwers, Alma Schaafstal and Marielle Stoelinga. The exhibition is expected to be on display in all Dutch CS departments during the next academic year. Moreover, a digital version of the exhibition is currently being prepared, and a new edition of the event is scheduled for November 2021 (in Nijmegen).

More information: https://fmt.ewi.utwente.nl/events/aliceandeve2020/ [56]

Figure 5.4
First meeting of 'Alice and Eve'

We reflect on the strategy needed for the future and present a SWOT analysis. The SWOT analysis forms the basis of the strategic plans for the six years to come.

6
Strategy for the next six years

6.1 SWOT analysis

Table 6.1 SWOT analysis

Internal organisation	**Strengths**	**Weaknesses**
	• Top-quality, multidisciplinary research • Collaboration between groups in a cooperative atmosphere • Good connections to society and industry • Good viability and adaptivity: young staff • Well-represented in local, national and international boards: policy, research	• Long completion times of PhD candidates • Diversity in terms of gender and inclusive work culture not good enough • Visibility of CS department as a whole • Shortage of lab space and technicians
External context	**Opportunities**	**Threats**
	• In society, software is seen as a key enabling technology • Increased funding for CS nationally: e.g. Sector plans • Growth in student population and junior staff • New collaborations: Apeldoorn, VU, WWM (see page 24)	• Difficult to attract qualified staff • Rapid growth in staff: fewer contacts between individuals • Unpredictable student numbers / fluctuations • Teaching workload undermines research capacity

In the previous chapters, we hope to have provided ample evidence for what we consider our strengths. We would also like to point to the KPI Raw data file [30] that provides an extensive but still incomplete list of performance indicators.
As to the opportunities, the importance of investing in information technology and technology in general as a driver of economic growth and as an important contribution to society at large is understood by the government in the Netherlands and in Europe. The investments that are being made (Sector plans, 'Groeifonds', 'AI-Ned' and others) are big. We are closely involved in defining the agendas for these initiatives.

The future growth in student numbers is unpredictable when one looks at longer periods of time. In the next years we believe that it will eventually a) help us to grow as a discipline and b) also in our research output. At the moment, the research capacity is still undermined by the teaching load, but we are investing in more teaching staff.

As we saw in Chapter 4, there is a decline in the number of PhD candidates. Besides the effect of the reorganisation, this is also partly due to a decline in the acquisition of funds in projects which we can attribute to a few causes. On the one hand the bigger national project funding was stopped (FES), on the other hand the reorganisation at the end of the previous reviewing period and the beginning of this reviewing period meant that staff was either fired or not replaced when retiring, resulting in fewer staff for the same tasks. With student numbers increasing, the workload for staff members became even higher. We have been taking various measures to counteract this.

Grants Office
Project Management Office

- One is to invest in support staff to help out, freeing up time for research staff to spend on content. We make use of a fairly new organisation at the university, Strategic Business Development, which provides support in the entire chain of the funding acquisition process. The *Grants Office* and *Project Management Office* at SBD provide grant development support, as well as project management services.
- Another measure is to hire new staff – which we have been working on for quite a few years now. However, this has long been a slow process as there is a high demand in the whole of the Netherlands. In the recent past, we have started to make good progress. Unfortunately, due to the pandemic, the new staff members have not had the chance to build a team. Another downside is that there will be a housing problem when staff returns to the office.

With the aforementioned reorganisation, there was also a severe cut in supporting personnel, in particular in lab support and scientific programmers. Even though we have a good amount of output in terms of open access data sets and tools that we produce and maintain for other researchers and organisations, in this period some tools could not be maintained. We recently started to remedy this situation by investing in support staff and lab facilities thanks to Strategic Impulse Financing provided by the faculty. As a side effect, this will mean though that the housing problem will get bigger in the short term. There are plans to expand, fortunately.

As we pointed out in Chapter 5, we have been making some progress with respect to diversity and inclusion but we did not reach our objectives yet: extra effort is needed. We are working on concrete steps to reach these goals, focusing on scouting, recruitment and promotion. The UT Diversity and Inclusion officer assists us in this process.

Although we are well represented in local, national and international boards, the department as a whole is less visible in the outside world with the change in the institutional organisation. By grouping research together under a more encompassing flag (Twente University Centre for Cyber-security Research: TUCCR, Centre for Networked Systems and Intelligence: NESSIE) we create more critical mass that leads to greater visibility.

6.2 Strategy for the future

Our choice to focus on and invest in five focal points, Cyber-Physical Systems, Cyber-Social Systems, Data, Software and Security, allows connections that combine relevant scientific expertise. This enables us to come to new, essential and fundamental insights in computer science. By strengthening fundamental research and the crossroads between them we are best equipped to engineer our digital society. Several new collaborations have been started recently.

Apeldoorn

In Apeldoorn a collaboration has been established between knowledge institutions, companies, organisations and governments (Police Academy, Saxion, Achmea, Tax Authority, Land Registry) in a Center for Security and Digitisation (CVD), which develops education, research and innovation trajectories at the intersection of digital transformation and security.

VU Amsterdam

The UT and the VU are strategic partners and together they are defining large and distinctive impact initiatives to make societies secure, responsible and smart. For example, for the smart societies programme, the goal is to accelerate the digital transformation, focusing on smart industry, smart areas, and smart health via technological learning and societal embedding. It should relieve the shortage of technical talents, address national social challenges, and strengthen the Dutch economy with new business around new solutions.

University of Münster (WWU)

The University of Münster (WWU) is also a strategic partner of the UT. WWU, the fifth largest university in Germany with 45,000 students, is a comprehensive university with no engineering disciplines. Some research projects in which researchers from the UT and the University of Münster collaborate have been awarded a collaborative research grant. The grants are intended as incentives for closer cooperation between both universities. An example is the project "*Scalable Verification of Industrial Embedded Control Systems*" of Prof. Marieke Huisman (UT) and Prof. Paula Herber (WWU). There are several co-appointments of professors between WWU and UT for Computer Science; Prof. Paula Herber (Embedded Systems) and Prof. Heike Trautmann (Data Science).

6.3 New strategic research fields, Focal Areas

In Section 1.4.1, the extra stimulus of the Sector plans has been described. All Focal Areas benefit from this stimulus of 6148 k€, good for 8 new staff members.

Focal Area 1 Dependable Cyber-Physical Systems

Centre for Networked Systems and Intelligence

Sector plan

The research on Dependable Cyber-Physical Systems will be strengthened and made more visible by establishing a *Centre for Networked Systems and Intelligence*. The research domain of the centre is the design and analysis of networked (Cyber-Physical) systems, their architecture, implementation, security, and applications. The CS research in this field will be augmented with research on networked and embedded systems within Electrical Engineering and research on energy systems within Applied Mathematics. Also, the newly appointed professors for the *Sector-plan* positions on 'measurement-based Internet security', 'system performance engineering', and 'resource-constrained networks', as well as the EE Sector-plan position on 'advanced computing' will be incorporated in the centre. The Centre for Networked Systems and Intelligence aims to be a key player in the field of networks and systems, including a wide range of topics such as the IoT, network security, smart grid, wireless networks, efficient processing, Internet measurement, mobility, embedded AI, energy efficiency and sensing and monitoring.

Focal Area 2 Dependable Cyber-Social Systems

Sector plan

With the appointment of two *Sector-plan* positions in the area of knowledge representation and cognitive modelling, this focal area complements the research in artificial intelligence both in the areas of interactive Cyber-Social systems and in the data science and engineering at the same time. This fills an important gap, as we were strong in sensing (input) and action (output) but less so in representing domain knowledge and reasoning about this.
It also offers the opportunity to collaborate more closely with other groups on the topic such as that of Prof. Guizzardi - also appointed on a Sector-plan position (in the SCS group).
We will furthermore extend the collaboration with experts in the application areas that we are working on by creating several part-time positions, in particular in the areas of health, well-being and sports.
Finally, plans are underway to create a Robotics Center Twente in which the social robotics research of the CS department will connect more closely with the robotics groups in the electrical engineering department and the groups in the engineerng faculty. A joint MSc Robotics programme is in the making.

Focal Area 3 Data Science and Engineering

Sector plan

The two *Sector-plan* positions, mentioned in the Cyber-Social paragraph are shared with the focal area Data Science and Engineering. A new activity is the Sport Data Valley infrastructure. It has been developed by a consortium of higher education institutions, besides University of Twente (project lead, DMB, SCS and HMI groups) also by Leiden University, Delft University of Technology, VU Amsterdam and Amsterdam University of Applied Sciences. Most partners bring in domain knowledge about sports and movement. Examples of current projects are given in the case study in Appendix C.3. As member of DSI, the CS department has been leading the working group on Research & Innovation of the Dutch AI Coalition [57]and has been an active member of a small writing team responsible for finalizing the proposal. This active membership has opened opportunities for future funding. We have also taken a leading role in creating a national network of seven AI Hubs, which led to establishing an AI Hub East Netherlands [58]. This Hub has led to an increased collaboration with Radboud University (in the field of machine learning for medical images) and further regional partnerships in various subfields of AI. Along these lines, we are proud to have recently become associate partner of the national Gravitation Program on Hybrid Intelligence.

Focal Area 4 Software Science and Engineering

In the coming period, we aim at strengthening our research programme on developing theories, methods, techniques, languages, and computational tools for systematically engineering trustworthy software systems. By that, we mean systems that are

a) aligned with societal values and goals, but also
b) aware and protective of risks and threats posed to these values,
c) compliant to ethical and legal norms,
d) verifiable and controllable,
e) safely inter-operable with other systems, including legacy systems, as well as sociotechnical systems,
f) able to maintain these properties in scenarios of continuous change in goals, threats, norms, requirements, technologies, and soon, that is to say, systems that are robust, resilient, and evolvable.

In order to achieve these goals, we are increasing the synergy between the SCS and FMT groups by combining the cutting-edge research of SCS on ontology-driven conceptual modelling (see Appendix C.4 on page 41, with FMT's competences on the development of formal verification techniques. We will work on guaranteeing formal foundations for all techniques that we develop, but at the same time make sure that the results scale to real-world systems, such that we can really have an impact on how software is developed. To achieve this goal, our research will also expand in directions such as suitable domain-specific languages, grammar technology, and improved compilers. The newly appointed professors for the *Sector-plan* positions (one in each group) in the area of Software Evolution will play an important role in this respect.

Sector plan

Focal Area 5 Security

Sector plan

Two positions were created thanks to the *Sector-plan* to strengthen the research on security. One position is in the DACS group and the other in SCS. In general DACS' security research focusses on network security, whereas the research in SCS deals with data security.
Strategic impulse funds from the faculty will be used to connect both strands of research by establishing a living lab on the Internet of Things.

Twente University Centre for Cyber-security Research (TUCCR)

In the reporting period the preparations have begun to start a research centre on cyber security: The Twente University Centre for Cyber-security Research (TUCCR) [59] which was launched in 2021. TUCCR is a public-private partnership where experts, professionals, entrepreneurs, researchers, and students from industry and knowledge partners collaborate to deliver talents, innovations, and know-how in the domain of cyber security.

6.4 Conclusion

The period under review started out with the effects of the reorganisation being felt deeply, with less time for research, less PhD students and less technical staff. The decline in students (BSc, MSc) was the major reason to reorganise. But soon the numbers picked up and rose beyond expectation. This meant an increase in teaching load, but also in the possibility to attract new staff and improve diversity. Still we feel more can be done. We have chosen to strengthen our collaborations inside and outside through various initiatives as we believe this is needed to reach our mission.

The self-evaluation document is complemented with a one-page summary.

7 Summary

In Figure 7.1 we summarise the main points we have addressed in this report by annotating the front page of the SEP protocol 2021-2027 [2], in the form of some yellow notes.

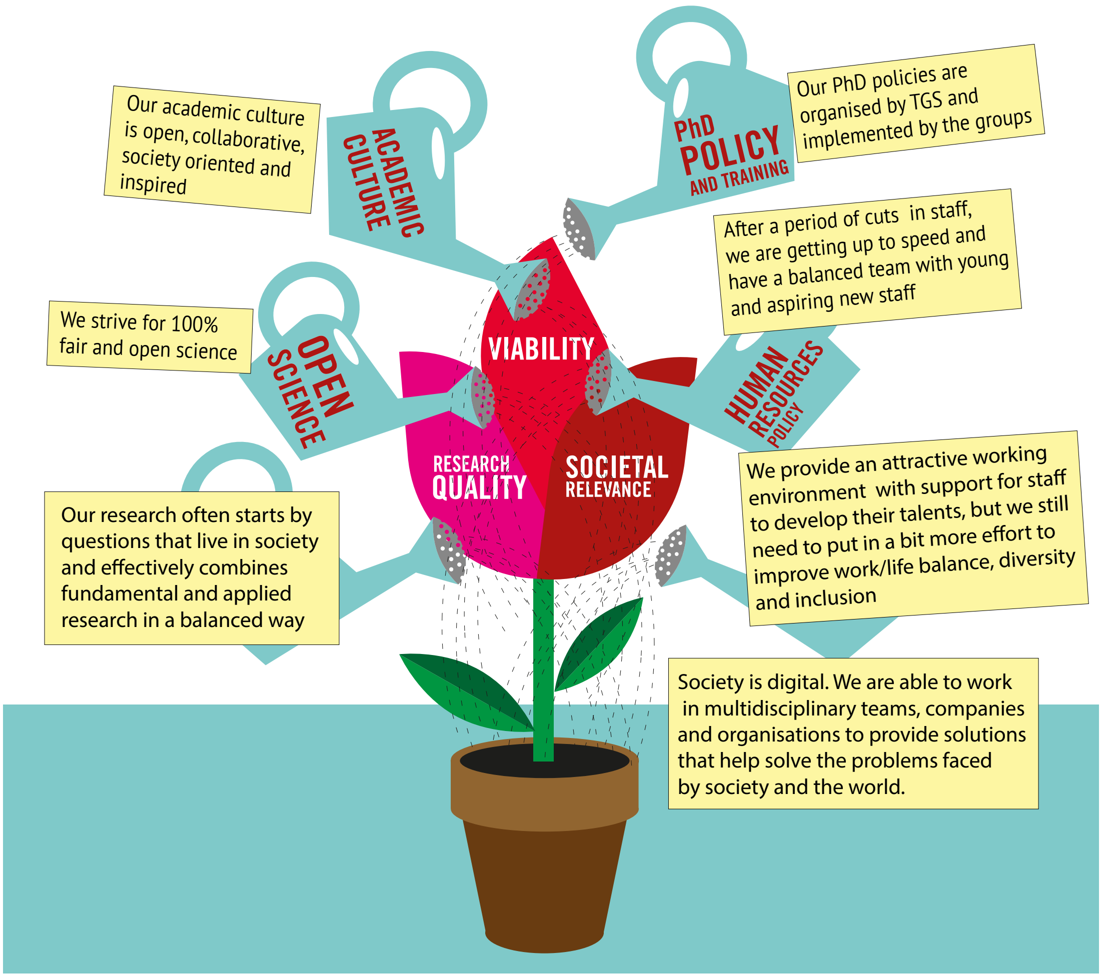


Figure 7.1
Viability, Research Quality and Societal Relevance


In the 12th century
FROG
FROG
FUN ROBOTIC OUTDOOR GUIDE
UNIVERSITEIT TWENTE

This appendix includes the compulsory tables of the SEP protocol

A
Appendix Tables

A.1 Key Performance Indicators

Table A.1
Key Performance Indicators (KPIs)

Assessment Dimensions	Quality domains: Research quality	Quality domains: Relevance to society
Demonstrable products	**1. Research products for peers** a. Publications: Articles in a selected set of main journals and conferences, PhD theses	**4. Research products for societal target groups** a. Well-educated Masters' and PhD graduates b. Media appearances
Demonstrable use of products	**2. Use of research products by peers** a. Use of data sets b. Use of software	**5. Use of research products by societal groups** a. Contract Research b. Spin-offs and Start-ups
Demonstrable marks of recognition	**3. Marks of recognition from peers** a. Major awards and grants b. Prizes	**6. Marks of recognition by societal groups/companies** a. Part-time positions financed by industry b. Ancillary positions

A.2 Research staff

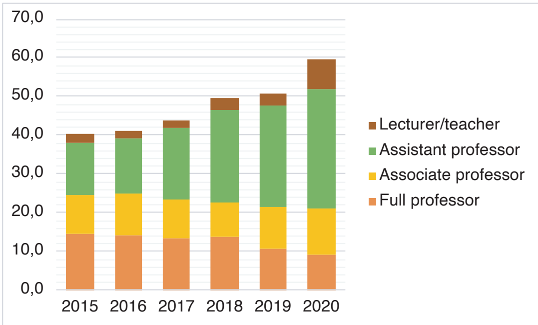
Table A.2
Scientific staff in FTEs

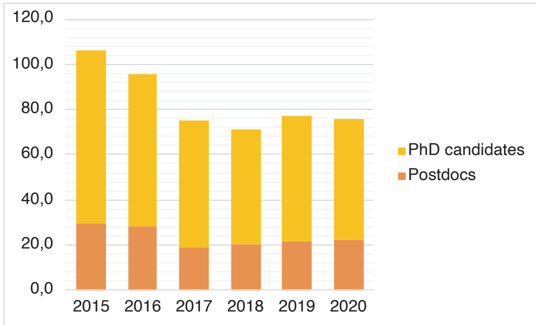
	2015		2016		2017		2018		2019		2020	
	#	FTE	#	FTE	#	FTE	#	FTE	#	FTE	#	FTE
Full professor	20	14,8	19	14,0	20	13,4	19	13,8	17	10,7	16	9,3
Associate professor	11	9,7	13	11,1	13	9,9	10	9,0	14	10,9	16	11,7
Assistant professor	18	13,7	20	14,1	25	18,5	27	23,8	32	25,9	38	31,0
Total research staff	49	38,2	52	39,2	58	41,8	56	46,6	63	47,5	70	52,0
Lecturer/teacher	3	2,2	4	2,0	3	1,9	5	2,9	8	3,4	12	7,5
Postdocs	52	29,5	42	28,5	37	19,3	36	20,4	33	21,8	39	22,3
PhD candidates	101	76,8	82	67,0	72	55,6	75	51,0	72	55,4	71	53,5
Total PD + PhD	153	106,3	124	95,6	109	75,0	111	71,4	105	77,2	110	75,8

In Table A.2 and Figure A.1 a full-time employed staff member is counted as 1 fte, thus also counting the time spent on teaching. Appointments ≤ 0.2 fte are not counted.

Figure A.1
left:
Scientific Staff (fte)
and right:
Postdocs and PhDs
(fte),

Based on table A.2





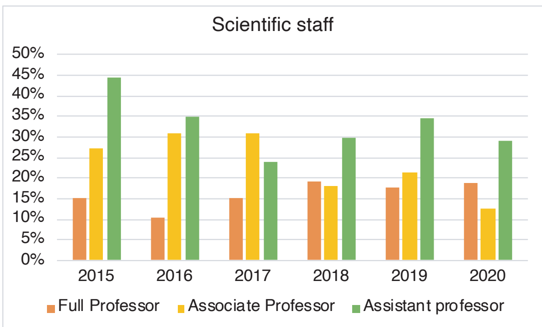
A.3 Diversity of research staff: Gender and nationality

Table A.3
Gender and Nationality

	2015				2016				2017				2018				2019				2020			
	Female		Male		Female		Male		Female		Male		Female		Male		Female		Male		Female		Male	
	NL	Int.	NL	Int.	NL	Int.	NL	Int.	NL	Int.	NL	Int.	NL	Int.	NL	Int.	NL	Int.	NL	Int.	NL	Int.	NL	Int.
Full prof	3	0	13	4	2	0	13	4	3	0	14	3	3	0	14	2	3	0	12	2	3	0	11	2
Associate prof	2	1	7	1	2	2	7	2	2	2	7	2	0	1	6	3	1	2	7	4	1	1	7	7
Assistant prof	3	5	7	3	2	5	9	4	2	4	10	9	3	5	10	9	3	8	12	9	3	8	13	14
Tot. Scient. staff	8	6	27	8	6	7	29	10	7	6	31	14	6	6	30	14	7	10	31	15	7	9	31	23
Postdocs	2	8	26	16	2	4	21	15	2	4	15	16	2	4	15	15	1	5	13	14	3	8	13	15
PhD candidates	4	8	44	45	4	6	33	39	2	6	33	31	4	9	32	30	5	13	25	29	6	15	20	30
Total PD + PhD	6	16	70	61	6	10	54	54	4	10	48	47	6	13	47	45	6	18	38	43	9	23	33	45

Figure A.2
Percentages female employees, based on table A.3

left: Scientific staff, right: Postdocs and PhDs



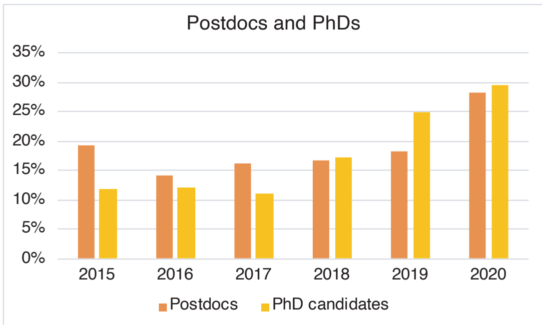
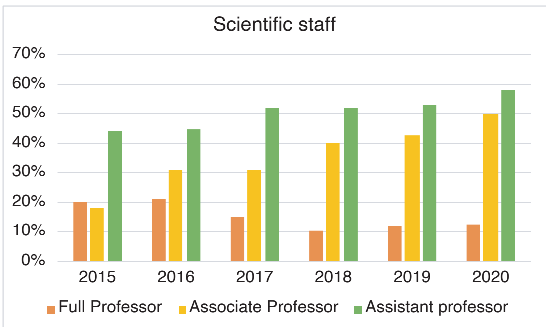
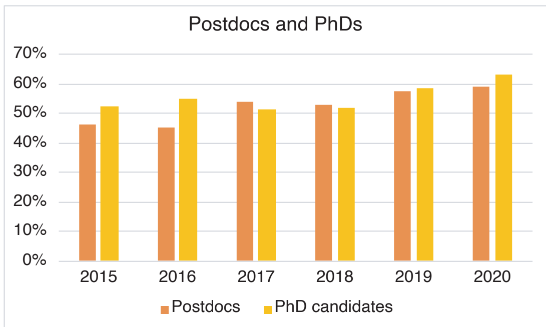


Figure A.3
Percentages international employees, based on table A.3

left: Scientific staff, right: Postdocs and PhDs



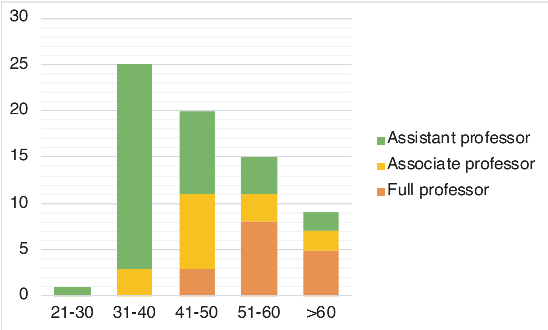


A.4 Diversity of research staff: Age distribution of scientific staff in 2020

Table A.4
Age distribution of scientific staff

	21-30	31-40	41-50	51-60	>60
Full professor	0	0	3	8	5
Associate professor	0	3	8	3	2
Assistant professor	1	22	9	4	2
Total Scientific staff	1	25	20	15	9

Figure A.4
Age Distribution of Scientific Staff. Based on table A.4



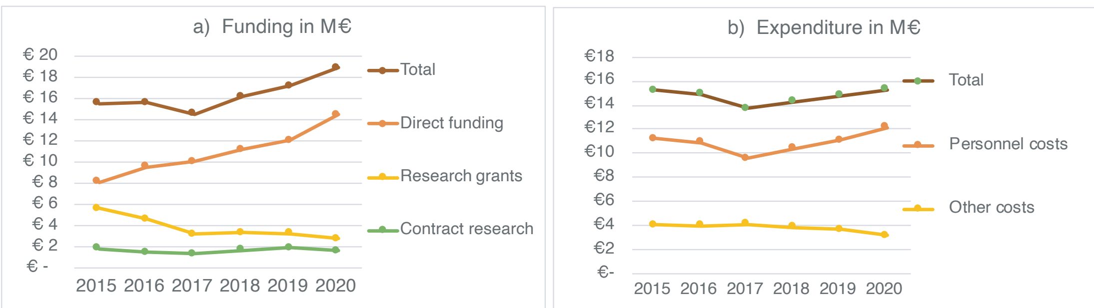
A.5 Funding and expenditure

Table A.5 Funding and Expenditure

	2015		2016		2017		2018		2019		2020		2021 [4]	
Funding:	M€	%	M€	%	M€	%	M€	%	M€	%	M€	%	M€	%
Direct funding [1]	8,119	52	9,545	61	10,006	69	11,150	71	11,982	70	14,456	77	13,673	76
Research grants [2]	5,579	36	4,579	29	3,202	22	3,354	21	3,251	19	2,737	14	3,096	17
Contract research [3]	1,821	12	1,487	10	1,325	9	1,661	10	1,898	11	1,641	9	1,190	7
Other	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total funding	15,519	100	15,611	100	14,534	100	16,165	100	17,131	100	18,834	100	17,959	100
Expenditure:														
Personnel costs	11,193	74	10,924	73	9,603	70	10,427	73	11,113	75	12,153	79	13,211	80
Other costs	4,039	27	3,986	27	4,147	30	3,856	27	3,656	25	3,160	20	2,358	20
Total expenditure	15,231	100	14,910	100	13,750	100	14,283	100	14,769	100	15,313	100	16,508	100

[1] Direct funding = funding by university ('basisfinanciering')
[2] Research grants = grants obtained in national and international scientific competition e.g. grants from NWO and KNAW, and ERC. (Note: this deviates from SEP, where ERC grants are listed under 3)
[3] Contract research = funding for specific research projects obtained from external organisations, such as industry, government ministries, and charitable organisations.
[4] Predictions, based on the budget for 2021.

Figure A.5
a) Funding and b) Expenditures in M€ , based on Table A.5

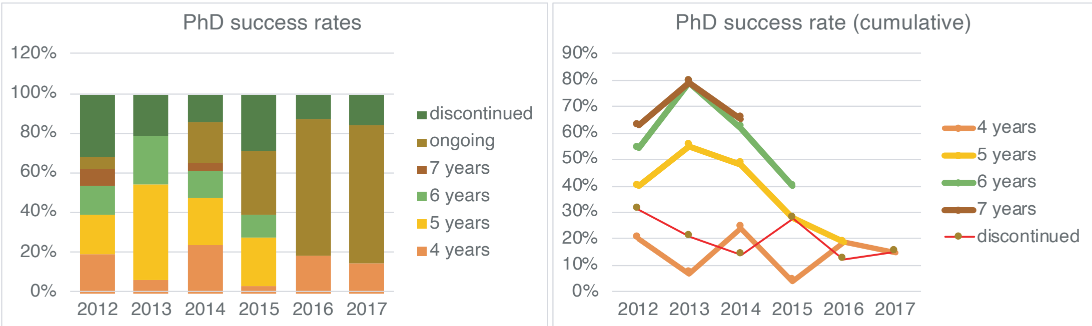


A.6 PhD candidates

Table A.6
PhD success rates

Enrolment				Cumulative success rates: PhD candidates graduating within											
Starting year	Male	Female	Total	4 years + 3 months		5 years		6 years		until Dec. 2020		Ongoing		Discontinued	
	#	#	#	#	%	#	%	#	%	#	%	#	%	#	%
2012	32	3	35	7	20%	14	40%	19	54%	22	63%	2	6%	11	31%
2013	26	3	29	2	7%	16	55%	23	79%	23	79%	0	0%	6	21%
2014	24	5	29	7	24%	14	48%	18	62%	19	66%	6	21%	4	14%
2015	17	8	25	1	4%	7	28%	10	40%	-	-	8	32%	7	28%
2016	14	2	16	3	19%	3	19%	-	-	-	-	11	69%	2	13%
2017	17	3	20	3	15%	-	-	-	-	-	-	14	70%	3	15%
2018	23	12	35	-	-	-	-	-	-	-	-	-	-	-	-
2019	17	9	26	-	-	-	-	-	-	-	-	-	-	-	-
2020	17	12	29	-	-	-	-	-	-	-	-	-	-	-	-
Total	187	57	244	23	15%	54	40%	70	59%	64	69%	41	27%	33	21%

Figure A.6
PhD success rates
More details in table A.6



A.7 Publications

Table A.7
Publications

	2015	2016	2017	2018	2019	2020
Journal publications, refereed	105	91	77	60	62	83
Conference publications, refereed	208	193	211	167	159	157
Book chapters	14	16	19	29	20	15
Books (monographs)	0	1	1	0	2	2
Books (edited)	2	4	7	10	4	1
PhD theses	24	23	29	28	22	7

Figure A.7
Publications
More details in table A.7

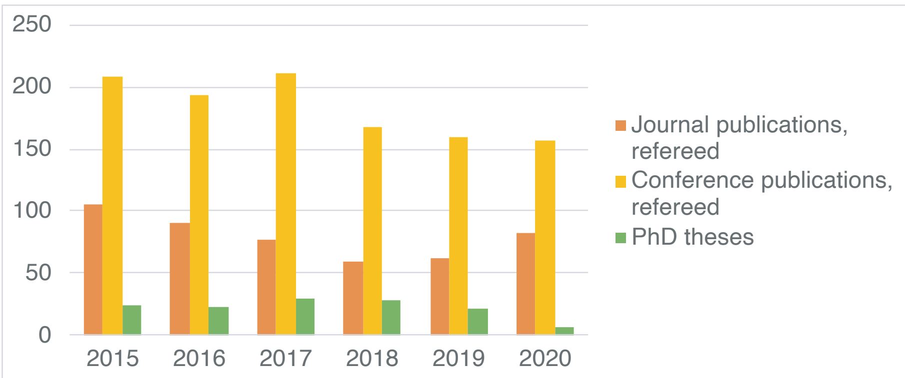


Table A.8 BSc and MSc intake Computer Science

	2015			2016			2017			2018			2019			2020		
	M	F	Total	M	F	Total	M	F	Total	M	F	Total	M	F	Total	M	F	Total
Intake MSc	33	4	37	52	15	67	70	7	77	73	12	85	89	24	113	84	18	102
Intake BSc	58	4	62	114	12	126	142	11	153	177	28	205	262	35	297	260	38	298

Figure A.8
left:
BSc and MSc intake Computer Science

right:
BSc and MSc graduates Computer Science

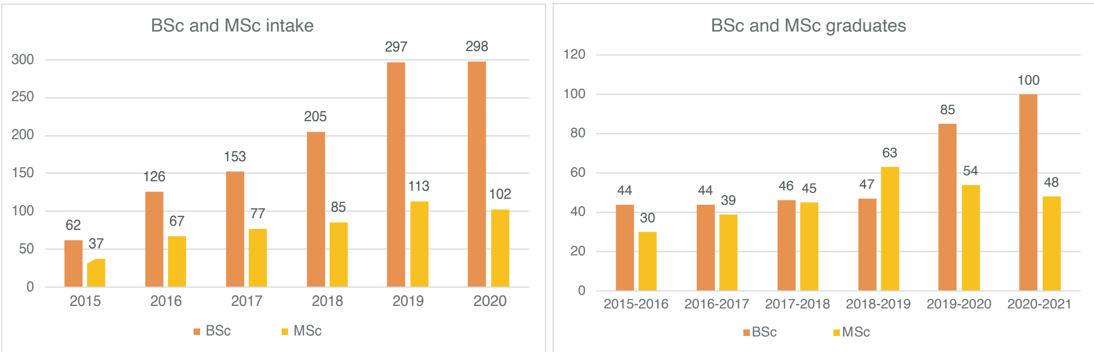


Table A.9 BSc and MSc graduates Computer Science

	2015-2016	2016-2017	2017-2018	2018-2019	2019-2020	2020-2021
intake BSc	44	44	46	47	85	100
intake MSc	30	39	45	63	54	48

B

5 Key Publications

1. **Cyber-Physical Systems** [31]
   M Shoaib, S Bosch, OD Incel, H Scholten, PJM Havinga, *Complex human activity recognition using smartphone and wrist-worn motion sensors*, **Sensors Journal, 2016 (4)**

   - The paper was one of the early papers in that domain, and nicely combines our expertise of smart sensing and data analytics.
   - A nice collaboration project with a top university in Turkey.
   - Many citations (295).
   - The dataset that is collected and used in this paper is publicly available, (KPI 2, use of data sets).

2. **Cyber-Social Systems** [32]
   Eyben, F., Scherer, K., Schuller, B., Sundberg, J., André, E., Busso, C., Devillers, L., Epps, J., Laukka, P., Narayanan, S., & Truong, K. P. (2016). *The Geneva Minimalistic Acoustic Parameter Set (GeMAPS) for Voice Research and Affective Computing* **IEEE transactions on affective computing, 7(2),190-202**

   - The paper is the result of collaboration between major research groups in affective computing around the world.
   - It has many citations (779).

3. **Data Science** [33]
   M Nauta, D Bucur, C Seifert, *Causal discovery with attention-based convolutional neural networks* **Machine Learning and Knowledge Extraction 1 (1), 312-340, 2019**

   - 36 citations since 2019
   - On DMB focus topic of explainable ML
   - Software is open source: https://github.com/M-Nauta/TCDF
   - Well-appreciated work as observed from personal communications by other researchers attempting to apply and extend it.
   - The GitHub page has a GitHub*-rating of 241.
   - Without special attention to gender bias, we selected a paper with an all-female authorship.

4. **Software** [34]
   Julio Cesar Nardi, Ricordo de Almeida Falbo, Joao Paulo Almeida, Giancarlo Guizzardi, Luis Ferreira Pires, Marten van Sinderen, Nicola Guarino, Claudenir Marais Fonseca, *A commitment-based reference ontology for services* **Information Systems 54 (2015) 263–288**

   This paper presents a core reference ontology for services that harmonises a number of service perspectives, based on the notions of service commitments and claims, grounded in the Unified Foundational Ontology.

   - Published in one of the key journals of our field with high impact (IF 2019-2020: 4.188)
   - It is well cited (94 citations) and still relevant (16 citations in 2020).
   - The research is done in collaboration with leading groups on service language engineering and ontologies, viz. the NEMO group of UFES/Brazil and the Laboratory for Applied Ontology of ISTC/Italy.

5. **Security** [35]
   Roland van Rijswijk-Deij, Mattijs Jonker, Anna Sperotto, and Aiko Pras, *A High-Performance, Scalable Infrastructure for Large-Scale Active DNS Measurements* **IEEE Journal on Selected Areas in Communications,34(6) 1877-1888, 2016**

   - This paper has been published in a top journal.
   - It is about a platform for collecting measurement data (KPI 2, use of data sets).

This appendix includes 6 Case Studies

C Appendix Case Studies

C.1 ProtoTree: Intrinsically Explainable AI

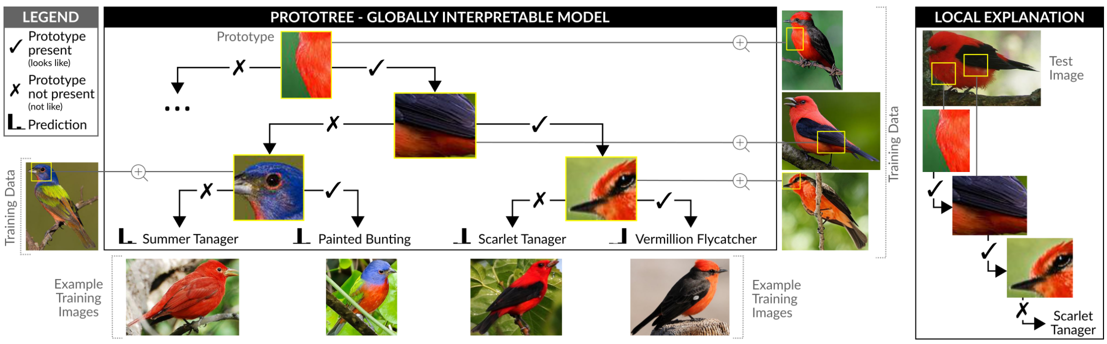
ProtoTree is a focus research topic of DMB, PhD project of Meike Nauta.

The main reason behind forming the research group DMB in 2018 was to bring an inter-disciplinary group of researchers together to work on important challenges and threats in machine learning, such as fairness, data quality, robustness, privacy, trust, bias, morphs, energy consumption, fake news, etc. The faculty decided to internally fund one PhD position on 'Explainable AI' as a fundamental focus research topic, since the black-box nature of deep learning models was and is considered a major obstacle in addressing several of these challenges and threats as well as in the adoption of AI in domains like health. What does a machine learning model actually learn? What is the reason behind a (wrong) prediction? Are our standard validation practices sufficient for obtaining robust and reliable prediction models?

In a research project demonstrating that ML works in practice with real-world data of regional strategic partner ZGT hospital, we observed for example that the model 'cheated' in the detection of hip fractures in X-Ray images: it looked for wrinkled skin and the presence of a diaper as evidence for a hip fracture, presumably because these indications of high age have a high a priori incidence of hip fractures. How can we truly detect this non-medical reasoning? And how can we make the model not reason in this way?

Most explainable AI research focuses on post-hoc explainability in which the model is interpreted after having been trained. Such methods generate explanations that approximate a trained model and therefore only give an intuition about how the model works. In our opinion, this does not suffice! Therefore, we decided to go in a different direction into which little research had been done: 'intrinsically interpretable machine-learning' being explainable by design.

Figure C.1.1
ProtoTree: Globally interpretable model



And with success. The approach we developed is called 'ProtoTree': it uses the expressiveness of deep learning to learn prototypes, which are a kind of neural representations of discriminating aspects in images, and at the same time learn a decision tree that uses these prototypes to make predictions. The prototypes are shown to the user by means of image fragments that illustrate the meaning of the prototypes. In one of the experiments, ProtoTree has been trained using a dataset consisting of images of 200 different bird species. We have shown that the performance of ProtoTree on this task is almost as good as what black-box deep learning models can do, but with the added advantage of truthfully exposing its own reasoning. When the model is exposed to an input image, the model looks for matching physical characteristics of a type of bird; for instance, the presence of a red breast, a black wing, and the absence of a black stripe near the eye will be identified as Scarlet Tanager (see Figure C.1.1). An example of a case of bias and non-robustness that could be discovered is that ProtoTree revealed that the model learnt to distinguish a water bird from a singing bird by looking at the presence of tree leaves. Apparently, the image collection did not contain sufficient images of singing birds with a non-tree background ... a deficiency which would not have been discovered with other deep learning approaches and common validation methods.

Basically, the models' reasoning is like the well-known game 'Guess who?'. While such reasoning is straightforward for humans, it should be emphasised that the machine learning method learns by itself what aspects to look at when making predictions, with nothing more than example images and class labels. The learning process is similar to teaching a child new things. We show a child dogs and photographs of dogs, but we do not tell the child what physical characteristics to look for. And still the child learns and will even be able to describe what a dog looks like and how to distinguish one from other animals.

The research done by Meike Nauta in 2019/2020 recently received significant recognition: her paper was accepted at CVPR 2021 [60], the annual Conference on Computer Vision and Pattern Recognition. A poster about the work at ICT.OPEN 2021 won the first prize in the poster competition. We put extra effort into dissemination of this work to the general public: A teaser video [61] has been developed , the software has been released in open source [62], and an article for the UT's websites [63] has been published. This has already been picked up by several popular scientific fora, such as NewScientist [64].

Next steps will be to experiment with the ProtoTree approach on other real-world scenarios such as medical diagnosis. This also requires extending it to different machine learning tasks: where the bird-example is a multi-class problem (200 different species to classify among), there are also tasks with much fewer classes (two or just a few), many more (e.g., face recognition), or tasks for predicting continuous values (regression). Furthermore, we would also like besides images, to extend ProtoTree to other types of input data such as sensor data, natural language, etcetera.

We truly believe that intrinsically explainable AI is the right direction for obtaining an AI that can be well-integrated in stakeholders' workflows, that respects people's rights (GDPR) on explanations for decisions that concern them, and whose reasoning can be verified by humans.

C.2 Predictive Maintenance for Very effective asset management

NWA project PrimaVera

No more train delays, production errors, or unplanned downtime. That is the point on the horizon in the field of Predictive Maintenance (PM), a.k.a. data-driven or smart maintenance. The central idea in predictive maintenance is to collect data via sensor technology, and then use data analytics to predict various prognostic measures, such as the remaining useful lifetime of an asset, so that maintenance can be planned more efficiently. The holy grail is just-in-time maintenance: performing maintenance exactly when and where needed.

Predictive maintenance is widely seen as very effective maintenance strategy, and as one of the most promising applications of the Internet-of-Things. In a recent study, McKinsey expects cost savings up to $630 billion annually, as well as down time reductions by 50%.

Of course, higher uptime at lower costs, that is what everybody wants. However, realising the envisioned benefits of predictive maintenance is nontrivial. Companies experience major obstacles in leveraging predictive maintenance technologies. While individual building blocks for PM exist, the integrating these into optimal maintenance and asset management solutions requires major challenges to be tackled.

Dutch Research Agenda NWA

This is why in 2019, the PrimaVera project (Predictive Maintenance for Very effective asset management) was funded by the *Dutch Research Agenda NWA*. The project, led by Prof. Marielle Stoelinga, brings together 6 knowledge institutes and 11 industrial/societal partners (incl ASML, NS, Royal Netherlands Navy).

Our overall goal of PrimaVera is to make predictive maintenance easier and more effective, thereby realising the full potential of PM: better performance and higher availability at lower cost. Indeed, predictive maintenance is a booming research area, where significant progress has been made during the past decade, both in industry and in academia. While many core building blocks of PM exist (such as sensor technology, failure prediction methods, and optimisation techniques), the overarching challenge of PM is to leverage these individual building blocks into an effective and efficient framework supporting optimal maintenance and asset management in a complex arena.

As stated in the roadmap Smart Industries:

> *The challenge is to reconcile the perspective of the domain experts with their failure-mode analyses with the perspective of the data analysts with their correlations between environmental and internal factors and degradation behaviour. After that, [..] organisational collaboration in managerial decision-making [..] and scheduling of the chosen course of action, and also from the organisational deployment of these decisions.*

Integral approach

The PrimaVera project picks up this challenge through an *integral approach*, which considers all steps in the predictive maintenance cycle: sensor technologies, data analysis, prognostics, and optimisation and decision making. Unique in this project is the involvement of human and organisational factors, ensuring that our solutions work for organisations and for people: No matter how accurate or fast failure prediction algorithms are, if people do not use them, then everything is in vain.

Via the university of applied sciences, we also work with maintenance experts at the vocational level (MBO), so that data driven maintenance techniques also reach the work floor.

PrimaVera has assembled a multidisciplinary team providing exactly these expertises. Together, we will provoke various *game changers needed to realise an effective PM workflow*:

The consortium includes leading industrial partners from important sectors of the Dutch economy.

1. Infrastructure (Rijkswaterstaat, Rolsch Asset Management, Waterschap de Dommel);
2. High-tech (ASML, Technobis, NS);
3. Maritime (Damen Shipyards, Alfa Laval, Royal IHC, the Royal Netherlands Navy).

Concrete outcomes are the instruments that make predictive maintenance effective: scalable, accurate, real-time health prognostics and diagnostics algorithms, and turn these into effective, robust, and usable maintenance decisions that can operate in complex and uncertain environments:

1. *An orchestrated approach to data-driven maintenance at asset or fleet level* based on a human-centric integration of advanced prognostics and adaptive maintenance planning technologies.
2. *Scalable, robust and accurate algorithms for health monitoring, diagnosis, failure prediction and automated root cause analysis* based on recent developments in data analytics such as causal inference techniques and hybrid approaches combining statistics and machine learning.
3. *Intelligent data acquisition technologies* for autonomous networked sensor systems that use soft computing to obtain targeted and reliable data for predictive maintenance.
4. *Organisational and human-centred decision support solutions* to effectively support companies to achieve a digital transition in maintenance based on new organisational and psychological theories on decision making under uncertainty.

In this way, PrimaVera works towards its ultimate technological vision: fully autonomous maintenance, where intelligent assets, self-report their health status, and decide on maintenance actions autonomously.

Primavera Testbench

C.3 UT partner in the Digital Transformation of other Scientific fields

Computer Science at the University of Twente enables digital transformation by constructing hardware, algorithms and software, and, is also a partner for other scientific fields in their digital transformation.

C.3.1 Arise biodiversity project

Arise in U today

Arise at the NOS

ARISE stands for Authoritative and Rapid Identification System for Essential biodiversity information

A successful example of the latter is the leading role of Twente Computer Science groups (PS, DMB, SCS) in the Arise biodiversity project [65], financed through the large-scale infrastructure programme (GWI) of NWO. In this project, the University of Twente is responsible for designing the digital research infrastructure, including data science and artificial intelligence, based on the combined body of knowledge in the research groups, ranging from FAIR data, databases, sensing, monitoring and software architecture. It gives ample possibilities for research projects that use this infrastructure – for example, based on the Arise infrastructure an NWO Gravity (Zwaartekracht) proposal has been submitted by the UT.

Image by Jill Wellington from Pixabay

The loss of biodiversity is one of the main threats to humanity's survival. But only if we know what is there, can we make an effort to preserve it. For this reason, we urgently need a better instrument for species identification and for monitoring biodiversity. The ARISE project aims to construct an infrastructure for doing precisely this for every species in the Netherlands (multicellular species only - for now). This infrastructure will be the first of its kind and combine information from eDNA, AI-based recognition of both images and audio, and radar data generated in new and existing monitoring programmes to yield a comprehensive picture of its biodiversity. It will also bring together many new insights in the fields of artificial intelligence and data science.

Consortium Arise

Universiteit van Amsterdam

Naturalis Biodiversity Center

UNIVERSITEIT TWENTE.

WESTERDIJK FUNGALBIO DIVERSITY INSTITUTE

This integrated infrastructure and facility will provide Dutch researchers, nature conservation organisations, policymakers, industry, regional water authorities, infrastructure developers, and many more with access to the most advanced near-real-time identification service for species detection and monitoring biodiversity. This, in turn, will yield new opportunities for understanding how ecosystems function. It will identify trends and ensure that biodiversity recovery receives the necessary attention in solutions for major societal transitions such as towards nature-inclusive cities and agriculture.

Consortium ARISE, includes, beside the University of Twente, Naturalis Biodiversity Center (Naturalis), University of Amsterdam and the Westerdijk Fungal Biodiversity Institute.

C.3.2 Sport Data Valley

Another example is the national Sport Data Valley [66]. Sports data can offer insights into an athlete's performance, but collecting and analysing this data in a way that respects data privacy can be a challenge. The online platform of Sport Data Valley provides a solution that enables researchers to capture and analyse data with less hassle quickly but with data privacy ensured. Furthermore, through the platform, scientific research can be made more accessible to a broad audience. It can also be seen as a platform for Citizen Science. As well as the digital infrastructure, a physical Sport Data Valley lab has also been realised in the Sports Center of the University of Twente.

Image from https://info.sportdatavalley.nl/english/

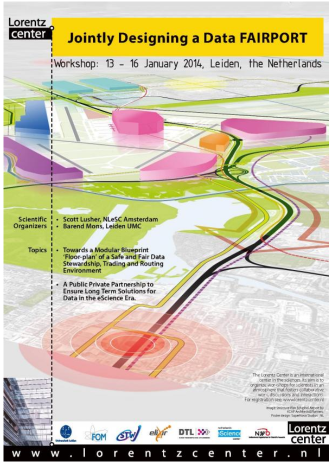
The Sport Data Valley infrastructure has been developed by a consortium of higher education institutions, besides University of Twente (project lead, DMB, SCS and HMI groups) also by Leiden University, Delft University of Technology, VU Amsterdam and Amsterdam University of Applied Sciences. Most partners bring in domain knowledge about sports and movement.

Again, a large number of projects is based on this infrastructure, for example Sportkeur 2.0 [67] and Smart Sports Exercises [68].

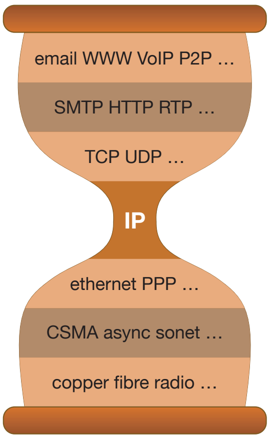
C.4 Findable, Accessible, Interoperable & Reusable Digital Objects (FAIR)

FAIR is a project in the Services and CyberSecurity (SCS) group

The research on Findable, Accessible, Interoperable and Reusable (FAIR) digital objects at SCS aims at improving interoperability and reuse of these digital assets in different layers of abstractions. The FAIR principles emerged from a workshop named 'Jointly Designing a Data FAIRPORT', which took place in Leiden, the Netherlands in January of 2014. In the workshop over 30 experts representing academia, industry, funding agencies and scholarly publishers from all over the world discussed improvements in the global data management. As a result of this workshop, in March 2016 a paper titled "The FAIR guiding principles for scientific data management and stewardship" [69] has been published with a list of principles to guide the improvements in findability, accessibility, interoperability and reusability (FAIR) of digital objects.



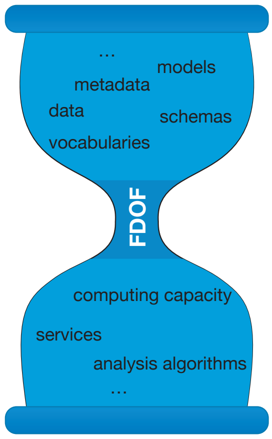
Since its publication in 2016, this seminal paper on the FAIR principles (co-authored by Joost Kok and Luiz Bonino da Silva Santos) gained enormous momentum. It has been cited over 5000 times, and was explicitly mentioned in official reports of the G20 (September 2016) and the G7 (May 2017) summits. It is being used as the basis of the European Open Science Cloud and as requirements for funding agencies around the world, including the European programmes Horizon 2020 and Horizon Europe and the American National Institutes of Health (NIH).



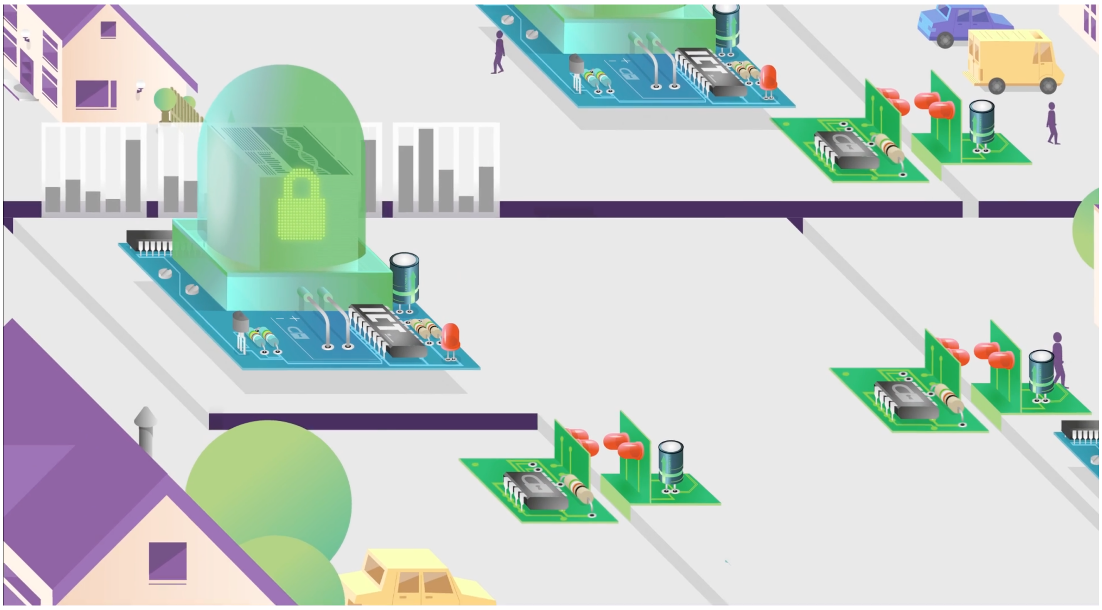
Internet hourglass

With so much attention, it was inevitable that stakeholders started to move from using the FAIR principles from general guidelines to design and implement approaches and technologies to realise them. In our research on FAIR, we adapted the hourglass metaphor used to describe the internet to be used as guidance for placing generic and specific approaches. In the Internet hourglass model, the Internet Protocol (IP) is placed at the thin waist of the hourglass to represent the minimal set of agreements that need to be made to connect the top layers, representing increasingly specialised protocols and applications, with the bottom layers, representing the physical networks and their protocols.

In our FAIR hourglass, the thin waist represents a framework, named FAIR Digital Object Framework (FDOF) composed of basic elements such as a predictable identifier resolution behaviour, a mechanism to discover the digital object's metadata, represented in a common presentation format, a digital object's typing system and a minimal metadata scheme for each type of digital object. The research on the FDOF includes the definition of the elements of the framework, how the framework can be placed on top of the current communication infrastructures, for example, Internet, WWW, and the related conceptual models to describe these elements for humans and machines.



Besides the research on the infrastructure foundation of FAIR represented by the FDOF, the SCS group also works on research covering other layers of the FAIR hourglass. From a methodological point of view, the work on the FAIRification process aims at defining a set of canonical steps to improve the FAIRness of existing digital objects. Regarding applications, we have been involved in the FAIR Data Point (FDP), a server solution aimed at defining how applications should expose their metadata in a FAIR way and the FAIRifier, a software solution to automate (parts of) the FAIRification process. Still in the application layer, we have been working on the FAIR Data Train (also known as the Personal Health Train), an architecture for privacy-preserving distributed learning using the train system metaphor where trains (the algorithms) visit stations and there interact with data (or other types of digital objects) leaving with the analysis results instead of moving potentially large amounts of data around.



The group is also involved in education activities to help increase the availability of FAIR-related capacity. Lectures on the FAIR principles and the FAIRification process have been included in the last Smart Industries System course. A new masters' course named FAIR data principles and the FAIRification process has been proposed for Computer Science and BIT students. This course is centered in a practical FAIRification project to be conducted by the students with lectures to provide the required background knowledge for them to perform the activities. Since the work on FAIR is highly reliant on semantics and semantic technologies, two other courses have been proposed by the group on ontology-driven conceptual modelling and Linked Data and Semantic Web technologies.

C.5 Cyber Security

The world is quickly changing into a digital society. All people are being connected through the Internet (Internet of People), all devices are being connected (Internet of Things), all companies are being connected as well as all services that we rely upon. For our digital society the ubiquitous availability of data has become crucial.

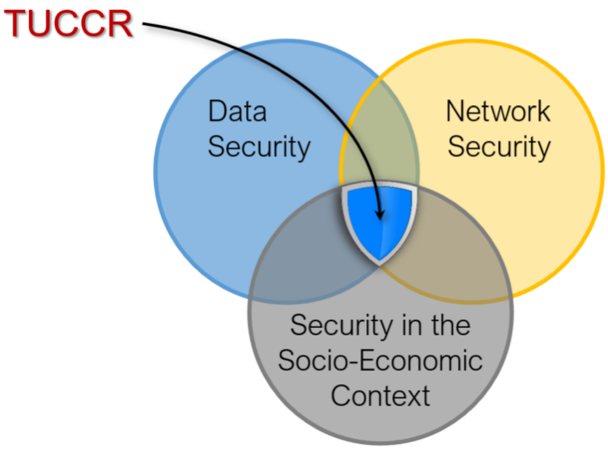
However, now that our society has changed into a digital society, we should understand that we completely depend on the correctness of our data as well as the proper operation of the underlying ICT infrastructure. We should trust our data under all circumstances, which requires it to be not only stored and exchanged in a secure and privacy preserving way, but also that we understand where the data comes from and how it will be used. Since our society cannot sustain without the Internet, we must certify that we understand its operation and keep control over it, under all circumstances. Whereas that was easy just one or two decades ago, nowadays it is a real challenge, especially since a small number of big players and nation states gained control over major parts of our ICT infrastructure and services, and thus our society. As a consequence, our digital sovereignty is at stake, and Europe runs the risk of being digitally colonialised by others.

But as well as nation states that use the Internet to gain more influence, traditional criminals have also discovered the Internet to make money by performing large scale attacks on users and systems connected to the Internet. Examples include data exfiltration attacks that frequently lead to mega breaches exposing sensitive data from millions of innocent people to criminals, as well as Ransomware and Distributed Denial-of-Service attacks that bring down the complete service of an organisation. On an almost daily basis, newspapers world wide report about such cyber-attacks and the impact that they have on our digital society.

TUCCR
Twente University Centre for Cybersecurity Research

To address these challenges, the UT established the Twente University Centre for Cybersecurity Research (*TUCCR*) [59]), with the goal to create a long-lasting Public-Private Partnership around cybersecurity at the regional and national level. TUCCR was officially opened on March 5. 2021, and its partners include Betaalvereniging Nederland, BetterBe, Cisco, NCSC, NDIX, Northwave, SIDN, SURF, Thales and TNO. TUCCR has strong connections with national cybersecurity agenda setting organisations, such as dcypher, ACCSS, NCSC, the Dutch Digital Delta and TNO, but also with international projects and organisations, such as CONCORDIA [70] and the CODE cybersecurity center [71] in Munich.

The mission of TUCCR is to make our society resilient against cyber-harm by researching digital technologies in the societal and economic context for their robustness against cyber-harm and by developing solutions that provide the necessary level of resilience and security. To this end, we investigate associated cyber-security challenges with a specialised focus on real-world data and network security in the socio-economic context (see Figure 1). We cover the complete range of steps necessary to develop secure solutions for the real world, starting from the analysis of known cyber-harm, - attacks and -vulnerabilities and their proper modelling, to the engineering of targeted protection, mitigation, detection, and response solutions, all the way to their implementation and extensive testing. In each of these steps, we are paying explicit attention to the demands imposed by the socio-economic context and the involved human factor, which can be part of the problem and part of the solution at the same time.



We target societal and economic impact by driving innovation. To ensure this, our research is highly use-inspired and largely driven by real-world challenges found at the TUCCR partners, but also elsewhere. We perform open and well-documented research to ease reproducibility and collaboration and to allow for effective knowledge transfer. Key components in this are, besides publishing our research at the top security conferences and in journals, the release of open-source tools and datasets as well as the creation of minimum viable products and businesses.

To deliver the next generation of cybersecurity experts that meet the demands in industry, government, and academia, our research and entrepreneurial ambitions are tightly coupled with our educational programmes. Our cybersecurity graduates have a T-shaped profile with 2/3 of deep technical knowledge and 1/3 of socio-economic knowledge in cybersecurity. See our cybersecurity master programmes for more details: 4TU Cybersecurity Master Specialisation [72] and EIT Digital Master in Cybersecurity [73].

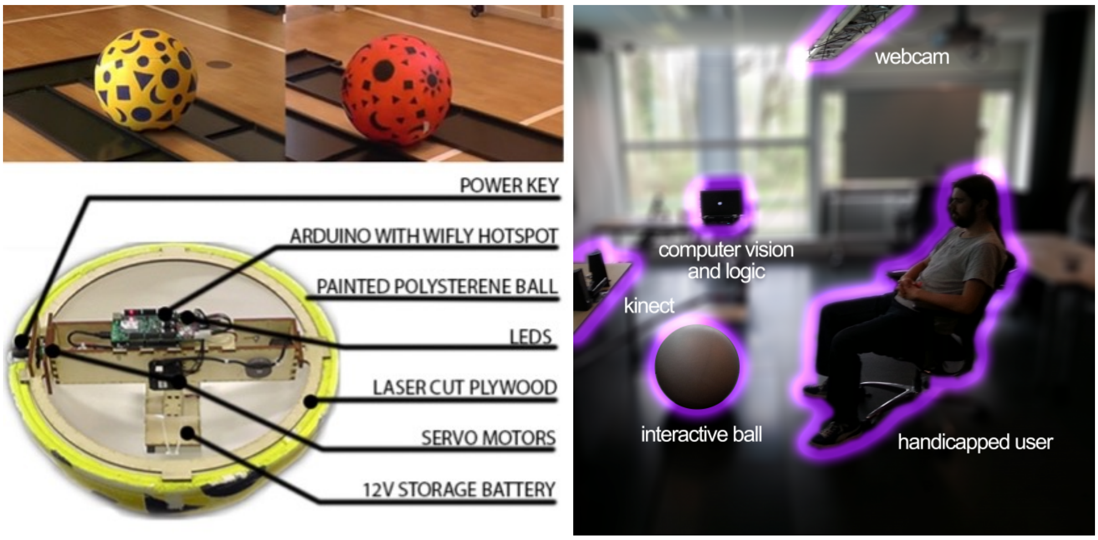
C.6 Technology for vulnerable people

People First University

As part of the “*People First University*” as the current slogan goes (a variant of the previous “High Tech, Human Touch” one), the department of Computer Science is also dedicated to having its research make an impact on society for the good of people. Much of our research is driven by societal needs. This holds in particular and by definition for the research on cyber-social systems: technology that is designed to be used by people.
The mission of the Cyber-Social groups is to develop technology that knows how to deal with people and that can be used easily and effectively providing pleasurable experiences. Over the years, there has been a growth in research that is devoted to study technology that helps vulnerable people of all kinds: children, elderly, people with mental or physical disabilities to support their daily life, to teach, tutor or coach them.
Working as a multidisciplinary team of scientists and clinicians in health and social care, we use a user-centered design approach to maximise technology added value as well as technology adaptation. This approach facilitates working with users with specific requirements due to their illness, disability, or severe psychosocial issues: these individuals inspire us to go the extra mile to reach our goal: technology for all. Here we provide a few examples.

BLOX

For one of the projects (*BLOX* [74]), we were commissioned by the Dichterbij Disability Care to build and study a set-up that would allow individuals with profound intellectual and multiple physical disabilities to interact and to give them a sense of control. Together with a local company, KITT Engineering, we created a remotely-controlled ball that responds to the body movement, focus of attention, and vocalisations of the people. In response to such actions the ball, wiggles, moves, shines, and makes sounds. With such a truly interactive system, we target to increase alertness, increase appropriate movements, and improve affect and satisfaction.



GREAT

GREAT was a small research project in which we created movement-based games for gait rehabilitation with personalisation based on gait characteristics. We used an eight by one meter pressure sensitive interactive LED floor. With the interactive games we attempted to steer different dimensions of people’s gait, increase motivation, provide an enjoying experience, and create an additional platform for gait rehabilitation by physical therapists. We performed several days of exploratory user tests with the created set of games, in total 56 patients and 30 therapists were involved. The set of games was positively received by therapists, who stated they could train a variety of targeted domains with it. Furthermore, many rehabilitants indicated they liked it more than normal training exercises. The possibilities for personalisation and the variety of games allowed users with a wide variety of skills and limitations to train their gait.

In mental health care we aim to contribute to an experience-based and practical approach in therapy. Though in psychiatry treatment is often centered around pills and talking therapy, for vulnerable groups (such as those with intellectual disability, or low adaptive functioning), experience and doing are often more important. This happens, for example, in studying Virtual Reality in the treatment of addiction (smoking, alcohol, drugs) in people with intellectual disabilities. TACTUS Addiction Care is an organisation that supports this research financially.

Adults with dementia

Together with colleagues from the psychology department we have been developing and investigating technology for older *adults with dementia*. We have been studying emotional expressions (vocal and facial) of older adults with dementia to learn how they change in time (due to progression of the disease), how they differ from healthy adults, and how we can improve and adapt recognition technology to capture these changes. Much of the currently available recognition technology is not flexible enough to deal with older adults' expressions that is known to differ from the larger, healthy younger adults population. Hence, one of our goals was to collect data with healthy older adults, and older adults with dementia over a period of time, to see to what extent current recognition technology can capture emotional expressions and how we can improve recognition accuracy.

EU project DE-ENIGMA

The UT coordinated the EU project DE-ENIGMA [75], which was completed in November 2019. It is one of the biggest projects investigating assistive technologies for autism, bringing together pan-European expertise to develop an intelligent humanoid robot. We developed state-of-the-art technical systems, based on Artificial Intelligence, to automatically detect and reason about behaviours of children on the autism spectrum during robot-based activities. One of the key objectives was also to test claims about whether predictable robot behaviour might positively impact children's interactions.

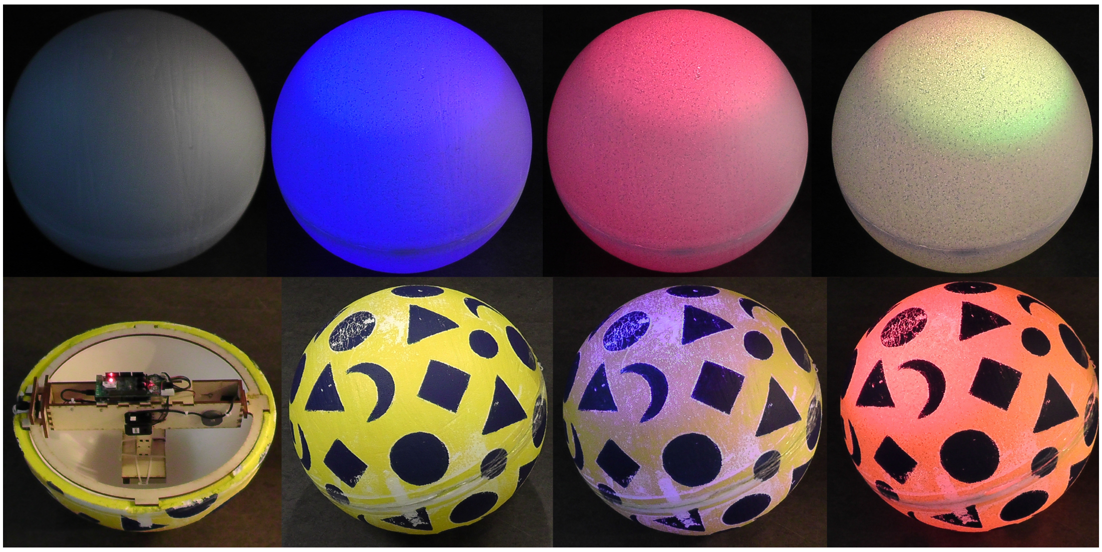
A few more examples are:

AIRPLAY [76]: Towards a 'Breathgiving' Approach

Sense-IT [77]: Development of an Ambulatory Biofeedback App to Enhance Emotional Awareness in Patients with Borderline Personality Disorder: Multicycle Usability Testing Study.

Wearable Breathing Trainer [78]

Blox balls



Short description of the research goups

D
Research Groups

CAES

Computer Architecture for Embedded Systems

The main emphasis of the Computer Architecture for Embedded Systems (CAES) group is on energy-efficient architectures for dependable networked embedded systems. Within this theme the chair performs research on three related key areas:

1. Design technology and efficient architectures for embedded, high performance and cyber-physical systems,
2. Architectures for efficient energy management in Smart Grids,
3. Design for Dependability of embedded integrated systems.

Efficient multiprocessor architectures

Efficient multiprocessor architectures rely more and more on the power efficient implementation of accelerators, while at the same time flexibility is key. FPGAs are a compromise between efficiency and flexibility and accelerator design on FPGAs is an important topic of research for the CAES group. As well as the designing the hardware itself, the CAES group studies the co-design of hardware and software, and the development of (streaming) real-time applications that are executed on such systems. Optimisation of energy management within *Smart Grids* is also an important subject of research where production and consumption of energy have to be aligned to guarantee energy delivery and prevent inefficiencies. This is an important application area for networked embedded systems.

Smart Grids

DACS

Design and Analysis of Communication Systems

Communication infrastructures such as the Internet and wireless networks are vitally important for society. Furthermore, an even stronger proliferation of such networked systems with new capabilities, more capacity and higher performance may enable us to tackle important societal challenges (e.g., smart mobility, by dramatically increasing road safety and efficiency). The mission of the Design and Analysis of Communication Systems (DACS) group is to contribute to the design and analysis of wired and wireless networked systems, focusing on their security, resilience and performance, by means of measurements, modelling and simulations. We do that by performing top research and by educating students. Our research currently has two main focus areas:

1. the analysis and (re)design of the core functions of the Internet (e.g., routing and the domain name system), considering current and future severe security threats, and
2. the design and modelling of wireless networks for extremely demanding applications in terms of real-time requirements, device density, reliability, energy consumption, etc. (e.g., Intelligent Transportation Systems).

DMB

Data Management and Biometrics

Digitalisation of society provides a treasure trove of data, based on an abundance of sensors and connectivity of services and people. Web and social media offer endless possibilities for people to connect, develop and use digital services. Our increasing data science abilities for data analysis and machine learning drive novel smart services. They provide solutions benefitting society in a large variety of domains, including health, engineering, safety and security, business, and science. At the same time, this digitalisation comes with challenges. You can think of concepts like fairness, data quality, robustness, privacy, and trust, and threats such as bias, morphs, energy consumption, and fake news that must be addressed. This requires a fundamental inter-disciplinary approach bridging fields like computational statistics, machine learning, image and signal processing, information retrieval, and data processing and management. It is our mission to work on *Explainable data science* by developing methods for autonomous, reliable and robust gathering, preparation, and analysis of the data, to enable relevant, trustworthy and explainable results.

Explainable data science

FMT

Formal Methods and Tools

The mission of *FMT* is to develop mathematical methods, high-performance data structures and algorithms, and suitable programming languages for the design of reliable software- and data-intensive control systems. We focus on modelling, synthesis, analysis, prediction and maintenance of their functional, structural and quantitative aspects. We aim to understand safety, reliability, performance, energy usage of complex systems and the risks and costs associated with their architecture, design, operation and maintenance.
Our mission builds on extensive experience in concurrency theory, static analysis, theorem proving, language design, model checking and term/graph rewriting. Our focus areas are:

1. Quantitative modelling and analysis for cyber-physical and socio-technical systems,
2. Programme design and verification for (concurrent) software,
3. High-performance algorithms and data structures for model checking and model transformation.

We apply our methods in projects with industrial and academic partners. Examples include safety-critical infrastructure (e.g. safety, reliability, maintenance of railway systems), verification of GPGPU software, low-power/high-throughput embedded computing, certified model transformation for large software projects, testing and quality assurance of compilers and other language processors, model-based testing, security and risk analysis and smart maintenance. We also investigate graph analysis of models in systems biology, health science and programmable nano-electronics.

HMI

Human Media Interaction

The research in Human Media Interaction concerns the perception-action cycle of understanding human behaviours and generating system responses, supporting an ongoing dialogue with the user. It stems from the premise that understanding the user – by automated evaluation of speech, pose, gestures, touch, facial expressions, social behaviours, interactions with other humans, bio-physical signals and all content humans create – should inform the generation of intuitive and satisfying system responses.
Our focus on understanding how and why people use interactive media contributes to making interactive systems more socially capable, safe, acceptable and fun. Evaluation of the resulting systems therefore generally focuses on the perception that the user has of them and the experience that they engender. These issues are investigated through the design, implementation, and analysis of systems across different application areas and across a variety of contexts.

PS

Pervasive Systems

The Pervasive Systems group studies the systems that are composed of a network of collaborative sensing, computational, and reasoning components that are highly embedded in and actively – yet unobtrusively – interact with the environment.
Embedding millions of networked smart sensing objects into an environment creates a digital skin which senses its immediate space. These massively distributed networks of smart objects communicate with one another and analyse and interpret the immense amount of low-level spatio-temporal information about the physical objects and environment to produce a representation of the overall environment.
Such distributed networks of smart objects cooperate to support an application as unobtrusively as possible (transparency), making efficient use of scarce resources independent of growth (scalability), in such a way that the system adapts to a dynamically changing environment (evolvability), and that

operates and gives results that can be relied upon (trust). Mainly due to resource constraints, devices and connections are inherently unreliable, yet the system should be able to provide reliable services (quality).
Situated at the core of the Internet of Things, our research has high societal and economic impacts in various applications in the area of Smart Urban, Smart Life, and Smart Industry such as environmental monitoring, ecology, ambient assisted living, agriculture, transport and mobility, smart industry, supply chain management, health, sports, asset management, predictive maintenance, and smart cities. Our system-oriented research is inspired by real problems, which makes multi-disciplinary collaboration natural.

SCS

Services and CyberSecurity

The Services and CyberSecurity group works on methods and techniques for requirements conceptualisation, architecture design, and model-driven engineering of service systems. The focus is on data-driven services that are able to make sense of their context and can reliably and timely react on changing situations. We develop service ontologies and service composition frameworks to realise semantic interoperability and meaningful enterprise services. To protect these services against cyber attacks, we develop algorithms and protocols that provably secure (within dedicated attacker models) the underlying IT infrastructure and that are able to thwart or detect attacks. For services that collect and process sensitive data, we build privacy-enhancing technologies and design data protection and anonymisation techniques to avoid or reduce data theft and privacy violations.
We apply and validate our results in various domains where data driven innovation plays an important role (healthcare, logistics, emergency management, smart cities), and where smart, secure and privacy-aware services are vital to society.

This appendix presents the reactions on the recommendations of the committee in the previous assessment.

E

Appendix Reactions previous report

The committee of the previous assessment was very positive about Computer Science at the UT:

> *"The committee is of the opinion that research quality continues to be very high despite restructuring around new areas. Good mentoring is in place for junior faculty and PhD candidates mostly get their research interests aligned with projects. The societal relevance of CTIT is impressive.*
> *There is a focus on interesting areas of multidisciplinary research. The number of spin-offs is large and greatly supported by the faculty. Twente has a very good portfolio of external funding but the direct funding, based on student numbers, has decreased. The committee feels that the strategies for the future of CTIT are well chosen."*

This resulted in high scores:

- Research quality: 1
- Relevance to society: 1
- Viability: 2

E.1 Recommendations by the committee

1. The committee recommends to continue leveraging the international network to find very high-quality, transformative faculty members, including the current efforts around attracting world class females.

Actions Taken

We have been successful in attracting more female staff members and also increasing diversity in terms of nationality. Also, we have a more balanced group with respect to age with an increase of younger staff members. Although we can be happy with these results, we did not reach our targets yet and we are implementing further measures to attain our goals.

2. The committee recommends to lead and being involved in large projects with major impacts to increase the reputation of the faculty and the research domains.

We have increased our involvement in national and international scientific and other committees such as, for instance, the Informatica Platform Nederland and the Dutch AI coalition. In the reporting period the COMMIT2DATA programme was led by Boudewijn Haverkort from the CS department.

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