SECTOR PORTRAIT 2022

# FOUNDATION UNDER THE DIGITAL SOCIETY

## SECTOR PORTRAIT
## DUTCH COMPUTER SCIENCES

## HEALTH

Healthcare is one of the domains where much is expected from the implementation of the key technologies AI and (Big) Data Analytics. Hospitals register data in abundance and many forms: clinical patient data, genetic information, medical images, consultation reports and data from wearables. Data form the basis of diagnosis and decision-making, risk analyses and monitoring, and real-time support during surgery or intervention.

Now that the amount of data per patient is increasing so much, it is becoming increasingly difficult for healthcare professionals to take all that information with them. AI can quickly recognise patterns and can support decision-making by comparing a patient's data with the data of previous patients. This helps healthcare providers select the most suitable treatment.

The COVID pandemic has accelerated research into a globally distributed data infrastructure. This will make it possible in the future to gain quicker insight into and control over an emerging pandemic via distributed learning.

AI and Big Data not only serve to support clinical decision-making but also as a lever for the faster development of new medicines and personalised medicine, and in the automation of the healthcare chain. This not only ensures that the patient is helped better and faster, but that care also remains affordable in the future.

# CONTENTS

MANAGEMENT SUMMERY ........ 4

IMPORTANT CONCEPTS AND ABBREVIATIONS ........ 7

INTRODUCTION ........ 9

COMPUTER SCIENCE AS THE BASIS FOR A STRONG DIGITAL SOCIETY ........ 13

COMPUTING SECTOR: ORGANISATION, QUALITY AND SIZE ........ 19

SECTOR PLAN GOALS: CREATING PEACE AND SPACE ........ 28

APPENDICES ........ 34

# THE FOUNDATION UNDER DIGITAL SOCIETY: PORTRAIT OF DUTCH COMPUTER SCIENCE (2022)

## MANAGEMENT SUMMERY

In the first Science and Technology Sector Plan 2018-2025, the Computer Science sector has been structurally allocated 8.4 million euros to strengthen its scientific foundation. The rapid growth and developments in the sector and the increasing student numbers are reasons for an additional application for a structural financial injection in the sector in 2022.

The world is digitising, and the Netherlands is at the forefront. The Netherlands has been among the leaders in the Digital Economy and Society Index (DESI) in recent years. New discoveries, techniques and applications in digital information and communications technology (ICT) accelerate developments and innovation in many scientific disciplines, services, business and therefore in society. All sectors and professions are experiencing these consequences of the ever-increasing digitisation. It is also becoming increasingly clear that digitalisation is indispensable for addressing important societal challenges, such as the transition to a sustainable energy and food supply, better care and education or good accessibility. Research plays a crucial role in this: innovations such as Artificial Intelligence (AI), which now spawn a plethora of new social and business opportunities, have evolved from a solid fundamental research infrastructure established decades ago.

Despite its good starting position and excellent digital infrastructure, the Netherlands now runs the risk of falling behind, according to the Digital Intelligence Index 2020. With a robust digitalisation policy aimed at stimulating science, business, 'startups', 'scale-ups', knowledge coalitions and the government, the government wants to join forces to capitalise on the opportunities that digital technology offers (Coalition Agreement 2021, p.30). The strong scientific information technology field in the Netherlands offers a good starting position to provide the desired pioneering role with a solid foundation, but additional investments in education and research are necessary to manage the further transition.

As one of the scientific pillars underlying developments in ICT technology, the Computer Science sector wants to achieve a number of goals with additional investments from this sector planning round (2022-2029): generate more education and research capacity, realise greater diversity in the staff population and create more peace and space to become more attractive as an employer and in this way retain talent. The need for highly educated computer scientists is greater than the number of alumni that universities can currently produce. An important part of this plan is to reduce the disproportionately high student/staff ratio of Dutch computer science courses in order to guarantee the quality of education. In addition, rapid social and digital developments require computer scientists with in-depth insight into AI, the Internet of Things, Big Data analytics, (sustainable) software development and cybersecurity. The latest insights are therefore being introduced into the curriculum at an accelerated pace.

# Computer science research plays a crucial role in addressing the social and scientific challenges that digitalisation and digital transformation entail

Additional structural investments through this second sector plan, which are in line with the continued and substantial growth of the Computer Science sector in recent years, will enable the universities to continue to contribute to the development of technology through disciplinary and interdisciplinary research and education. This will result in new knowledge, applications and innovations in our own sector and in the many other sectors where digitalisation is now an important driver of new developments and discoveries. By focusing on blue sky research, in addition to application-oriented research and innovation for the benefit of the Netherlands' earning capacity, our country will be able to maintain its leading position and better meet the challenges of both the present and the future. Strengthening the Dutch IT foundation will significantly contribute to the mission-driven government innovation policy, the questions and routes from the Dutch Research Agenda, the European digitalisation strategy and achieving the Sustainable Development Goals.

## SAFETY

The digital society increasingly influences the lives of citizens. At the same time, confidence in digital  language society is declining due to increasing concerns about learning algorithms, data leaks, digital surveillance and fake news. Cybercrime causes considerable damage to Dutch society and the Dutch economy. Researchers are therefore continuously working to expose criminal capabilities and to devise new defences for a secure digital world: formal methods that guarantee correctness, operating systems that are robust against attacks, databases that guarantee the anonymity of data, learning algorithms that compensate for bias in datasets, and methods for detecting unwanted expressions on social media. Dutch cryptography forms the core of new international standards for securing data. Automatic verification based on fuzzing helps identify errors in software in a timely manner. Unfortunately, research shows that not only software but also hardware are vulnerable. While software bugs can be fixed with a simple update, hardware vulnerabilities are far more difficult, and often impossible. The rise of open hardware is therefore an interesting development.

# IMPORTANT CONCEPTS AND ABBREVIATIONS

| | |
|---|---|
| **AI** | Artificial intelligence |
| **ICT** | Information and Communication Technology |
| **ICT sector** | According to the definition of Statistics Netherlands (CBS), the Dutch sector consisting of the ICT industry, the wholesale trade in ICT equipment and the ICT services sector |
| **Computer Science** | The field of digital information processing and communication and forms the basis for software, artificial intelligence (AI), data science and computer systems, and for ICT in general |
| **IoT** | Internet of Things |
| **IPN** | ICT Research Platform Nederland |
| **KIA** | Knowledge and Innovation Agenda |
| **ML** | Machine Learning |
| **NWA** | Dutch Research Agenda |
| **NWO** | Dutch Research Council |
| **Sector Computer Science** | The academic knowledge institutions with significant IT expertise educational and/or research focus, united in IPN |

## AGRICULTURE, FOOD & WATER

Computer scientists engage with researchers from various fields to make the urgent transition to a future-proof agriculture and food chain possible. Highly anticipated innovations include the development of robust crops and healthy livestock breeds, minimising the use of raw materials and auxiliary materials, and integrating food production and ecosystem services. Machine learning (ML) and deep learning (DL) offer enormous opportunities in these complex applications and are widely used for the analysis of molecular processes, organisms and populations, with a significant role in plant and animal breeding. Digital twinning, remote sensing and Virtual and Augmented Reality (VR/AR) are used in precision agriculture and in the modelling of and decision support for the agricultural process. In addition, we map the ecological footprint of the food chain, from farm to fork, so that we can make more sustainable choices about what we import and what we put on our plates.

# INTRODUCTION

## THE STARTING POINT: SECTOR PLAN SCIENCE AND TECHNOLOGY 2018-2025[1]

In 2019, a brief domain image was published for the Science and Technology domains. In the Science domain, the disciplines of Mathematics, Computer Science, Physics and Chemistry (together the Physical Sciences subdomain) were prioritised to be included in the first Science and Technology Sector Plan 2018-2025 (further referred to as Sector Plan 1 in the document). At the end of May 2022, the sector plan committee produced an interim evaluation report on the halfway progress of this sector plan, which was submitted to the Minister of Education, Culture and Science (OCW).

### GROUNDS FOR A SECOND SECTOR PLAN FOR COMPUTING AND A NEW SECTOR VIEW

**Research.** The awarded funds from the Sector Plan have been successfully used to strengthen the IT foundation by filling tenured scientific staff positions in seven focus areas. These investments are necessary to keep pace with the digital revolution and to meet major societal challenges. Computer science research plays a crucial role in addressing the challenges posed by digitalisation and digital transformation and in shaping the opportunities that emerge for a secure, prosperous and sustainable future for everyone. In its recently (2021) published vision[2], ICT research platform Nederland (IPN) calls fundamental research crucial as a driving force behind the digital society. The investments from Sector Plan 1 are not yet sufficient in this regard, according to IPN. The vision states: *"Currently, investments in fundamental information and communications technology (ICT) research lag significantly behind the social and scientific importance of the field."* The interim evaluation of Sector Plan 1 will then be delayed. We also see that the participating universities have additionally attracted approximately the same number of staff with their own resources[3] to further strengthen their chosen profile.

**Education**. The lagging funding for fundamental research is not the only bottleneck for further development and innovation in the Dutch Computer Science sector. The continuous developments in the field of ICT, and the many applications that arise from them, mean that funded and unfunded IT education is developing rapidly.

1 The files mentioned in this paragraph can be found here (sectorplan-betatechniek.nl)
2 https://ict-research.nl/2021/11/ipn-vision-strengthening-the-foundations-for-a-strong-digital-society/
3 Achieved through increased income from increasing student numbers.

The relevance and dynamics of the sector have great appeal to an increasing number of students who are finding their way to a computer science education. Between 2018 and 2021, student numbers in computer science courses increased by a similar percentage (43%) as staff numbers, meaning that the excessively high student/staff ratio (>30) has not decreased. To stay up-to-date, new insights and social implications are being introduced more quickly into the bachelor's and master's curricula. In addition, education is developed in co-creation with external partners to keep existing professionals' knowledge up to date. This is reflected in various short and longer trainings and courses, but also in complete educational programmes, such as executive master programmes and Engineering Doctorates (EngD, specifically for the 4TU). The educational pressure, which was already high, has increased even further in the recent period due to this combination of factors.

In short, due to the turbulent developments in society, science, innovation and education, the joint efforts have not yet led to the desired peace and space for the sector. This is why IPN, on behalf of the sector, submitted a second sector plan application to the Minister of Education, Culture and Science as part of the current round of National Sector Plans 2023-2029. In addition, the sector wants to use the submission of the second sector plan computer science to advance the IPN vision and (the impact of) recent social and scientific developments[4] included in a refined sector picture.

[4] Consider, for example, the impetus in AI research and innovation through the investment in AINed from the National Growth Fund, the acceleration in digitalization due to the COVID-19 pandemic and the challenges facing it areas of digital inclusion, security and reliable digital services that this entails
but also the importance of research into sustainable computing and the role of digitalization in it
achieving the climate objectives.

## HUMAN-CENTRED AI

With major advances in neural networks, computer vision, natural language processing and more, AI is becoming an integral part of our daily lives. We now have the exceptional ability to add ‘intelligence’ to machines, allowing systems to assist and facilitate people in a wide range of tasks. However, many questions remain: how do we anchor this ‘intelligence’ in a responsible, fair and sustainable way? Who participates in the design of these systems and who frames the discussion? What do we expect from our AI-based systems? What are the innovative design processes and patterns to make these systems reliable and successful for individuals, communities and society?

Computer science researchers are working on design principles in the age of AI. Research is being conducted into machine learning algorithms and evaluation methods that aim to best combine the benefits of intelligent assistance with social values and frameworks, thereby building AI systems that benefit us all.

## COMPUTING FOR A SUSTAINABLE FUTURE

The social task of the energy transition places high demands on innovation capacity in all sectors. The use of intelligent technology can serve as a lever in realising our ambitions in the context of the energy transition and the European Green Deal. Computer science researchers are therefore working on, among other things, self-learning algorithms to adjust the demand for electricity on the supply (which is increasingly dependent on the weather), instead of (as now) the electricity supply from the power station to vote on the question.A useful tool for this is Digital Twins, for example of the electricity grid.

At the same time, ICT infrastructure is a major consumer of energy, responsible for 5-9% of Dutch electricity consumption. Therefore, IT research focuses on improving the energy efficiency of data centres (smarter distribution of data and services), reducing energy consumption by ‘smart devices’ on the Internet of Things (programming models for devices in a low-energy mode), and cost reduction for AI (through lower costs for training deep learning models, but also with alternatives such as bio-inspired hardware and neuromorphic computing). Reducing the energy consumption of software is becoming important. This leads to research into methods and techniques to enable software engineers to systematically consider energy consumption when developing new software systems.

# COMPUTER SCIENCE AS THE BASIS FOR A STRONG DIGITAL SOCIETY

## COMPUTER SCIENCE: FUNDAMENTALS AND APPLICATION IN ONE

**Computer science forms the foundation of the digital society.** Computer science is the field of digital information processing and communication and forms the basis for software, artificial intelligence (AI), data science and computer systems, and for ICT in general. New discoveries, techniques and applications in ICT have followed each other in rapid succession in the past decade, creating a far-reaching digital society. This digital transformation, which is now being followed by hyper-automation, has radically changed the way we live and work. Nowadays, ICT is so intertwined with society that the two are inextricably linked. We have reached the point where large parts of society can no longer function if digital systems fail. In addition, digital systems have become so complex that we need specific knowledge/expertise to prevent failures. The Dutch ICT sector has grown by 40% in recent years to approximately 6% of the labour market and a predicted growth to 10% in 2030[5]. There is an increasing demand for highly trained ICT professionals with knowledge and skills in, among other things, the rapidly evolving digital technologies in the field of AI, Internet of Things (IoT), Big Data analytics and cybersecurity. Further digitalisation also means that the work of non-IT staff increasingly requires basic digital skills.

## NATIONAL AND EUROPEAN POLICY AGENDAS

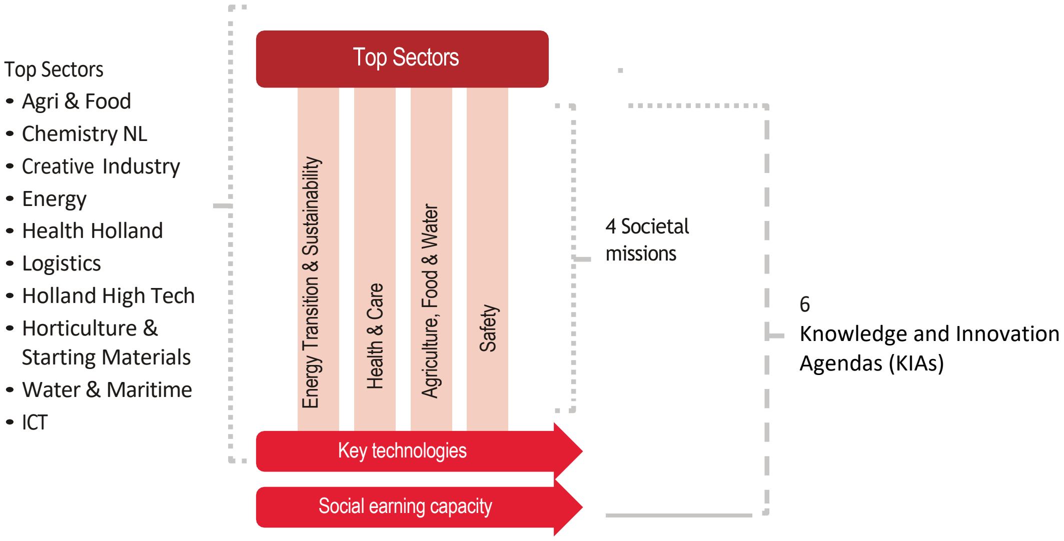
Informatics in the Dutch policy agendas: application and enabler of innovation.
As a key technology[6], computer science is the driving force behind innovations in both social and economic developments as well as in many other scientific disciplines. Digital technology is an integral part of most, if not all 25, routes of the Dutch Research Agenda (NWA). (New) digital techniques are developed and/or applied in various routes appropriate for addressing societal issues. In routes 18, 20, 21 and 25, the development and implementation of ICT itself is central[7]. The Top Sector ICT (Dutch Digital Delta) is therefore one of the ten top sectors in the Dutch government's mission-driven top sectors and innovation policy (see Figure 1). The top sector prioritises five key technologies (AI, Big Data Analytics, Security, Future Network Services and Blockchain) that correspond well with the IPN agenda.

In the underlying Dutch Knowledge and Innovation Agendas (KIAs), the ten Dutch top sectors jointly express their ambition in the areas of the four societal missions, the key technologies, and the social earning capacity. ICT is part of the intersecting key technologies and is therefore, as with the NWA routes, interwoven in all societal missions.

[5] See Appendice 2 for an extensive labor market analysis.
[6] A key technology is a technology with a broad range of applications in various innovations and/or sectors
[7] Quantum and nano revolution (route 18), smart industry (route 20), smart/liveable cities (route 21), and big data (route 25)

**Computer science and digitalisation in the international policy agendas.** It is not only the Netherlands that recognises that ICT as a foundation is an important driver for social and economic growth. The United Nations identifies ICT as a 'key enabler' for achieving the Sustainable Development Goals 2030 (SDGs)[8], and the European Union (EU) is investing heavily in digitalisation and digital technology, digital inclusion and digital autonomy. In its strategy, the EU focuses mainly on the further development of AI[9]. Accordingly, it wants to invest one billion euros per year in the period 2021-2027 from Horizon Europe and the Digital Europe programme[10]. Other important European investment programmes for ICT are the Connecting Europe Facility for digital infrastructure, the Recovery and Resilience Facility (RRF Fund) and the Structural Funds. In the field of digitalisation, the Dutch KIAs are substantively in line with this European policy and investment strategy[11].

FIGURE 1. THE DUTCH MISSION-DRIVEN TOP SECTORS AND INNOVATION POLICY




**Legend:** The top sectors formulate their ambition in the areas of the four societal missions, the key technologies, and the social earning capacity in six Knowledge and Innovation Agendas.

8 Digital technologies to achieve the UN SDGs (itu.int)
9 European Commission (2018) Communication Artificial Intelligence for Europe. COM (2018)237
10 European Commission (2021) Coordinated plan on Artificial Intelligence Review. COM (2021)205
11 The concept of key technology in the KIAs includes both the Key Enabling Technologies (KETs) and the Future and Emerging Technologies from the European programmes Horizon 2020 and its successor Horizon Europe Digital

## THE ROLE OF THE UNIVERSITIES – SOCIAL IMPACT

The challenges for computer science are strongly influenced by the wave of digitalisation sweeping through society. ICT is getting closer to the individual. This entails scientific, technical, social, and ethical challenges. The universities make an indispensable contribution to addressing these challenges through computer science education and research.

By generating new scientific knowledge and training a new generation of scientists and professionals with in-depth IT knowledge, we enable society, policymakers and the international community to provide society's digital transition with a solid foundation, and to facilitate this with various (new) applications.

### Free to: A stronger foundation for a strong digital society - IPN vision

As the main gateway to academic ICT research in the Netherlands, IPN and its members are committed to a bright and sustainable future for our digital society through the following two missions:

• Developing future societal game changers through ICT research.
• Training a new, diverse generation of ICT researchers and professionals.

IPN does this in collaboration with key decision-makers in government, business and society.

BOX I

### IMPACT BY PUBLIC-PRIVATE PARTNERSHIPS - KNOWLEDGE SHARING AND JOINT RESEARCH

A key aspect of the societal mission (see Box I) is the development of future game changers through ICT research in which fundamental and application-oriented IT research at universities in collaboration with other knowledge institutions, non-profit organisations, governments, and business (including SMEs) are both crucial. This is reflected, among other things, in student (graduation) projects at companies and institutions, which directly lead to value creation and test knowledge for its relevance. All universities are individually and/or jointly involved in public-private partnerships, which is reflected in various forms of joint research, from (dual) PhD students and collaboration in consortia to commissioned research in living labs, living hubs and field labs. A special example of this is the national Innovation Centres for Artificial Intelligence (ICAI), see Box II.

## Innovation Centres for Artificial Intelligence

The national Innovation Centres for Artificial Intelligence (ICAI labs) have focused on research collaboration through a specific formula since 2018. These labs have a duration of five years, during which research is conducted on behalf of a private partner (or government partner) by at least five PhD students per lab. In 2022, the ICAI structure will have 29 labs.

BOX II

These collaborations regularly result in new patents, spin-off companies/start-ups and open source code that is widely used in various domains. Dutch scientific results are not only cited worldwide but are also valuable for the development of new applications in the four social missions, Health & Care, Energy & Sustainability, Agriculture, Water & Food, and Safety.

Social interconnectedness is also evident from the many researchers and professors who hold part-time positions within public organisations, government, and business and/or are members of advisory boards and interest groups. As a result, academic knowledge finds its way directly into both professional practice and policy agendas. Through COMMIT2DATA, the AI-Coalition and the associated Growth Fund programme AiNed, the Dutch Blockchain Coalition, Future Network Services, and dcypher within the Top Sector ICT, we shape public-private partnerships between computer scientists, companies and governments.

### IMPACT THROUGH EDUCATION AND OUTREACH

To keep pace with the digital revolution, it is essential that we train enough experts and increase the overall level of digital literacy. The labour market and universities need a larger and more diverse population of people with in-depth ICT knowledge. Academic computer science courses are popular, and because ICT is a key technology that contributes to the acceleration of developments in many other domains, computer science courses and minors are increasingly offered as part of bachelor's and master's programmes in other sectors and domains.

The demand for education for professionals has also increased sharply. The universities struggle to realise their commitment to offer a state-of-the-art curriculum in all forms of education and in line with recent technological and social developments. The digitalisation wave also presents us with a broad social challenge in the growing need for digital knowledge and skills. Digital inclusion and digital literacy are therefore important national and international themes. This requires various forms of educational outreach towards the adult population and towards students in primary and secondary education. The universities are committed in various ways through collaborations with museums, public lectures, contributions to festivals, podcasts, teaching materials and tailor-made courses for involving students. Much experience has been acquired regarding outreach to primary and secondary education with the Platform Talent for Technology and also at many local activities, often connected via the national science support centres.

## DIGITAL SKILLS IN EDUCATION

Being able to use a computer is one thing, but knowing how a computer works and how to solve problems with a computer is a completely different story. Computational thinking is an essential 21st century skill and is simply translated as 'thinking like a computer'. First, analyse a problem and then produce solutions as a computer could implement them. Using a programming language, you can learn to solve a problem in logical steps. There is creativity and problem-solving skills are required.

Computational Thinking Education is an exciting field that focuses on the development of teaching methods for computational thinking in primary and secondary education. Dutch researchers in this field built a new programming language for primary school students: Hedy. Children learn to make interactive stories or living drawings and even songs with Hedy in a playful way. This way they learn that programming is fun and feasible before it becomes more complex. In secondary education, we focus on authentic challenges in context, where students in the school subjects Physics/Chemistry, Biology and Chemistry, for example, learning to program robots with sensors using the 'Sense-Reason-Act' method.

*Various computer science education projects are financed through the Outreach Fund of Sector Plan 1 Science and Technology.*

A total of €700,000 from Sector Plan 1 resources is made available each year by the participating institutions in a common fund for outreach projects in the fields of mathematics, physics, chemistry and computer science. This fund is managed by the vice deans for education, who annually allocate resources to strong project proposals. Two examples of successful outreach projects within Computer Science, which are stimulated with sector plan resources, are Hedy (step-by-step programming Python for children) and the activities of the Computer Science Olympiad.

# COMPUTING SECTOR: ORGANISATION, QUALITY AND SIZE

## NATIONAL ORGANISATION

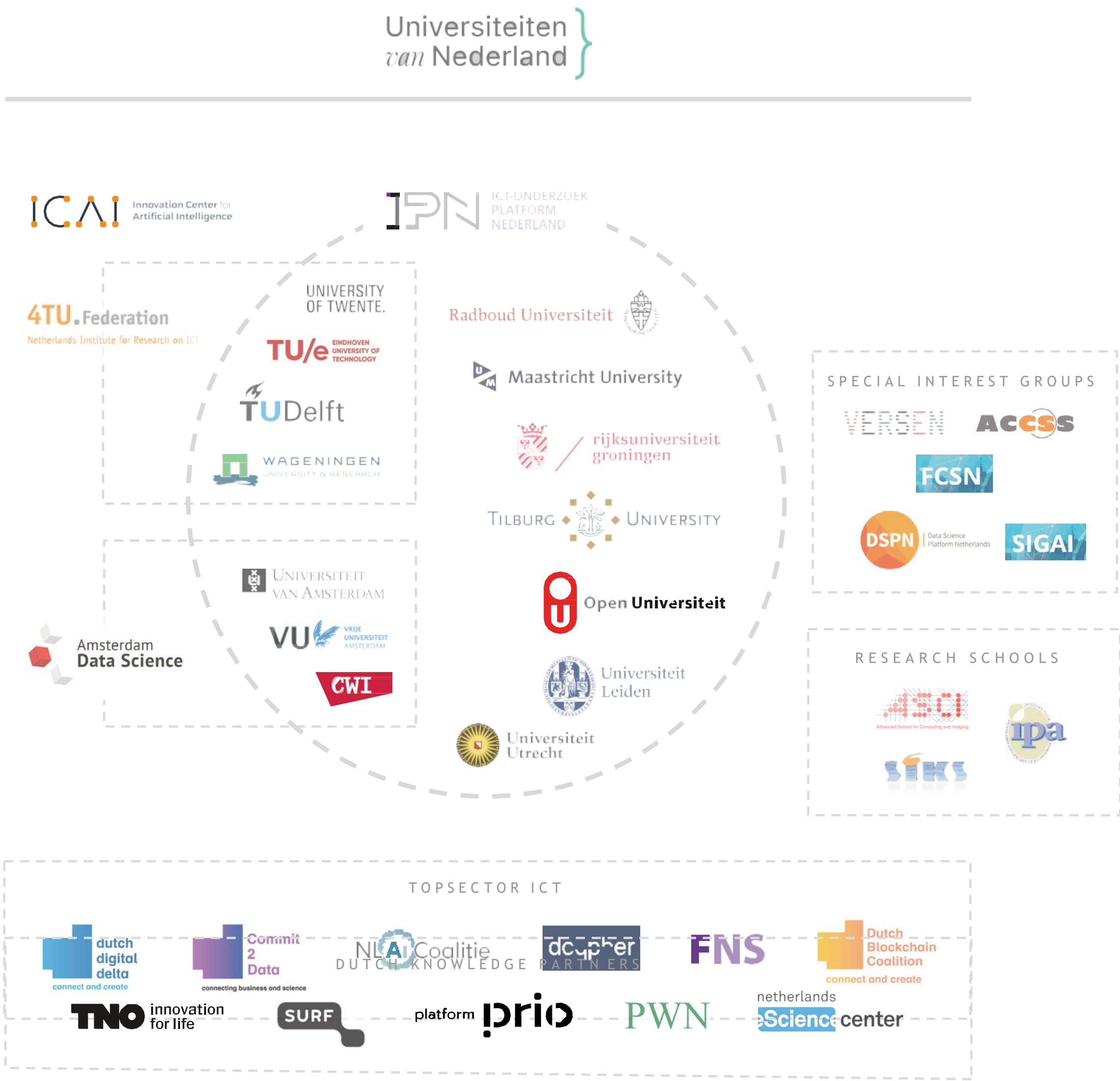
Dutch university computer science has a long tradition of national cooperation. The computer scientists are organised in the ICT research platform Netherlands (IPN). The members of IPN, shown in the upper part of Figure 2, are the general universities and the universities of the 4TU with a significant computer science research and/or education focus, and the Centre for Mathematics and Computer Science (CWI). A significant part of the CWI staff also has a position as assistant professor, associate professor or professor in computer science at a university and therefore plays an important connecting role between the institutions. Through its new strategy[12], the CWI is emphatically committed to facilitating and intensifying national cooperation within the IT sector in the coming years.

Within IPN there are intensive collaborations in specific sub-areas in the 'Special Interest Groups (SIGs)': VERSEN (Association for Software Engineering), SIG Cyber Security/ACCSS, SIG Artificial Intelligence ((SIGAI)[13], Data Science Platform Netherlands (DSPN), and SIG Future Computer Systems and Networking (FCSN). The three national IT research schools (ASCI, IPA, SIKS) work closely together, and there are also local and interlocal initiatives for research and education coordination (such as NIRICT between the four technical universities, and Amsterdam Data Science (ADS) in the Amsterdam cluster). The IPN network 'ICT Next Generation' emerged from NIRICT and COMMIT, a national community of young ICT researchers. There are also good ties with various other special members, including TNO, SURF and *Platform Wiskunde Nederland* (PWN). The annual national ICT.OPEN conference, which aims to bring together scientists from all ICT research disciplines and bringing industries together to meet, learn and exchange ideas, is jointly organised by IPN, the HBO-ICT lecturer network PRIO, and NWO.

In addition to the vibrant community and intensive sectoral collaboration, there is frequent collaboration with other university disciplines and domains, especially in cross-disciplines and in the contextual application and further development of digital technology. This is reflected, among other things, in collaboration in various cross-sectoral training courses, for example in the field of Data Science and Human AI and in training courses such as Bioinformatics and Robotics. In the current sector plan applications from all domains, it is striking that these digital scientific methods are becoming increasingly integrated into research and education in all disciplines.

[12] CWI Strategic Plan 2022-2027
[13] The SIG-AI is the Dutch part of the Belgian-Dutch Association for Artificial Intelligence (BNVKI)

FIGURE 2. NATIONAL ORGANISATION OF THE COMPUTING SECTOR




**Legend:** In this figure the Dutch language is used. The top block in the figure shows the universities as they are united in IPN, including the special interest groups, research schools and partnerships. Some important Dutch knowledge partners have been named below (not exhaustive). The bottom block shows the organisation of the Top Sector ICT. The universities are also well represented in the five top sector initiatives through figureheads, researchers, coordinators and programme managers.

# QUALITY AND EXTENT OF OUR RESEARCH

In the recent research evaluation report on Computer Science for the period from 2015 to 2020 (publication May 2022), the visitation committee mentions, among other things, the consistently high quality of the Dutch computer science research field (see Box III)[14, 15].

**Translated from: Research evaluation report Computer Science 2015-2020**

Dutch computer science research (..) is in a decent shape with many excellent examples of research output and the presence of a large number of internationally leading scientists. Computer science in the Netherlands has always had a strong position internationally, with high-quality research and impact. The committee is pleased that this is still the case during the period of this visit.

Computer science is very well represented in the national Gravitation programmes and in the routes and subsidies of the Dutch Research Agenda (NWA). With the current national network of ICAI labs, after initiation in 2018 by the universities in Amsterdam, direct financing of research from the private sector has increased significantly.

The organisation of the university IT field has greatly improved with a vital role for IPN and its Special Interest Groups and a coordinating role in the sector plan.

BOX III

However, the Dutch market share[16] in international scientific computer science output, measurable via the parameters field-weighted citation impact score (FWCI) and output score (OSI), has been declining for years. The Dutch citation impact score is average in the period 2017-2020 (0.9 < FWCI <1.1), and therefore stable compared to the previous period. Dutch research is in specific areas, including AI is leading (FWCI = 2.08 over 2013-2018, #4 worldwide)[17].

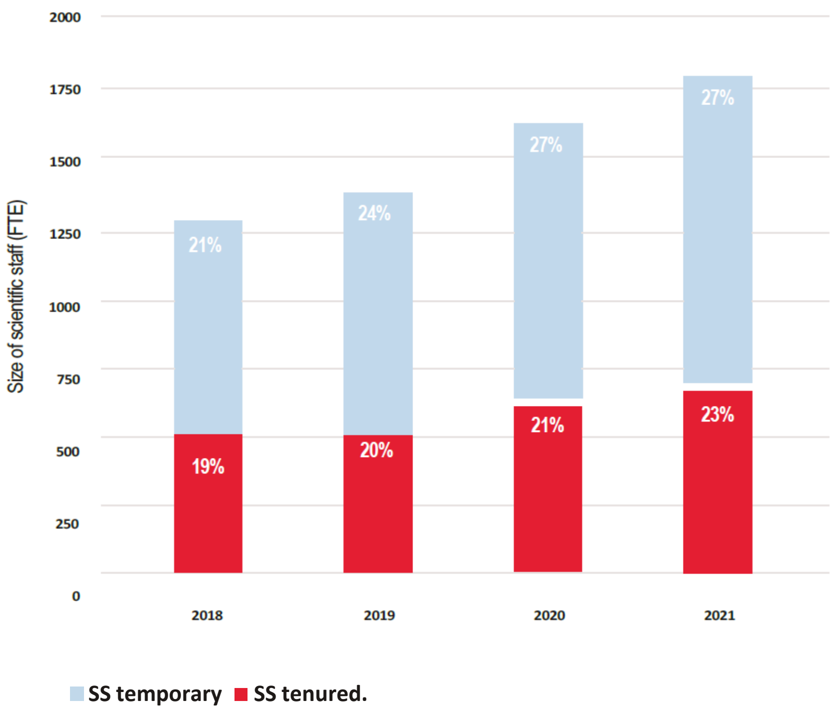
The number of publications, however, in international peer-reviewed journals continues the downward trend from the first sector picture and is below the international average (OSI score < 0.8).

This has three main causes. The first cause lies in the limited Dutch investments in scientific computer research compared to international competition. Also, in our own country, the relative allocation of grants for fundamental computer science research from the national research funds (indirect government funding) lags behind other science disciplines. The interim report on the sector plan shows that the Physics sector, which is comparable in size (national permanent staff) to the Computer Science sector, is consistently allocated 3.5 times as many resources per FTE each year via indirect government funding.

[14] Research assessment report Computer Science 2015-2020, De Onderzoekerij (2022, see Appendice 6 for a summary of the main points, full report available on request)
[15] See Appendix 7 for a list of quality indicators for the sector, including personal grants and gravity programs
[16] Performance profile of the Dutch research system | Rathenau Instituut
[17] Research into artificial intelligence in the Netherlands | Rathenau Instituut

A second partial cause lies in the focus on application-oriented computer science research. Many universities manage to double the direct government funding through indirect government funding, international research funds and public-private partnerships (non-government funding). However, the policy agendas behind these additional funding flows pay only limited attention to basic science. Most of the budget is therefore intended for further development, innovation and application.

FIGURE 3.
DEVELOPMENT IN SCIENTIFIC STAFF BETWEEN 2018 AND 2022




**Legend:** SS = scientific staff. Tenured SS consists of full, associate and assistant professors, tenure trackers, teachers and other permanent employees. Temporary SS consists of postdocs, PhD students, lecturers, and others. The percentage in the bars represents the percentage of women in the relevant category.

Based on an ambition to create space for researchers to achieve new breakthroughs within a broad spectrum of research themes, the resources from Sector Plan 1 have been used to boost fundamental computer science research. These structural resources have now led to an increase of at least 64 FTE in the permanent academic staff in the Computer Science departments of the participating universities. In addition, the institutions have created 90 FTE permanent positions in the focus areas from direct funding. However, due to increasing student numbers in the same period, the intended space was not created. The persistently high teaching pressure is therefore the third partial cause of a lower number of applications submitted for fundamental research grants from the sector than would be possible with a better balance in the division of research and teaching tasks among academic staff.

# QUALITY AND SCOPE OF OUR EDUCATION

Developments in digital technology and digitisation are following each other at a rapid pace. This has resulted in a sharp increase in the demand for knowledge and skills in the field of rapidly evolving digital technologies in the field of AI, IoT, Big Data analytics and cybersecurity [18]. This translates into a national education offering that rapidly introduces new developments into the curriculum and is therefore rapidly evolving. In addition to the existing offering, several courses have been phased out since the start of Sector Plan 1, new specialisations and tracks have been introduced in existing courses, and several new courses have been (or will soon be) launched [19]. In the bachelor's phase, the offering focuses mainly on the broad formative studies of (Technical) Computer Science, Information Science, Artificial Intelligence, and Data Science. Students can choose different specialisations and minors, the range of which differs per university and depends on the local scientific focus. The training offer in the master's phase is more extensive and, due to the research-oriented design of the second year of these research masters, is firmly embedded in the research focus of the institution. Within the range of broad IT courses, almost every institution offers specialisations/tracks in the fields of Software Engineering, Data Science, AI, Algorithmics and/or Cybersecurity.

## STUDENTS: ENTRY, NUMBERS, DIPLOMAS AND GENDER

The total number of students at universities increased by 18% in the period from 2018 to 2021 [20]. The Ministry of Education, Culture and Science expects that this growth will continue in the coming sector plan period [21]. Figure 4a shows that in the same period, the average student intake in computer science courses increased by 36%, while the total number of computer science students increased by 43%. The growth for computer science courses is therefore far above the national average, with the result that the growth ambition until 2024, as formulated in Sector Plan 1, was already amply achieved in the academic year 2021-2022. Both the bachelor's and master's degrees are growing, with the master's expanding slightly faster, partly due to an increase in international inflow. The continued growth also translates into more alumni: 61% more students graduated in the 2021-2022 academic year than in 2018-2019.

## STUDENT/STAFF RATIOS

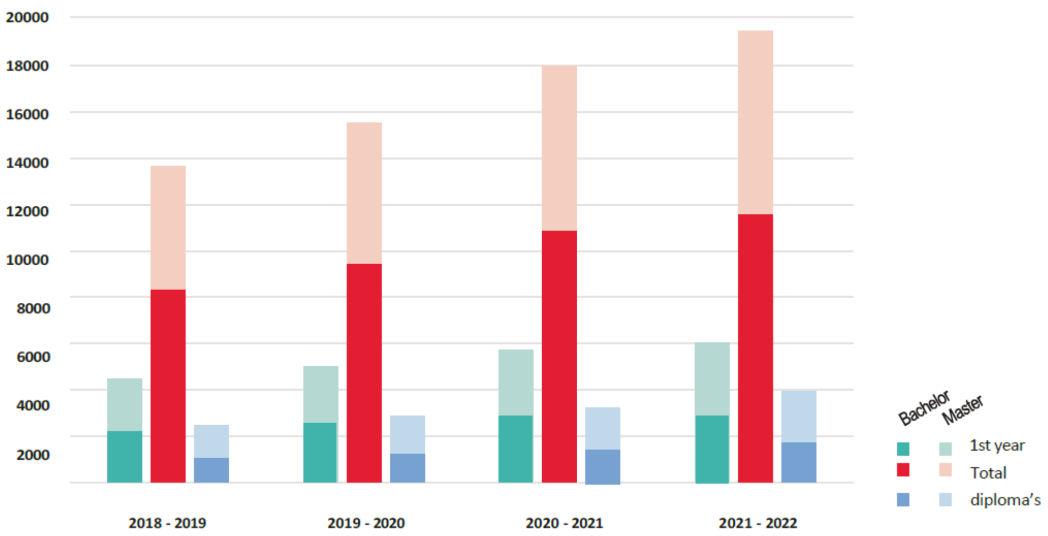
The student/staff ratio of a course is included as a quality indicator in the cycle of educational inspection reports. In addition, it is an important indicator of education-related workload among academic staff. The national benchmark, the average student/staff ratio across all universities and disciplines reported in the period covered, was around 19.7 [22] in the period from 2018 to 2021. Figure 4c shows that for the bachelor's and master's programmes included in this sector plan, this number was 31.3 in the same period. The considerable spread in the ratios of the institutions is striking. If the Computer Science sector wants to bring the student/staff ratio to the level of the national benchmark through investments in personnel, the sector must (with constant student numbers) realise a growth of 377 FTE permanent scientific staff (to 1000 FTE nationally). A fixed intake has been introduced for a number of bachelor's programmes to keep the student/staff ratio and teaching pressure manageable. The Science Technology Education Sector Plan (2020) [23] of the 4TU federation, with special

[18] ICT labour market research with Top Sectors 2019 by Berenschot
[19] See Appendice 5 for the list of courses.
[20] UNL: student growth and student/staff ratios 2012-2021
[21] OCW in figures: Forecast number of university students
[22] UNL: student growth and student/staff ratios 2012-2021
[23] Sectorplan bètatechniek (4tu.nl)

attention to computer science courses, also mentions the major challenge facing the courses and focuses on, among other things, increasing capacity through targeted actions. Only when the student/staff ratio has been brought to an acceptable level can capacity limits be raised for some of the current fixed intakes.

## EDUCATION KEY FIGURES IN THE PERIOD FROM 2018 TO 2022

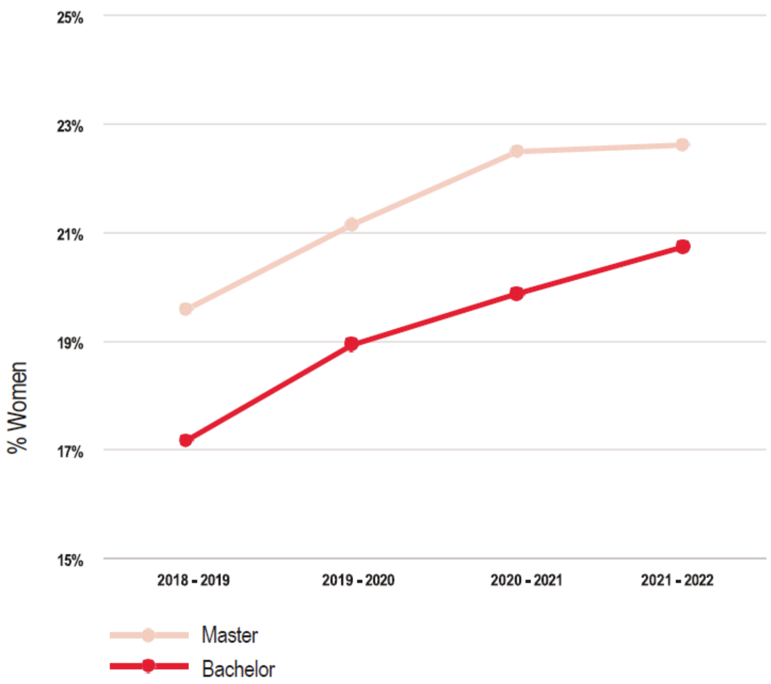
### FIGURE 4A. DEVELOPMENT IN STUDENT NUMBERS AND DIPLOMAS BETWEEN 2018 AND 2022




**Legend:** The height of the bar charts is the sum of numbers in the bachelor's and master's degrees. Data comes from DUO, reference date 1 October of the given academic year. The courses that were included are shown in Appendices 5 and 6. The data for Open University courses are not included here.

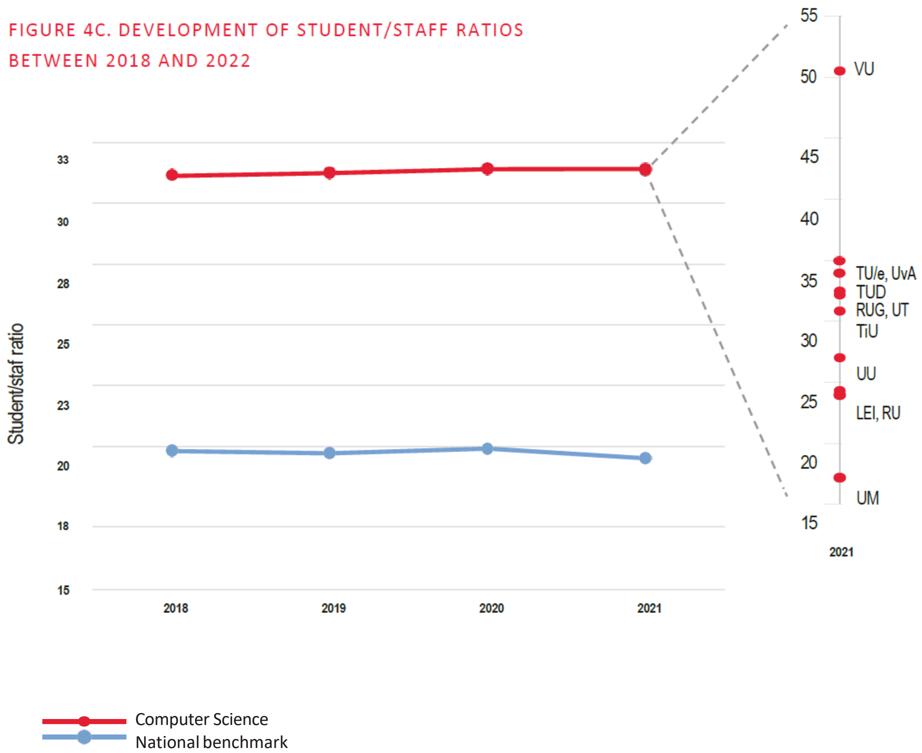
The number of women in computer science education, bachelor's and master's programmes, is slowly increasing (Figure 4b) but is still far from the sector's own target in Sector Plan 1 of 27% for 2024.

FIGURE 4B. STUDENT POPULATION: DEVELOPMENT IN GENDER BALANCE BETWEEN 2018 AND 2022




**Legend:** Percentage of women in the total number of students in the bachelor's or master's programme. Data comes from DUO, reference date 1 October of the given academic year.

FIGURE 4C. DEVELOPMENT OF STUDENT/STAFF RATIOS BETWEEN 2018 AND 2022




**Legend:** Student/staff ratios per calendar year are calculated as the total number of students on the reference date of 1 October, over the tenured academic staff present, including teachers (reference date of 31 December). The distribution has been made transparent for 2021.

### STUDENT SATISFACTION, CONNECTION WITH THE LABOUR MARKET AND EMPLOYER RESEARCH

Student satisfaction, as measured in the most recent National Student Survey (NSE, 2022), is above average in both the bachelor's and master's programmes (both score an average of 3.8 with a range of 3.4-4.1 and 3, respectively). 5-4.1 on a scale of 5). Every year, many more new vacancies arise than there are qualified, highly educated ICT specialists on the labour market, so the employment prospects of alumni are excellent; 92%-96% of computer science alumni (depending on major) have a job within the sector upon graduation or shortly thereafter. In the National Alumni Survey (NAE, 2019), our alumni paint a favourable picture of the fit between university IT courses and the labour market. However, in the successive labour market ICT studies by Berenschot (2019) and CentERdata (2020, 2021) commissioned by the Foundation CA-ICT, employers indicate that the Netherlands not only needs more pure IT specialists, but that these specialists must also have the skills that enable them to translate this into the needs of people, the market and society. According to the employers, this is another task for the universities.

## OUR OTHER FORMS OF EDUCATION

### TEACHER TRAINING IN COMPUTER SCIENCE

The number of secondary schools where computer science is offered as a final examination subject is decreasing. An important reason for this is a shortage of teachers. The status of computer science as a school examination subject, a subject that is taught in less than half of the schools, and which is only taken as an examination subject by 12% of students at HAVO/VWO[24], makes it difficult to attract professionals who can take the first-level teacher training course in Computer Science. The Science Deans work together to stimulate the influx of teachers into first-degree courses for the four shortage subjects of mathematics, physics, chemistry and information technology.

First of all, this occurs through the Bèta4all lateral entry programme, which is financed by the Science Deans and managed by their Vice Deans for Education in collaboration with the educational directors of university teacher training courses (ULOs). In the IT part, Co-Teach, eight subjects are taught with which future entrants to the Computer Science teacher training course can eliminate their deficiencies. This was done in 2020-2021 by 33 unique participants. In addition, the Science Teachers' Room has been set up, containing influential experts from the trade associations (including IPN), the ULOs and secondary education (VO). Through the Co-Teach project, unauthorised guest teachers with ICT knowledge are linked to subject teachers. They jointly teach the Computer Science subject. Starting from the 2022-2023 academic year, 12 secondary schools will participate in Co-Teach, concentrated in the Utrecht and Twente regions.

### EDUCATION FOR PROFESSIONALS

Developments in ICT are moving so quickly that knowledge and qualifications quickly become outdated. In addition, there is an increasing need from the professional field to focus on strengthening the general digital knowledge and skills of non-ICT professionals. Professionals will therefore increasingly have to train or retrain to remain relevant on the labour market. The universities, together with employers, take their responsibility in this regard and provide an increasingly broader range of options for professionals. This range varies from short and longer trainings and courses, to complete educational programmes, such as executive master's programmes and Engineering Doctorate programmes (EngD, specifically for the 4TU).

[24] Ontwikkelingen-ICT-2019.pdf (ptvt.nl)

## NEVER AGAIN TRAIN DELAYS?

The Dutch railway is one of the busiest rail networks in the world. Within various research projects, we look at how we can improve the reliability of the railway. For example, we develop methods with which we can predict failures in the infrastructure based on data analyses. This is called predictive maintenance. We can monitor the condition of rails, for example, via smart sensors. We then use AI algorithms to predict where cracks may form. This allows us to plan maintenance better and more efficiently. We can then calculate the best time to grind or replace rails. Another research project focuses on the EULYNX standard. This is a special modelling language to describe the behaviours of track elements, such as signals and switches. Computer scientists design methods to check whether these EULYNX models are correct: does a switch respond correctly to all environmental signals? Can so-called deadlocks occur, in which a signal ‘hangs’ and no longer responds at all? By thoroughly checking these models, we ensure that trace elements do not contain any errors.

# SECTOR PLAN GOALS
# CREATING PEACE AND SPACE

Despite the effective expenditure of the resources from the current sector plan (Sector Plan 1), the urgency of some of the themes mentioned in the box below has further increased during the current sector plan period. These most important opportunities and bottlenecks in the realisation of the sector plan goals[25] were already identified earlier in, among others, Sector Plan 1 and the associated interim evaluation report, the IPN vision, the IT research evaluation report (period 2015-2020), and several other social and policy reports.

The new sector plan resources are a second step in the right direction, but we do not expect these resources to be sufficient to bring the necessary peace and space to the sector. Below, we explain the opportunities and bottlenecks that the sector faces.

## OPPORTUNITIES AND BOTTLENECKS

Opportunities and bottlenecks are two sides of the same coin. In practice, the combination with various other variables in the playing field and the resulting possible perspectives for action (or lack thereof) usually determines whether an opportunity can be taken advantage of or whether the opportunity is in fact a bottleneck. The most important challenges for the universities in response to the opportunities and bottlenecks from Box IV are explained in more detail below. Box V summarises point by point how the new sector plan resources can be used to meet these challenges.

| Opportunities | Bottlenecks |
|---|---|
| 1. Very rapid developments in the field | 7. Very tight labour market |
| 2. A lot of social attention for the importance of digitisation and digital technology | 8. Workload due to increasing student/staff ratios |
| 3. Funding of applied research | 9. Lack of diversity in student population and staff |
| 4. Role of computer science as a methodology in other disciplines | 10. Limited funding for fundamental research |
| 5. Increasing student numbers | 11. Limited attention to Computer Science in primary and secondary education |
| 6. Tapping into new target groups | 12. Absorptive capacity in case of too fast growth in staff |

BOX IV

[25] See framework for sector plans 2022/2023 – 2028/2029

# ONGOING MISMATCH BETWEEN SUPPLY AND DEMAND

**Training: a qualitative and quantitative challenge (K1, 2, 5, 7, 8).** The far-reaching transition to a digital society is a constant driver for developments in the IT field, both in the fundamental principles and in the application. Developments are happening so rapidly that knowledge quickly becomes outdated, and adjustment of the educational curriculum is a constant point of attention. The shift to a more digital society is also accompanied by an increasing need for highly trained ICT specialists. To meet the labour market demand between now and 2030, universities (and colleges) will have to train considerably more computer scientists. In recent years, the influx into university computer science courses has increased significantly (Figure 4a). This increase is expected to continue for the time being, but it will not be sufficient to meet social needs in the coming years. Besides increased workload in our own educational programmes of regular bachelor's and master's education, the staff of IT groups/institutes are increasingly being called upon to provide courses as part of other training courses (service education) and to provide education for professionals. Both private and public parties repeatedly call on universities to develop new scalable forms of education for further training of their professionals.

The challenges for the courses are therefore complex and lie in a combination of offering a relevant and high-quality curriculum and simultaneously (phased) scaling this up and providing it without this having unacceptable consequences on the workload and attracting and retaining (sufficient) researchers and teachers to realise the educational offer (in their own courses and beyond). The latter is a major challenge in the very tight labour market where talented computer scientists are scarce, whereas there is a lot of demand for them throughout the labour market.

**A challenge in growth and finding balance (K5, 7, 8, 12).** Student numbers and scientific staff in the IT institutes have increased at the same pace in the first three years of Sector Plan 1. The investments have therefore not yet led to a reduction in the workload and/or the desired improved balance between research and teaching tasks. Important points of attention are the absorptive capacity of the fastest-growing institutions and the retention of attracted talent. **Additional investments from the Sector Plan 2022/2023-2028/2029 are therefore essential: on the one hand, for the further expansion to expand the tenured staff with teachers and researchers, and on the other hand, to attract high-quality support staff.**

**A Diversity Challenge (K6, 9, 11).** Digitalisation shapes society, it is therefore important that the people developing new digital technologies are representative of a broad spectrum of perspectives and social values. This means that we must make people with diverse backgrounds – in terms of gender, nationality and socioeconomic status – enthusiastic about a computer science education. The challenge for the sector lies in reaching these diverse target groups through outreach, inclusive education and role models. A diverse target group is reached through outreach activities to students in primary and secondary education, but these short interventions do not yet translate into a strong increase in diversity in the intake of bachelor's degree programmes. In the current sector plan, the universities have successfully committed themselves to recruiting female researchers. This strategy will also be continued in the coming years. **The universities are also committed to the new sector plan resources to a recruitment strategy in which a woman is hired for 50% of the positions**. However, it is not enough, and diversity is more than gender.

An important bottleneck outside the direct sphere of influence of the universities is the fact that ‘Digital Literacy’ as a theme and computer science as a subject are still moderately integrated in primary and secondary education. As early as 2012, the Royal Netherlands Academy of Arts and Sciences (KNAW) advised the Ministry of Education, Culture and Science to include Computer Science as a subject within the central final examination [26]. The ICT sector (Ag Connect and VNO-NCW) also strongly pushed for ICT as a subject in primary and secondary education in 2017 [27]. In 2019, the primary and preparatory education field, as part of curriculum.nu, made various recommendations and proposals for elaborating the theme in the curriculum (primary, secondary and vocational education) [28]. A recently submitted opinion piece by a student in the newspaper Het Parool [29] endorses the importance and urgency of learning skills (including computer languages) for ‘automating and solving everyday problems with computers’, which is also felt by secondary school students. Unfortunately, the various proposals and signals have still not led to adjustments in the curriculum.

## FINDING THE BALANCE BETWEEN FUNDAMENTAL AND APPLICATION-ORIENTED RESEARCH

**A Financial Challenge (K3, 10).** In its assessment report, the research assessment committee mentions the disproportionate imbalance in the Netherlands in the financing options for research in favour of application-oriented and multidisciplinary research. This is also identified in IPN’s vision as a major bottleneck and missed opportunity, as curiosity-driven research, also known as blue sky research, has led to the development of groundbreaking technologies.

The importance of the ICT sector is great, and in the order of 6% of the total labour market (with a predicted growth to 10% in 2030) [30]. Given the social importance of digital technology and the speed of developments in ICT, an appropriate share of the Dutch research budget is at least a comparable percentage. **New sector plan resources will be used by the universities to further strengthen the foundation and set out the long-term vision for computer science research in the Netherlands (and Europe).**

A social and (mono, inter and trans) disciplinary challenge (K1-4, 10). The pull from society and other scientific disciplines for computer scientists towards more application-oriented research is considerable. Digitalisation has been identified as one of the three major transitions that the government’s mission-driven innovation policy focuses on (Coalition Agreement, p29-32). Computer science and its applications are also being studied more often and in an increasingly broader range of scientific disciplines, used as a methodology and/or further developed in research in a context-oriented manner. In the online UNL environment ‘Digital Society: from Ambition to Approach’, the universities indicate that they want to profile themselves as a testing ground for digital innovations. It explicitly advocates an approach from a broad spectrum of disciplines, and in close collaboration with the private and public sectors.

The broad attention to the application and innovation of digital technology provides a valuable impetus to the sector, but there is also a danger that was strikingly expressed earlier in 2010 by the current Minister of Education, Culture and Science. In one of his columns in

[26] Lenstra, J. K., Barthel, J.P., Brock, E. O. de., Jong, F. M. G. de., Lagendijk, R. L., Oortmerssen, G. v., et al. (2012). Digital literacy in secondary education; Skills and attitudes for the 21st century. Amsterdam: KNAW
[27] AG Connect research: ICT should become a compulsory subject - AG Connect
[28] Elaboration of Digital Literacy - Curriculum.nu
[29] Lena van Kruisdijk (14 September 2022) Opinion: 'Teach us programming languages Python and Java, instead of French and German' (parool.nl)
[30] See Appendice 2 for an extensive labour market analysis.

the NRC[31], Robbert Dijkgraaf called Computer Science 'par excellence, a science in which the application is so self-evident that it is often forgotten that it is also about science'. To make a lasting contribution, and to be able to contribute innovations from an interdisciplinary and applied setting, the Computer Science sector itself will have to stimulate and safeguard its own curiosity-driven research. The ultimate challenge lies in combining the different forms of research on Pasteur's continuum (from fundamental to applied) in such a way that the perspectives converge so that new insights and innovations are not hindered, but rather accelerated by the collaboration.

## Our ambitions summarised

1. The universities want to use the new sector plan resources to further expand the tenured staff with lecturers, researchers, and high-quality support with the aim of:

2. More educational capacity to meet societal training needs and to realise a relevant and high-quality training offer for the increasing numbers of students on the one hand and professionals on the other.

3. More research capacity so that we can permanently guarantee the research and development foundation under the societal and scientific digital transition. The research capacity will benefit both disciplinary research and contribute to cross- and transdisciplinary challenges.

4. More diversity in the staff so that the Computer Science sector becomes a better reflection of society. Greater diversity in the sector is expected to contribute to a more diverse intake into training courses and, in the long term, to a more diverse ICT workforce. Not only is greater diversity important for utilising societal potential, but diversity is also essential in preventing bias and misrepresentation of different population groups in the code behind ICT products and systems.

5. Retaining talent through sufficient support, diverse and inclusive departments, and a range of tasks that includes sufficient space for both education and research.

BOX V

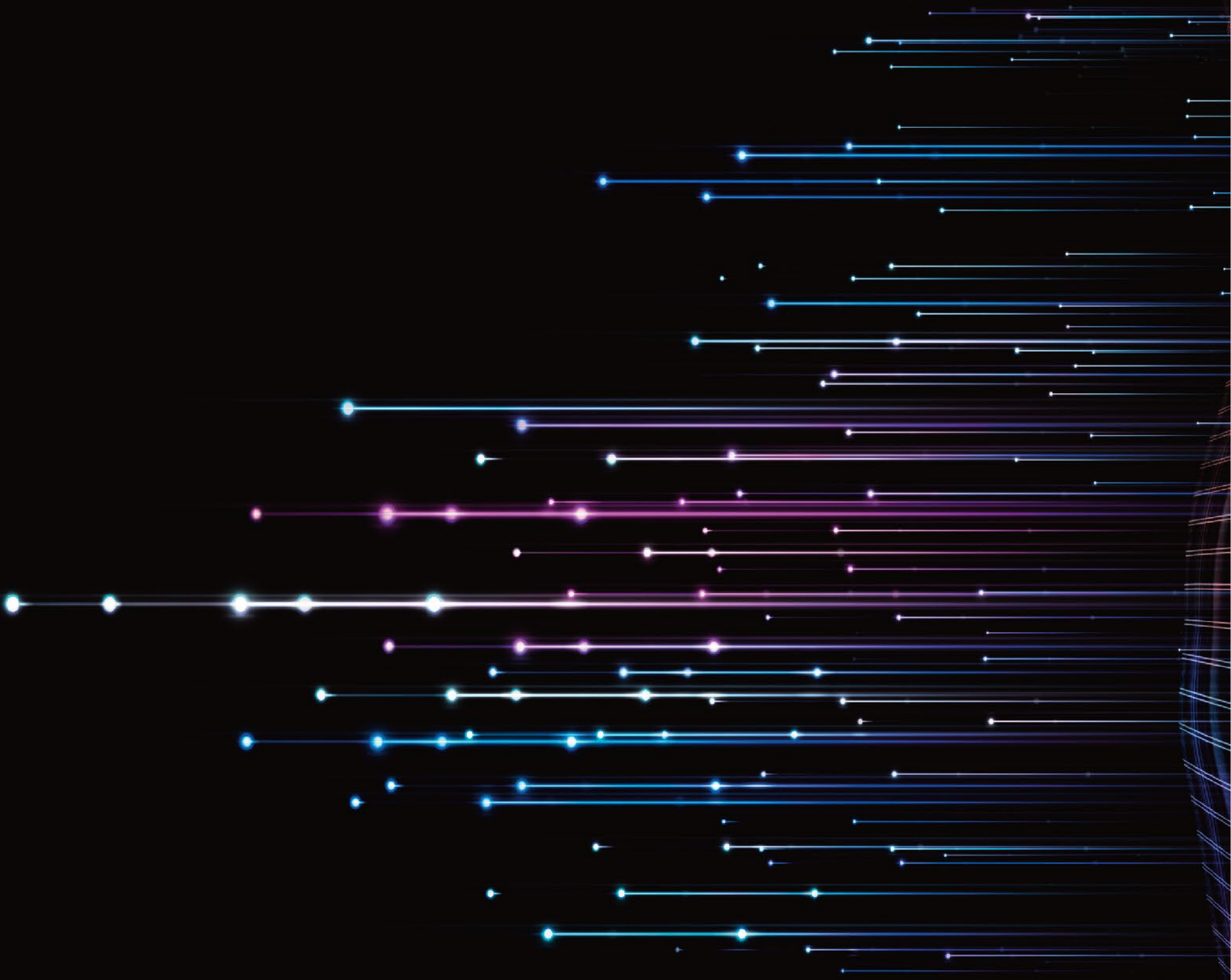
[31] Robbert Dijkgraaf (2 October 2 2010) The curse of the application - NRC

# ACHIEVING OUR AMBITIONS

We achieve the aforementioned ambitions within research and education by concentrating on strengthening the university landscape in specific focus areas. The following division into seven focus areas has been made for Sector Plan 1, which is still relevant:

1. Modelling and analysing data
2. Machine learning
3. Machine reasoning and interaction
4. Algorithmics
5. Software
6. Security and privacy
7. Networked computer and embedded systems

The focus areas are described in more detail in Appendice 3. In terms of content, they have been adjusted for this refined sector picture compared to the descriptions in Sector Plan 1 so that recent developments are visible. We have made their embedding and impact visible in the context of major scientific issues and societal themes. The focus areas include (in name or content) the five key technologies chosen by the Top Sector ICT as national spearheads: AI, Big Data, Blockchain, Cybersecurity and Future Network Services. Besides a clear focus on the scientific importance of each focus area, attention is paid to new developments, innovations and applications that have the potential to make an important contribution to solving the major societal challenges as formulated in the KIAs and NWA routes.



## KILO-MEGA-GIGA-TERA-PETA-EXA-ZETTA

The amount of data we collect is unimaginably large. In 2025, we are already talking about more than 180 zettabytes. This exponential development allows tech giants, such as Google, to create machine learning models that produce predictions beyond the capabilities of a human.

These are exciting developments for potential applications from medical diagnoses to improving the distribution of sustainable energy, but they also pose a number of challenges for research and practice. How do we efficiently and effectively prepare the extremely large volumes of data for analyses and how do we maintain their value over time? The focus of the data science community in the coming decade is to create efficient distributed methods for computing exponentially growing amounts of data, so that the volume of data collected does not become overwhelming in practice and does not lead to errors. Another challenge is the definition of mechanisms for the accessibility of this wealth of data, or describing data and the models used so that they are findable, accessible, interoperable and reusable (FAIR).

# APPENDICES

# APPENDICE 1.
# COMPOSITION OF IPN BOARD AND WRITING TEAM

This sector overview was created under the coordination of the ICT research platform Netherlands (IPN). This sector overview contains input from all members.

**The IPN board is formed by:**

| | |
|---|---|
| Catholijn Jonker, Chair | Delft University of Technology/Leiden University |
| Gerard Barkema | Utrecht University |
| Andy Pimentel | University of Amsterdam |
| Patricia Lago | VU University |
| Han la Poutré | Centre for Mathematics & Computer Science (CWI) |
| | Delft University of Technology |

**The IPN board is supported by:**

| | |
|---|---|
| Femke Stephan | NWO |
| Esther Vleugel | NWO |

**Composition of the writing committee for this sector overview:**

| | |
|---|---|
| Gerard Barkema, Chair | Utrecht University |
| Ton de Kok | Centre for Mathematics & Computer Science (CWI) |
| Mark Winands | Maastricht University |
| Tanja Vos | Open University |
| Arjen de Vries | Radboud University |
| Paris Avgeriou | University of Groningen |
| Alan Hanjalic | Delft University of Technology |
| Arie van Deursen | Delft University of Technology |
| Bettina Speckmann | Eindhoven University of Technology |
| Johan Lukkien | Eindhoven University of Technology |
| Marie Postma | Tilburg University |
| Alfons Hoekstra | University of Amsterdam |
| Aske Plaat | Leiden University |
| Marieke Huisman | University of Twente |
| Johan Jeuring | Utrecht University |
| Jaap Heringa | VU Amsterdam |
| Dick de Ridder | Wageningen University & Research |
| Bedir Tekinerdogan | Wageningen University & Research |

**Coordination, writing and editing of the sector image was in the hands of:**

| | |
|---|---|
| Cocky de Wolf | Utrecht University |

Contributions in text and images have been made by many involved researchers (writing teams focus areas) and by the IPN special interest groups (thematic insets).

We are incredibly grateful to the following people for their valuable feedback and for reading the text: Maarten van Steen (University of Twente), Inald Lagendijk (Top Sector ICT and Dutch AI Coalition), Frits Grotenhuis (Top Sector ICT) and Marcel Staring (I-craftsmanship, Ministry of the Interior and Kingdom Relations).

# APPENDICE 2.
# THE ICT SECTOR: A LABOUR MARKET ANALYSIS

**Analysis of the labour market: demand for ICT specialists until 2030.** The far-reaching digitalisation of society is an international trend that has accelerated even further due to the COVID-19 pandemic. This shift to a digital society is accompanied by an increasing need for (highly) trained ICT specialists in virtually all sectors. The ICT Labour Market Surveys with Top Sectors 2019 (Berenschot and CentERdata), 2020 (CentERdata), and 2021 (CentERdata) commissioned by the CA-ICT[32] also show that the Netherlands needs a more digitally skilled workforce across the full breadth of the labour market to keep up with, or even lead, the digital revolution.

The European Commission has included the ambition in its Digital Agenda that Europe will have 20 million ICT specialists by 2030 (~ 10% of professionals)[33]. In 2021, this percentage for the Netherlands was 6.7% (EU-wide < 5%), according to the most recent report from the 'Digital Economy and Society Index' (DESI, 2022)[34]. If the size of the working population remains the same, this translates into a need for ~300,000 additional ICT specialists in the Netherlands alone in the next eight years. However, there is already a shortage of sufficient ICT specialists. An employer survey by the UWV[35] shows that 63% of the vacancies in the ICT sector that will arise in 2021 will be difficult to fill.

The Eurostat database[36] has shown explosive growth in the number of jobs in the ICT sector in recent years. For example, in the last five years, the number of jobs in this sector in the Netherlands grew by 43% from 433.9K FTE in 2017 to 620.6K FTE in 2021. This picture of 30-40% growth is confirmed by a recent labour market survey[37] among Dutch employers. The research also shows that one-third of this growth is at master's level, and that two-thirds of the positions are filled with professionals at bachelor's level (higher professional education and university education). If this growth continues towards 2030, as the DESI predicts, the Netherlands will have a labour market need of 100,000 ICT specialists with a master's degree in the next eight years. With a balanced distribution over the indicated period, this amount to 12,500 alumni per year.

The Research Centre for Education and the Labour Market (ROA) of Maastricht University issues a comparable forecast for the Netherlands in its labour market information system[38], albeit more conservatively. Over the entire period from 2020 to 2026, the ROA forecasts an influx into the labour market of 15,300 graduates at master's level in Computer Science and Electrical Engineering (this includes various Computer Science master's courses, including Technical Computer Science and Computer Science), compared to a labour market need (replacement and expansion demand) of 19,400 professionals. At bachelor's level, the ROA sees a much larger shortage in the coming period. For every bachelor's alumnus, 2.4 job openings will be created until 2026 (21,800 alumni/52,100 jobs). The ROA calculations seem too conservative as CentERdata's quantitative research for CA-ICT shows that the demand for skills in the field of big data analytics and, among other things, AI, IoT and cybersecurity has increased fastest in vacancies in the Netherlands in the period since 2012. This also applies to the demand for robotics, blockchain, cloud computing and 3D printing skills. Furthermore, the vacancy survey points to a doubling in demand for skills in 'Specialized Software', 'Project Management Software' and 'Digital Transformation', the latter being a category that largely

[32] Research - CAICT (the three consecutive studies can be downloaded from this page)
[33] Europe's Digital Decade: 2030 targets | European Commission
[34] Human Capital and Digital Skills in the Digital Economy and Society Index | Shaping Europe's digital future
[35] Unprecedented tightness on the ICT labour market (werk.nl)
[36] Statistics | Eurostat (europa.eu)
[37] NIDAP report commissioned by the 4TU in connection with the science technology education sector plan. Delivery is expected in Q4 2022, the concept is available on request.
[38] Labor market forecasts until 2026 per education type (maastrichtuniversity.nl)

encompasses skills related to Industrial Revolution 4.0.

Supply of computer scientists on the labour market. The figures in this report and various other reports show that the number of students in university computer science courses has risen sharply in recent years. Only one in five IT specialists and alumni from IT courses in Europe are women[39]. The inadequate participation of women means that a considerable potential remains untapped. Furthermore, the lack of diversity (in a broad sense) also has an undesirable influence on the development and application of digital technique. The skewed male-female ratio has been present since the influx of computer science training staff.

Analysis of the Computer Science student landscape by the University of Twente shows that since 2017, an average of 70% of university bachelor alumni have progressed to a major master training[40]. 30% start a career after their university bachelor's degree. On the other hand, bachelor alumni from universities of applied sciences overwhelmingly prefer to enter the labour market after completing their training (90%). Every year, approximately 2000-2500 students successfully complete a master's programme with a major computer science component (see Figure 4a and Appendice 4). This number will increase in the coming period due to the increased intake for the bachelor's degree, but it will not come close to meeting the needs of the ICT sector (estimated by DESI at 12,500 graduates per year).

Alumni from various other disciplines, especially science courses, also find their way to a job in the ICT sector, as shown by the ROA figures. In addition, various government-funded and private knowledge institutions offer courses, modular education, and retraining programmes for lateral entrants and for ICT professionals who want to continue developing. Due to the severe labour market shortage, the government stimulates many retraining programmes in IT through learning subsidies, including via the Human Capital Agenda-ICT[41]. In addition, employers are increasingly offering learning and retraining programmes as part of the secondary employment conditions. A good range of education for professionals is highly desirable for both lateral entrants and those who progress. In the 2019 ICT Labour Market Survey with Top Sectors, Berenschot makes nine recommendations on how educational institutions, employers and government can work together towards a more digitally skilled workforce. These recommendations are largely in line with the five lines of action for universities as formulated in the Science Technology Education Sector Plan 2020[42].

[39] Human Capital and Digital Skills in the Digital Economy and Society Index | Shaping Europe's digital future (europa.eu)
[40] Public projects | Education sector plan | BI-Studio (utwente.nl)
[41] Home page | HCA ICT
[42] Sector Plan Education Beta Technology - final (4tu.nl)

# APPENDICE 3.
# THE FOCUS AREAS IN 2022

We achieve our sector plan ambitions within research and education by focusing on strengthening the university landscape in specific focus areas. The following division into seven focus areas was made for Sector Plan 1 and is still relevant:

1. Modelling and analysing data
2. Machine learning
3. Machine reasoning and interaction
4. Algorithmics
5. Software
6. Security and privacy
7. Networked computer and embedded systems

**1. Modelling and analysing data.** The emergence of Big Data as a basis for understanding business processes and new developments in science and society represents an ongoing challenge throughout the data life cycle: from modelling, organisation, processing, storage, analysis to data visualisation and decision-making. The amount and diversity of data, collected from a wide variety of sources (sensors, social media, multimedia databases, open web, etc.) leads to several fundamental questions. Which data should be selected and for what processing, without losing sight of basic values such as privacy? Do we want to analyse, store and process data centrally? How do we deal with the associated security risks, or is decentralisation of data processing a better alternative in which privacy and security can be better guaranteed? How does decentralisation relate to the scalability of analytics? Answers to these questions require further development of theory, methodology and tools in computer science.

Modern data processing systems not only support processes with a Machine Learning (ML) core, but also contain large components based on ML. This makes 'Machine Learning Operations' one of the major challenges for the future. The goal is to develop products based on machine learning that are just as dependable and easy to validate as other software. Data-driven AI systems must meet increasing requirements in terms of complexity, data volumes, scalability, flexibility and ultimately energy efficiency. The way data are modelled and pipelines are designed, determines how they perform, evolve in the absence of disruptions and how they can be made future-proof. This allows changes resulting from new functionality, regulations and social requirements to be applied sustainably with no or minimal downtime. Big Data and ML require a lot of resources, both in energy consumption and required hardware. In the context of that other important transition on sustainability and energy, how can this be reduced without sacrificing quality?

**2. Machine learning.** In the past ten years, ML has developed rapidly through a combination of increasing computer power, the internet and the enormous availability of data and new computing techniques. These learning systems can adapt their behaviours to the data they observe and are used, for example, to keep healthcare affordable, optimise energy supply and transport, automate trading processes, and monitor banking transactions. Variants of deep learning, such as the use of highly layered neural networks for learning patterns, are now widely used in practice. The Netherlands is a leader in developing new algorithms that can make large-scale ML faster and more energy efficient, and that can learn in practice by interacting with their environment. In addition, much groundbreaking research is being done into ML techniques that are also suitable for small datasets, by effectively combining the available domain knowledge (both in human experts and in computational models, such as physics- and biology-informed learning) and classical models with Transfer ML techniques and learned models to new tasks. The Netherlands is a leader in describing and tracing causal relationships that are necessary to correctly interpret data.

The massive increase in ML also poses major challenges. For example, combining learning systems leads to complex, difficult-to-predict behaviour, which hinders its application in critical situations and autonomous systems. And the selection of data used for the learning process can have major consequences for the result, which entails risks of discrimination and social exclusion. Consequently, there is a great need for methodology for fair, explainable and reliable ML techniques that guarantee the predictability of systems and respect people's rights and privacy.

**3. Machine reasoning and interaction.** In addition to the rapid developments in self-learning AI, which is strong in pattern recognition, there is a great need for AI systems that can reason on a more abstract and general level. The next step in the evolution of AI towards human-level intelligence is therefore machine reasoning; the ability to apply learned knowledge to new situations. The combination of machine reasoning and self-learning algorithms is particularly promising. DeepMind's Alpha Zero, which can play various games such as chess and Go at a superhuman level, is a good example of the breakthrough that can be achieved when a reasoning technique such as 'heuristic (Monte-Carlo) search' and deep learning are combined.

Further integration of these methods will increase the quality of automated decision-making, whether used to make decisions autonomously or to provide a human planner/operator with a range of sensible options. Machine reasoning is essential for AI because responsible decision-making requires thinking about the consequences of future decisions. Machine reasoning must take into account the people involved and their preferences, and the (reasons for these) decisions must be based on available data and explainable for human experts and policy makers. This leads to so-called Hybrid Intelligence, in which people and machine complement each other's capabilities. Such AI systems that enable collaboration between humans and machines are also known as human-centric AI. Research in the field of human-oriented AI focuses on how AI can support people in many vital applications, including negotiation and group decision-making processes, decision support in healthcare, human resources policy, smart industry, smart and sustainable agriculture, (personalised) news and new forms of access to cultural and/or historical collections. The interaction between humans and intelligent machines is essential to arrive at technologies that incorporate our norms and values. The big questions and challenges we face are: How do we bridge the gap between the AI of rules that are easy to understand and the AI that learns from data? How do people communicate with intelligent machines when their internal representations are completely different? How can we develop transparent AI systems that provide people with clear explanations about automated decisions, without making concessions in terms of performance and usability? How can we measure and prevent AI from disadvantaging certain groups? How can we ensure that people maintain control over personal data that an AI system uses, and can monitor an AI system's decisions? These fundamental questions have been around for decades but are now more urgent than ever due to rapid developments in self-learning AI. A multidisciplinary approach, where computer science works together with the humanities and social sciences, is crucial for tackling these challenges.

# QUANTUM COMPUTING

**A** quantum computer is a radically new computer that will be able to perform certain calculations faster than classically designed computers will ever be able to do. Applications include vast improvements in optimisation, machine learning, quantum chemistry and materials, but there is also the risk that the enormous computing power will break the current information security techniques.

Quantum computers work on the basis of quantum effects, such as superposition, interference and entanglement; they calculate with quantum bits, or qubits, instead of the well-known classical bits that can only be 0 or 1. Fortunately, quantum effects can also be used to realise new quantum communications, the security of which is guaranteed by the laws of physics.

Current quantum computers have a limited number of qubits and are far from perfect. That is why research is being conducted into applications and algorithms with few qubits that nevertheless perform better than classical algorithms. At the same time, ways are being developed to test, measure, verify and debug quantum computers. The completely different nature of quantum computers requires fundamentally new algorithms, but also drastically changes what we know about the limits of what we can do with new computing technologies.

**4. Algorithmics.** Algorithmics is concerned with developing new methods to solve complex calculation problems. The emphasis is on methods that can be demonstrated to exhibit efficient scaling behaviour and that provide demonstrably correct results. This fundamental approach makes algorithmics one of the pillars of computer science. Algorithmics research in the Netherlands has been among the world's top for many years. The rapid increase in the amount of data that needs to be calculated, in combination with the increasingly complex tasks for which algorithms are used, means that the importance of efficient algorithms continues to increase. Moreover, the number of sub-areas and application areas of algorithmics continues to expand. In addition to the classic graph, geometry, string and optimisation problems, research is being conducted into issues relating to the energy grid, climate and environmental modelling, logistics, healthcare, visualisation, data science, machine learning and AI. These modern applications with heterogeneous, sometimes distributed stored datasets that are constantly changing, lead to new algorithmic challenges. In addition, the data is not always dependable: measurement data (such as GPS coordinates or sensor data) are not 100% accurate and sometimes some of the data is simply incorrect. Algorithms that can deal with uncertainty in the data therefore need to be developed. Moreover, all kinds of new paradigms are emerging (think of quantum algorithms or programmable matter, as well as distributed and streaming algorithms, and new conditional lower bounds) as well as new quality measures for algorithms (such as a focus on energy use, instead of on computation time or memory usage). With all these new applications and paradigms, reliability and scalability of the developed algorithms, and explainability and quality of the results, remain essential. Therefore fundamental algorithmic research is and will remain of significant importance.

**5. Software.** Software is the basis of the advancing digitalisation of our society, with direct consequences for industry, services, government, education, healthcare and all branches of science. Software engineering stands for the systematic design, development, verification, testing and maintenance of software. Modern industrial software consists of millions of lines of code and forms the basis of digital applications in, among others, cars, aircraft, medical robots, the financial sector, healthcare and the public sector. Due to the growing interrelationship of software with our daily lives, the demand on the labour market for highly educated software specialists has increased significantly and the major challenges for software research have become increasingly topical. In Technology Trends Outlook 2022, McKinsey therefore identifies 'next generation software development' as one of the most important technological trends of the coming years. The Dutch software researchers, united in VERSEN, published a manifesto in 2020 in which they indicate that they want to address the following four important social and technological challenges in the coming period: (1) how do we provide guarantees about the reliability of software systems, so that these comply with social and personal needs and can withstand unorthodox use? (2) How do we achieve significant improvements in the efficiency and effectiveness of the development process of software systems now that the continued development of software has accelerated? (3) How do we improve flexibility and maintainability and what does this mean for the sustainability of existing software systems? (4) How do we train enough new software engineers and scientists to meet social needs and manage the digital transition?

**6. Security and privacy.** The security of information systems and critical infrastructures is crucial for maintaining Dutch prosperity: without a secure foundation, the Netherlands not only makes itself vulnerable, but also unattractive for economic activity. The digital society is vulnerable to external attacks and the systematic collection, analysis and exploitation of data by Big Tech and state actors. The motives are still mainly financial, but also increasingly strategic/political. In the words of EU

Commissioner Thierry Breton[43], "we need to build a proper cybersecurity shield for the coming decades". He also mentions supply chain security and quantum computing as strategic topics. The Netherlands has an excellent scientific reputation in the field of cybersecurity and cryptography. The researchers, united in ACCSS, formulated the fundamental research questions in this area in the National Cyber Security Research Agenda (NCSRA III). The first major challenge for computer science is how to demonstrate the (in)security of a system and how to automatically detect and repair any vulnerabilities. The second, equally important, challenge concerns methods to develop computer systems and critical infrastructures that are secure by design—not only today, but also in a future where the cryptographic foundations of these systems must be resilient to the threat of powerful quantum computers. No matter how well the first two points are resolved, cybercrime and state actors will always be part of our lives. Therefore, the third essential challenge focuses on methods to detect and respond to attacks—always from a better understanding of the economics of cybersecurity and the attackers' strategies. Finally, there is the fourth challenge: how to guarantee privacy and policy compliance in the digitalised society, while the boundaries of technological solutions are still unclear and laws and regulations remain necessary to enforce protection, but the same laws and regulations lag years behind technological developments. It is crucial that research conducted in this regard identifies privacy bottlenecks at an early stage, so that they are avoided where possible. That can be achieved by implementing privacy-by-design principles and giving users control over what happens with their data.

**7. Networked computer and embedded systems.** Computer systems form the essential infrastructure for the Dutch top sectors and innovation areas and will play a significant role in the necessary energy transition. Innovations within the domain of computer systems have, in many cases, been instrumental for important developments in computer science (such as Cloud Computing, Big Data and the current AI revolution) and will continue to be so in the future. Many of these computer systems cannot be recognised as such but are embedded in larger devices such as cars, aircraft, medical equipment, smart buildings, robotics, etc. In addition, future computer systems will be increasingly networked (via, among others, 5G and beyond 5G networks), and they will become increasingly distributed and autonomous. In addition, many systems will have to deal with extremely high-quality requirements (such as Cyber Physical Systems) and will be involved in the large-scale collection of data about artefacts (objects, processes) in the physical world (such as sensor networks and in the 'Internet of Things'). This domain of networked computer and embedded systems is currently one of the largest IT sectors in the world. The research at Dutch universities in the field of (networked) computer and embedded systems is excellent and has united in the national IPN Special Interest Group' Future Computer Systems and Networking'. The scientific challenges lie in realising and miniaturising the computer systems and in their energy consumption, reliability and sustainability. Furthermore, the rapidly increasing complexity of the systems is an additional complicating factor: computer systems integrate more processors, are often heterogeneous, sometimes in a distributed context, and possibly also result in complex systems-of-systems (as can be found, for example, in the so-called Edge-to-Cloud continuum). The unsustainable climate footprint of the large-scale use of computer systems themselves within our current and future ICT infrastructures must also be addressed. This requires the development of new, effective (software) solutions for an integrated approach to the design, analysis and optimisation of the hardware and software for these networked computer systems. These solutions need to efficiently and effectively deal with the complexity, heterogeneity and dynamics of these systems and make them manageable.

[43] https://ec.europa.eu/commission/presscorner/detail/en/STATEMENT_22_5173

# APPENDICE 4. NATIONAL KEY FIGURES OF UNIVERSITY COMPUTER SCIENCE EDUCATION AND RESEARCH

## EDUCATION

| Students | 2018-2019 | 2019-2020 | 2020-2021 | 2021-2022 |
|---|---|---|---|---|
| Bachelor | 8291 | 9422 | 10853 | 11568 |
| % women | 17% | 19% | 20% | 21% |
| Master | 5363 | 6101 | 7140 | 7946 |
| % women | 20% | 21% | 22% | 23% |
| **Total** | **13654** | **15523** | **17994** | **19514** |
| % women | 18% | 20% | 21% | 22% |

| First year | 2018-2019 | 2019-2020 | 2020-2021 | 2021-2022 |
|---|---|---|---|---|
| Bachelor | 2211 | 2556 | 2859 | 2887 |
| % women | 21% | 22% | 23% | 22% |
| Master | 2244 | 2450 | 2872 | 3149 |
| % women | 23% | 24% | 24% | 25% |
| **Total** | **4454** | **5006** | **5731** | **6036** |
| % women | 22% | 23% | 24% | 23% |

| Graduations | 2018-2019 | 2019-2020 | 2020-2021 | 2021-2022 |
|---|---|---|---|---|
| Bachelor | 1030 | 1203 | 1415 | 1686 |
| % women | 15% | 17% | 18% | 20% |
| Master | 1423 | 1674 | 1793 | 2264 |
| % women | 22% | 22% | 22% | 26% |
| **Total** | **2453** | **2877** | **3208** | **3950** |
| % women | 19% | 20% | 20% | 23% |

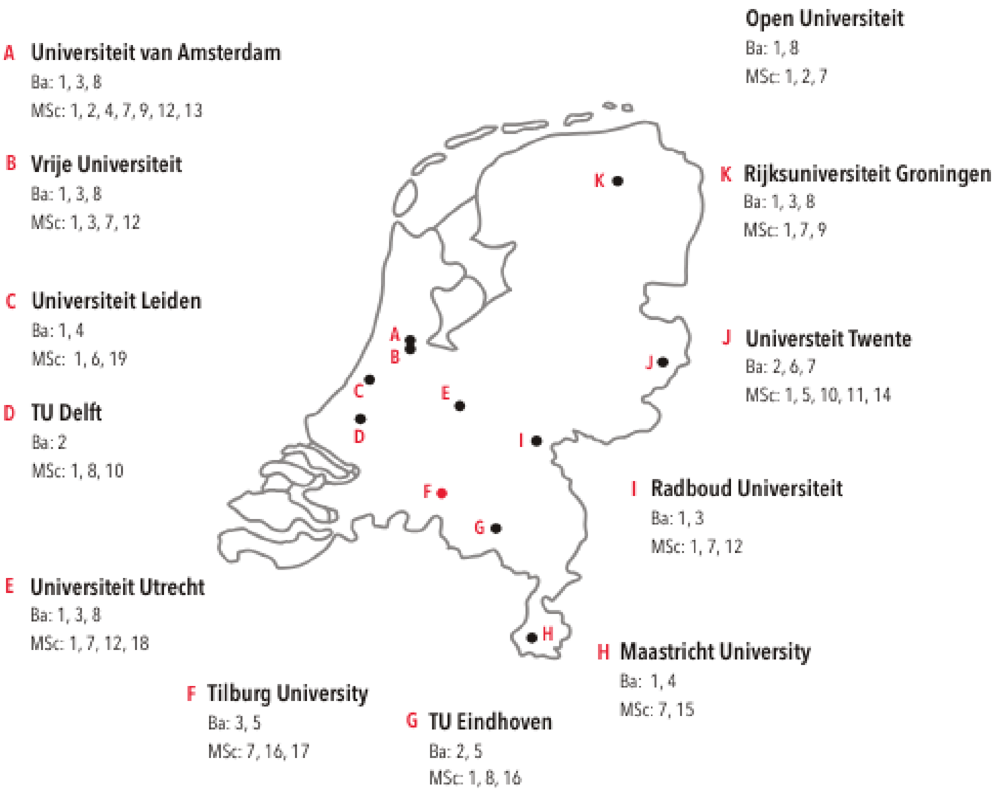
The figures are on the reference date 1 October of the academic year in question. Data come from the public education registers of DUO. The courses/croho labels included here are shown in the overview in Appendice 5. A percentage of shared courses has been included.

## RESEARCH

| Graduations | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|
| WP fixed | 472 | 536 | 611 | 667 |
| % women | 19% | 20% | 21% | 23% |
| WP temporary | 821 | 862 | 1011 | 1128 |
| % women | 21% | 24% | 27% | 27% |
| **Total** | **1293** | **1398** | **1622** | **1795** |
| % women | 20% | 22% | 25% | 26% |

The data regarding staffing has been provided by the participating universities. The reference date is 31 December of the calendar year in question. The universities included here are Leiden University, Open University, Radboud University, University of Groningen, Delft University of Technology, Eindhoven University of Technology, Tilburg University, University of Amsterdam, Maastricht University, University of Twente, Utrecht University and VU Amsterdam.

# APPENDICE 5.
# COURSES OVERVIEW OF UNIVERSITY COMPUTER SCIENCE AND INFORMATION SCIENCE EDUCATION




**Bachelors**

1. Computer Science (croho 56978, 59326, 50426)
2. Technical Computer Science (croho 56964, 59335, 50447)
3. Artificial Intelligence (croho 56981, 56945, 59338)
4. Data Science and Artificial Intelligence (Croho 50300)
5. Data Science (croho 55018)
6. Business Information Technology (Croho 56066)
7. Creative Technology (croho 50447)
8. Information Science (croho 56842, 56869)

**Masters**

1. Computer Science (and Engineering) (Croho 60300, 65014, 60364, 66978, 60438)
2. Software Engineering (croho 60228)
3. Computer Security (croho 60802)
4. Security and Network Engineering (Croho 60227)
5. Interaction Technology (croho 60030)
6. Media Technology (croho 60206)
7. Artificial Intelligence (croho 66981, 60969)
8. Data Science and AI (Technology) (Croho 60976)
9. Computational (Cognitive) Science (Croho 60653, 65015)
10. Embedded Systems (croho 60331)
11. Robotics (croho 60973)
12. Information Science(s)/Studies (Croho 60255, 60809, 60229)
13. Logic (croho 60226)
14. Business Information Technology (Croho 60025)
15. Data Science for Decision Making (Croho 60125)
16. Data Science in Business and Entrepreneurship (Croho 65018)
17. Data Science & Society (croho 60964)
18. Applied Data Science (croho 60971)
19. ICT in Business and the Public Sector (croho 60205)

# APPENDICE 6.
# SHORT SUMMARY RESEARCH VISITATION 2015-2020

All research units of universities and NWO and KNAW institutes are externally evaluated once every six years. This evaluation is done according to the SEP (Standard Evaluation Protocol), drawn up by the VSNU, NWO and KNAW. Units are assessed on three criteria: (1) scientific quality of research and contribution to scientific knowledge, (2) social relevance, and (3) viability; the ability to realise the scientific and social ambitions.

The most recent research inspection of the Computer Science departments and institutes in the Netherlands was conducted in accordance with SEP protocol 2021-2027 in January 2022 by the Research Department. Participating universities were Leiden University, Open University, Radboud University, Delft University of Technology, Eindhoven University of Technology, University of Amsterdam, Maastricht University, University of Twente, Utrecht University and VU Amsterdam.

The general conclusions of the committee are as follows:

1. Research at the institutions assessed is in a good condition, with many excellent examples of research output and internationally prominent researchers. Dutch Computer Science has always had a strong position with high-quality researchers and a major international impact. The committee concludes that this is still the case.

2. Examples of research programmes with great social relevance were seen at all participating institutions. They also perform well in outreach. There are various short-term financing options for socially relevant research programmes. For long-term innovations and applications, fundamental scientific computer science research needs to be strengthened.

3. The viability of the sector is exceptionally good. However, the committee has two major concerns:

   A. The limited financing options. All departments have grown significantly in the past period despite an extremely competitive labour market. It is essential that financing options for fundamental research in Computer Science improve to retain and further grow the talent attracted by the sector. [..]

   B. The student-staff ratio of the departments is still far too high. The committee recommends that the institutions request a second Sector Plan for Computer Science to address this imbalance further and strengthen national coordination between the departments. The committee recommends that all IPN members be included in a second application.

# APPENDICE 7. QUALITY CHARACTERISTICS OF THE COMPUTING SECTOR (2018-2022)

## STANDARD INDICATORS

| NWO | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|
| VENI | 2 | 9 | 7 | 7 | n/a |
| VIDI | 4 | 4 | 3 | 2 | 4 |
| VICI | 1 | 1 | 1 | 1 | 1 |
| TOP | 2 | 6 | 2 | | |
| **ERC** | | | | | |
| Starting | 1 | 2 | 2 | | |
| Consolidator | 2 | 1 | | | |
| Advanced | 3 | | | | |
| Synergy | | | | | |
| **Total** | **15** | **23** | **15** | **10** | **5** |

## DUTCH RECOGNITIONS AND APPOINTMENTS

| | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|
| Stevin Prize | | | | 1 | |
| KNAW appointment | 1 | | 1 | 1 | |
| *KNAW Young Academy* | | | 1 | | |
| KHMW appointment | | | 1 | 1 | 1 |

## INTERNATIONAL RECOGNITIONS AND APPOINTMENTS

| | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|
| MSCA fellow | | 1 | | 2 | |
| ACM fellow | | | 1 | 1 | |
| IEEE fellow | | | | | 1 |
| Humboldt foundation | 1 | | | 1 | |

Research groups at all institutions in the Computer Science sector frequently work together in consortia and through public-private partnerships in (field) labs, innovation hubs, living labs and PhD programmes. The various privately funded PhD labs, including the ICAI labs, will consist of more than 50 individual labs with more than 100 partners by the end of 2022. In addition, the sector is the initiator of, or participant in, various Growth Fund, NWO, NWA, and Horizon projects. Financing research (collaboration and training) through indirect and contract funding is an important source of income for the sector, which at least doubles the income from direct funding. A selection of projects is included in the table on the next page to give an impression of the broad participation and size. The list is far from complete.

## NWO PERSPECTIVE CONSORTIA

| | Year | Secretariat | Participant |
|---|---|---|---|
| EDL: Eff Deep Learn. | 2018 | TU/e | RU, TUD, UvA, VU |
| DIGITAL TWIN | 2019 | RUG | LEI, TUD, TU/e, TiU, UT |
| MEGAMIND | 2020 | TU/e | TiU, TUD, UT |

## NWO GRAVITY CONSORTIA

| | Year | Secretariat | Participant |
|---|---|---|---|
| Quantum Software C. | 2018 | UvA | CWI, LEI, TUD, VU |
| EsDiT | 2020 | UT | LEI, TUD, TU/e, UU, WUR |
| Hybrid Intelligence | 2020 | VU | LEI, RUG, TUD, UvA, UU |
| Brainscapes | 2020 | VU | TUD, LEI, UU |
| Stress in Action | 2022 | VU | RUG, UT |
| ALGOSOC | 2022 | UvA | EUR, TiU, TUD |

## NWO KIC CONSORTIA

| | | Year | Secretariat | Participant |
|---|---|---|---|---|
| MOCIA | (Crossover) | 2020 | RU | UMCG, AMC, UT, UM, WUR |
| ROBUST | (LTP) | 2020 | UvA | UU, UT, TU/e, JADS, LEI, UM, RU, TUD, EUR |
| PLANT-XR | (LTP) | 2020 | UU | TUD, UvA, WUR |
| LEAPFROG | (KIA-ST) | 2022 | VU | OU, VUMC, AMC |
| HEWSTI | (KIA-VEI) | 2022 | VU | LEI, TUD |
| AI4Int | (KIA-VEI) | 2022 | UvA | UU, TU/e, VU |

## GROWTH FUND (NGF), NWA, TOP SECTORS (TS)

| | | Year | Secretariat | Participant |
|---|---|---|---|---|
| AINed | (NGF) | 2022 | TUD | VU, TiU, RUG, RU, UM, UU WUR, LEI TU/e, UT, UvA |
| OLAI | (NGF) | 2022 | RU | UU, UM |
| CROP-XR | (NGF) | 2022 | UU | WUR, UvA, TUD |
| INTERSCT | (NWA-ORC) | 2020 | TU/e | UT, VU, TiU, RU, TUD |
| Cortex | (NWA-CS) | 2019 | LEI | UvA, CWI, RU, TUD |
| Primavera | (NWA-CS) | 2019 | UT | RU, TU/e |
| Thesues | (NWA-CS) | 2021 | TUD | VU, TiU |
| Catrin | (NWA-CS) | 2021 | UT | LEI, TUD, TU/e, UvA |
| Hapkido | (NWA-CS) | 2021 | TNO | TUD, CWI |
| C-SIDe | (NWA-CS) | 2021 | LEI | |
| PROACT | (NWA-CS) | 2021 | LEI | RU, TUD |
| SHARE | (TS-CS) | 2020 | UT | |
| Serenity | (TS-CS) | 2021 | UT | TU/e |
| Upin | (TS-CS) | 2021 | UT | UvA |
| Medusa | (TS-HTSM) | 2021 | TU/e | |
| Smart Two | (TS-HTSM) | 2021 | TU/e | |

## H2020 / HORIZON

| | Duration | Name | Universities (S/P*) |
|---|---|---|---|
| H2020-SU-RIA | 2019-2022 | Concordia | UT (P) |
| H2020-ICT-RIA | 2019-2022 | IV4XR | UU (P) |
| H2020-SU-RIA | 2020-2023 | ASSURED | TUD (P) |
| H2020-SU-RIA | 2020-2023 | AssureMOSS | TUD (P), VU (P) |
| H2020-ICT-IA | 2021-2023 | CoRoSect | UM (S) |
| H2020-SU-IA | 2021-2024 | IRIS | TUD (P) |
| Horizon-AG | 2022-2025 | Openwebsearch.eu | RU (P) |
| Horizon-AG | 2022-2025 | TANGO | TUD (P) |

* S = Secretariat, P = Participant

Abbreviations Dutch Universities:

UU = Utrecht University

CWI = Centre for Mathematics & Computer Science (CWI)

MU = Maastricht University

OU = Open University

RU = Radboud University

UG = University of Groningen

TUD = Delft University of Technology

TU/e = Eindhoven University of Technology

TiU = Tilburg University

UvA = University of Amsterdam

LEI = Leiden University

UT = University of Twente

VU = Free University Amsterdam

WUR = Wageningen University & Research

**CREDITS**
Dutch version November 2022
English version May 2024

**COMPUTER SCIENCE**
ICT Research Platform Nederland (IPN)
Post Box 93460
2509 AL The Hague
The Netherlands
ipn@nwo.nl

**PHOTOGRAPHY**
iStock Photo unless noted otherwise.

**BASIC DESIGN OF WAT ONTWERPERS**
Layout: IPN|NWO