Estonian Research Council

TARGETED EVALUATION OF IT ACADEMY PROGRAMME ICT SCIENCE SUPPORT MEASURE

Evaluation report 2023

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1.

INTRODUCTION

The objective of this report is to provide an overview of the outcomes of the targeted evaluation of the IT Academy programme ICT science support measure. This targeted evaluation encompassed the three higher education institutions involved in the IT Academy: The University of Tartu; Tallinn University of Technology; and Tallinn University. The IT Academy is a cooperation program between the Estonian state, universities, vocational schools and information and communication technology (ICT) companies which aimed to improve the quality of ICT-related education, to develop research in the field and to ensure the ongoing availability of the required labour resources.

Pursuant to the Organisation of Research and Development Act §20², the Ministry of Education and Research has the right to organise targeted evaluations for preparing field development plans (which guide research and development or other research policy decisions and measures) and to assess and analyse their impact. The purpose of targeted evaluation is to provide expert feedback to a variety of stakeholders, including researchers, positively evaluated research and development institutions, research funding organisations, research and development and higher education policy makers, and the wider society.

Pursuant to the Minister of Education and Research's Directive No. 1.1-2/22/348, the evaluation process of the IT Academy programme ICT science support measure was facilitated by the Estonian Research Council (ETAG). Also pursuant to the Minister of Education and Research's Directive No. 1.1-2/22/348, the targeted evaluation concerned the field of natural sciences and technology within the Estonian Research Information System, within which sit the subfields of computer science and information and communication technology. The targeted evaluation concerned the volume, level, sustainability and impact (including the impact on higher education) of Estonian research and development, in the fields of computer science, and information and communication technology, as compared to internationally recognised level. The effectiveness and impact of the IT Academy's ICT science support measure was also evaluated. The evaluation focused on the seven priority areas of the ICT research measure of the IT Academy programme. These priority areas were: Artificial Intelligence and Machine Learning; Data Science and Big Data; robot-human collaboration and Internet of Things in industrial processes; software reliability; Internet of Smart Things;

security and reliability of hardware and systems; and digital transformation and lifelong learning. The evaluation period covered the years 2018-2022.

The targeted evaluation involved a peer review process. The Evaluation Committee based its assessment on both the reports provided by the evaluated institutions and the information gathered during site visits. Prior to the evaluation, the Evaluation Committee was provided with the field overview compiled by ETAG. The overview addressed the ICT research and development activities in Estonia as a whole and included an overview of ICT research and development activities beyond the evaluated institutions.

The Evaluation Committee visited Estonia from the 3rd-5th October 2023. During this period, site visits were made to each of the three evaluated universities. The University of Tartu was visited first, on 3rd October 2023, followed by Tallinn University of Technology on 4th October and Tallinn University on 5th October. During these site visits, the Evaluation Panel toured the facilities of each university, and had meetings with university administrators, senior managers and research staff.

During the evaluation process, the following steps were taken to ensure the quality of outcomes:

1. Six meetings of the Steering Committee were held, to discuss the methods of evaluation and procedure, and the content of the field overview, and to select the Expert Panel. At these meetings, the Steering Committee also reviewed the expert evaluation report, and prepared the answers to the questions in the Minister's directive.
2. An Evaluation Committee briefing was conducted by ETAG to introduce the current state of R&D evaluation in Estonia, to explain the aim of the IT Academy programme ICT science support measure targeted evaluation, and to outline the organisation of work within the Evaluation Committee. At this briefing, the Evaluation Committee also elected the Chair and Vice Chair.
3. A coordination meeting was held prior to the site visits, to draft the agenda and to select people for interviews.
4. A meeting was held between selected members of the Steering Committee and the Evaluation Committee to discuss the focus of the evaluation and to respond to questions from the experts.
5. Site visits to the evaluated institutions took place over three days (see above).
6. Minor revisions of the evaluation report were made, based on the recommendations of the Steering Committee.

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2.

EVALUATION COMMITTEE'S EVALUATION

2.1. University of Tartu evaluation

ICT research in the institution

ICT research of the institution in priority areas

The University of Tartu (UniTartu) is Estonia's largest university founded in 1632. Currently, UniTartu has around 14,000 students and about 3,500 employees. It is the only Baltic University within the top 1% of the world's most cited universities.

UniTartu is organised into four faculties and 31 institutes of which two, the Institute of Computer Science and the Institute of Technology, received support from IT Academy (ITA) funding. Information has been provided for these two institutes, for groups working on themes of the priority areas, both for groups supported by ITA and on research topics led by groups that, while not directly funded by the IT Academy, operate within its priority areas.

The Institute of Computer Science (UniTartuCS) is a research and education centre covering major aspects in the field. UniTartuCS has more than 330 employees and around 1400 students. Over 50% are international staff. Work is organised under six chairs – Programming Languages and Systems, Data Science, Software Engineering, Natural Language Processing, Distributed Systems and Security, and Theoretical Computer Science. Also, both the university-wide consortium and the national centre for scientific computing (HPC) are hosted at the institute. At UniTartuCS, ITA funding-supported capacity-building is mainly in three areas: a) AI and Machine Learning, b) Data Science and Big Data, and c) robotics and IoT. Group leaders were recruited on tenure-track positions, and the groups' cores were built up in the expertise gaps. As a result, new groups working in these areas have been established.

The Institute of Technology (UniTartuTech) is a multidisciplinary research institution that provides education in computer engineering, robotics, electronics, embodied intelligence, biosciences, and environmental technologies. UniTartuTech has more than 170 employees and around 400 students. Only a part of this Institute was evaluated; according to the provided material this Institute was the recipient of one-sixth of the UniTartu ITA funding. At UniTartuTech, the ITA funding supported establishing a full research group in motion planning for human-aware autonomous systems.

a) Research quality

The university is very strong in some of the priority areas, and in particular in process improvement and bioinformatics in the priority areas of Data Science and security.

The university was the recipient of two European Research Council grants, the ERC Advanced grant PIX (The Process Improvement Explorer, 2019-24, led by Prof. Dumas) and the Consolidator Grant CerQuS (Certified Quantum Security, 2019-24), led by Prof. Unruh.

The level of publications is very good. A quarter of publications are among the top 10% internationally. During the considered period, 21 European H2020 grants were received, for a total of 12 million euros over 5 years, showing an intense level of international collaboration.

In artificial intelligence and Machine Learning new groups have emerged, and the research and teaching capacity has increased significantly. The research groups range from basic research (e.g., uncertainties of Machine Learning, neural networks) to applied research and experimental development (e.g. ML in bio- and health informatics, natural language processing, AI in education, music, process management etc.). In general, the fundamental research appears to be in an initial development phase in AI/ML areas, while it is very well developed in application areas. The research in NLP in particular (which is not only limited to the Estonian language), is very good and also focuses on fundamental research.

Research groups in Data Science and Big Data range from more fundamental research to applying Data Science and Big Data research in health informatics, managing electrical systems, logistics, sociotechnical systems, music, language models etc. They have managed to establish and grow the Big Data systems group, human agent-centric AI group, and increased security research groups. In general, the research in Data Science and Big Data appears to be oriented towards application areas, and in security, it focuses mainly on cryptography with very good results and also on applied cybersecurity.

The output of the research is very good and world-leading in the areas of Software engineering and information systems and Bioinformatics.

In robotics and IoT, the workgroups of distributed and pervasive computing, mobility modelling, autonomous driving, collaborative robotics, extended reality, and mobile and cloud computing have emerged and grown. The autonomous driving research focussed on real world trials and collaborations with the end users (Bolt, and the municipality), however the sustainability of the core research group beyond the immediate results with database curating and end-user engagement needs to be considered. The collaborative robotics have addressed core research ideas that are more scalable and evidently broader in scope, with excellent research outputs and international collaborations.

b) Sustainability

Although the groups working in AI/ML and Data Science and Big Data are successful, there is a lack of focus on core AI / ML research and they specialise on applications. In the long run, this might be problematic for sustainability since they might start to lack the background for developing new advanced research skills in these areas.

There is an unbalanced ratio of external funding in groups and this might impact the continuity of the teams. As an example, in the area of security, a leading researcher, one of the ERC recipients, is moving to another university.

While there is a good level of collaboration across the research groups, some groups base their activities on projects led by other groups. It would be important for the research groups to base their operations on core scientific expertise, vision and mission and carefully planned collaboration to support their goals and the common larger-scale goals. From the sustainability point of view, small groups and highly overlapping groups can be challenging. Sustainability can be improved by combining research groups into larger research units capable of building more momentum and achieving a higher impact.

c) Impact outside research

Collaboration with industry is well organised and involves leading industries, such as Bolt, Cybernetica, and Revvity, and collaboration with the Ministry and public administration, as in the case of precision medicine. Several projects are funded by companies, also involving PhD students. Several courses are offered, both of general interest, and on the themes of the different research groups. UniTartuCS opened a new curriculum on Data Science in 2020. An industrial Master's programme is offered, with students conducting structured internships and Master's projects at companies.

Positive aspects

The University of Tartu has strong research groups already working in some of the priority areas. New research directions have been initiated with funds provided by the ITA programme.

In general, most of the evaluated research activities related to the priority areas are developed within UniTartuCS. Besides classical computer science subjects, UniTartuCS excels in interdisciplinary research into bio- and health informatics, computational neuroscience, business operations, smart and sustainable mobility, autonomous driving, NLP, quantum cryptography, etc. They have systematised the knowledge transfer activities and collaborations with industry from lightweight to advanced forms of collaboration, enhancing the two-way knowledge transfer between UniTartu and companies/public sector.

The success in receiving additional funding, with two European ERC projects and a large number of research grants, is considerable. There are major R&D collaborations with companies. In UniTartuTech, the research evaluated was only within the ITA funding umbrella, with activities mainly in robotics (Collaborative robotics group). Excellent infrastructure in HPC has been developed and is available for research activities. There appears to be a strong utilisation of the available resources.

Areas of development

Some general challenges are encountered in the development of research activities, in particular in recruiting, both at the professor and PhD level. To reach the general goal of supporting the development of activities in the national priority areas, efforts should be made to decrease both the significant dropout rates at all study levels and the duration of PhD studies, which is currently around five to six years. In addition, the low percentage of Estonian PhD candidates is also an impediment to retaining new graduates in the country. Without PhD graduates fluent in Estonian, universities cannot fulfil the national obligation to conduct bachelor's studies in Estonian.

Activities should be promoted to increase collaboration across groups beyond the participation in common projects. Activities appear to be fragmented and could benefit from systematic forms of collaboration. Examples might include Special Interest Groups, PhD summer schools, national workshops or grant networking events.

The development of strategic research plans should be encouraged in general, and in particular in those areas which are currently well developed but probably will also need to follow new directions due to new international research developments, such as, for instance, in NLP research. A departmental strategy should be developed, defining objectives for research

evaluation and establishing key performance indicators.

The quality of publications, with some notable exceptions, seems to be at a medium level of ambition. Given the amount of activity in the most active groups, they should set as a priority the targeting of major conferences and journals in their domain of interest.

In some areas, the size of the groups is limited and new resources in terms of new researchers are needed. In particular, the cryptographic group is in a critical situation. A roadmap should set the directions of development in these cases, e.g. applying for grants in post-quantum topics.

Recommendations

To avoid dropouts, in particular in PhD studies, the PhD salary should be increased to favour the completion of those already enrolled, instead of looking for a higher number of admitted candidates. Both the dropout rates and the length of studies should be lowered. Higher salaries should also increase the attractiveness of PhD positions in comparison to industrial jobs.

The stated goal to increase the PhD intake to 30 positions per year in computer science and 10 positions per year in robotics to guarantee a sufficient number of scientists and lecturers for the next generation seems difficult to achieve in the current situation, so the reduction of dropout rates should rather be pursued, by providing satisfactory salary levels and a reasonable completion time (four years or less).

The use of AI/ML in all the CS chairs is pervasive. Actions should be taken to provide a common level of background knowledge for all involved, to increase synergies among groups, to develop an institutional strategy in this area to reduce replication, and to identify research priorities in tune with state-of-the-art international trends in the field.

Research strategies on security and cryptography should also be defined and supported.

Note: Sasu Tarkoma declared a conflict of interest with the Distributed and Pervasive Systems group due to some coauthored papers and therefore did not participate in the evaluation of the group.

2.2. Tallinn University of Technology evaluation

ICT research in the institution

ICT research of the institution in priority areas

The Tallinn University of Technology (TalTech) School of IT employs a total of 347 staff members, which includes 236 academic staff members and 74 junior researchers who are PhD students with formal employment contracts. The school is currently responsible for educating around 3000 undergraduate ICT students and over 100 PhD students. The School of IT has five departments. Each department brings together research groups with similar focuses, resulting in a total of 26 research groups within the School.

As a result of the IT Academy (ITA) programme, the School has successfully established two new research groups in priority areas which were not sufficiently covered before the inception of the programme. These are the Centre for Hardware Security, led by Professor Pagliarini, and the Lab for Compositional Systems and Methods, led by Professor Sobociński. Furthermore, the ITA programme has led also to the development of a new virtual IoT competence centre for the Internet of Smart Things research field, led by Professor Kuusik, based on six selected laboratories and research groups to fulfil the objectives of the IT Academy Internet of Smart Things project, focusing on embedded (edge) Machine Learning topics, which was a novel research direction for TalTech.

The ITA has also resulted in new PhD student positions for the involved groups. A competitive allocation of funds for PhD positions was performed, based on proposals from the research groups. TalTech has defined six priority R&D areas (taltech.ee/en/objectives): Smart and energy-efficient environments, Dependable IT solutions, Innovative businesses and future governance, and Health technologies; all ITA research fields are well aligned with these areas. In addition, in 2021 TalTech established the EDIH AIRE (European Digital Innovation Hub – AI & Robotics in Estonia). AIRE is the only EDIH in Estonia; it is coordinated by TalTech and includes two other universities, two science parks and an applied research centre.

a) Research quality

The university reports a significant volume of scientific publications in the ICT area with many groups having an excellent or very good level of high impact publication. Concerning the ITA impact, 281 publications have been reported.

Overall, the publication forums could be more ambitious, choosing the respected top forums of the scientific communities. For example, multiple MDPI journal and IEEE Access publica-

tions were reported as highlights, although more ambitious and highly rated forums in the different research areas would have been appreciated.

Good research results have been presented by the Nonlinear Control Systems group, Information Systems group (with a significant reputation for Estonia research in the area), Lab for Compositional Systems and Methods, Centre for Environmental Sensing and Intelligence, Center for Dependable Computing Systems, Centre for Biorobotics, in particular in the field of underwater robotics, Communication Systems Research Group, and the Center for Hardware Security.

The IoT Competence Center should be commended as a good institutional strategy responding to the need to create synergies among groups and to cope with difficulties in recruitment. The university, with the support of the ITA funding, has been building up competence in the areas of Digital Forensics and Cyber Security. The ITA programme has also been pivotal in fostering interdisciplinary collaboration. Some significant international recognition has been achieved, such as the 2022 Kleene Award in Logic in Computer Science and the first place in world leading Hardware IP Protection competition, sponsored by Intel (HeLLO: CTF 2022). One spinoff company has been reported as a result of the ITA. It would be good to see more activity in this area in the future.

b) Sustainability

The ITA programme has helped grow external research funding from 5.6M euros to 10.3M euros and contracts with industry are increasing (49 new contracts since 2020). However, the project-based orientation could be risky in the long run, as it is reportedly hard to obtain funding in Estonia. TalTech priority areas are well coherent with the University Strategic plan. On the other hand, sustainability in the long term is a question. A clear path to improve research quality and ambition level should be defined as a strategy to obtain new funding based on research excellence.

c) Societal impact outside research

The ITA programme has been vital in providing synergy with other initiatives due to significant growth of capacity in all ICT research fields, thus enabling more beneficial collaboration with industry than before.

Several large-scale knowledge transfer events have been organised, e.g., the Innovation Festival. Transfer of knowledge to industry has been successful, in particular in the fields of energy efficiency, embedded AI, cyber security, and e-governance. Initiatives have been started to export the e-Estonia research results through training, including the unique M.Sc. programs on cybersecurity and e-governance. One spinoff emerged from the IOT Competence Center.

Positive aspects

The programme goals have been very well achieved. New research groups are active in topics such as quantum software and quantum-safe security, software reliability methods for safe and trustworthy AI, and applied aspects of hardware security. The research output, international visibility, and ability to attract external funding has grown across the School (R&D revenue grew from 5.6M to 10.3M euros between 2018 and 2022). The new research groups are internationally well recognised and additional PhD students have enabled the existing research groups to become more competitive. The new research groups have already demonstrated their ability to attract external national and international funding and the IoT Centre has been selected as one of the key partners in the Estonian Fair Transition programme.

The ITA programme also helped to widen the cooperation with municipalities, and with state and public institutions, and has opened up possibilities for free / reduced cost consultations in programme-related R&D topics. Collaboration with industry across the School has increased in the period under consideration.

The EU Innovation Hub on AI & Robotics in Estonia, coordinated by TalTech and including two other universities, two science parks and applied research centre, provides opportunities for consulting, training, networking, and most importantly, finances test-before-invest pilot projects to transfer universities' research outcomes to the industry. By the end of 2022, 17 companies have benefited from this pilot support scheme with ambitious growth goals for the coming years.

Areas of development

General challenges concerning the difficulty of recruiting both staff and new PhD candidates are present also at TalTech. To achieve the general goal of supporting the development of activities in the Estonian national priority areas, efforts should be made to decrease the duration of PhD studies, which is currently around five years (decreasing) and to provide high salary levels for all hired PhD students to increase their completion rates.

Artificial intelligence and Machine Learning and Data Science and Big Data are considered mainly as horizontal topics and are present in most if not all the research groups. As a consequence, research related to these areas is mainly applied and attention to fundamental research is lacking. In particular, some groups are acting mainly as knowledge transfer facilitators (e.g., the Applied AI and Embedded AI Research Lab which is focusing its attention mainly on problem solving activities). There is a need to define some unique directions characterising the institutional strategy and also in the direction of developing new original topics in these areas. Research collaboration between groups should be encouraged with a focus on core scientific problems rather than applied projects.

Recommendations

During this period, TalTech has developed cutting edge research in the nationally prioritised direction of a horizontal and broad use of IT. However, the focus of research is on a broad variety of application areas and a better focus on basic research questions and fundamental research could be beneficial to maintain a competitive advantage in the priority research areas at an international level.

Research leadership should be further developed and encouraged in the research groups, specific training programs should be provided, and the contribution of PhD holders to the research programme development should be valued. Some research development programs (e.g., for building up skills for writing EU ERC grants) could help increase the quality of research ambitions. During the discussion, it emerged that structural support for IP negotiations and developing more customised contract models could be beneficial for all groups.

2.3. Tallinn University evaluation

ICT research in the institution

ICT research of the institution in priority areas

ICT-related academic activities at Tallinn University are conducted primarily in the School of Digital Technologies (DTI).

Tallinn University was involved in the IT Academy programme in a later stage, in 2019, with a focus on a single priority area, Digital transformation and lifelong learning. For the ITA programme implementation, the university made a strategic decision to open a new group in Digital transformation and lifelong learning (DTL3), which was started in 2020. The group belongs to the Applied Informatics academic direction. Digital transformation is a key anchor for the ITA-related activities at Tallinn University. The aim has been to connect the research groups in relevant areas for synergies in research and societal impact. The closest cooperation is with research groups of Technology Enhanced Learning (TEL) and Human-Computer-Interaction (HCI) academic directions, both included in the self-evaluation report.

In the Development Plan of the University for the years 2023 to 2027, digital and media culture were declared as one of the focus fields of the University. One of the assets of the research on these themes is the development of educational software, which has been encouraged and successful over the years. Research in gaming technologies is also performed within this scope, but it has been left out of the evaluation since it is not one of the ITA priorities.

a) Research quality

The groups demonstrate a good publication level, in particular on the topics of trust, teaching analytics, and digital creative arts. Some European projects have University of Tallinn as a coordinator, in particular EU project MODINA and H2020 iHub4Schools project. However, research is more oriented towards evaluating the impact of using IT in different areas (e.g. education) and in developing educational tools rather than on developing innovative advanced research within these fields.

b) Sustainability

The funding of the groups is based on small grants and projects. As a consequence, research directions are strongly dependent on these, and as a result they are not always very clearly defined.

c) Impact outside research

Collaboration outside the universities is mainly with non-academic public institutions (e.g. hospitals, schools, and municipalities) rather than with industry. Cooperation with industry concerns policy definition, teaching and course activities by industry experts, co-supervision at Master's level, and involvement of industries in projects. Workshops are held with industry, collaborating for instance with the national manufacturing association. There is some active collaboration with learning technology companies. No evidence for the creation of startups or other entrepreneurial activities has been provided.

Positive aspects

The DTL3 research group was formed formally only in 2021, and so the impact on the growth of innovation capacity of the Estonian economy and society is currently relatively small. However, despite this the group shows fast growth.

The scope of the school's research activities has been significantly expanded with the help of the ITA research initiative. Previously, the focus of the school was primarily the digital transformation of educational institutions. A specific focus has been identified on Digital technologies in the manufacturing industry, in particular for SMEs and creative industries. However, several other topics are being considered, without a specific focus having been identified. Across the different groups the understanding of learning processes and the use of motion capture and biosensors are themes that characterise the research.

The groups have effective bottom-up practices for supporting the sharing of best practices, supervision, and for collaborating on research related matters through meetings and workshops. The collaborative planning and information sharing could be made more systematic. The adoption of the "Tallinn University Institute of Digital Technologies cooperation strategy with companies and institutions" activated a systematic cooperation with private and public sector institutions, although its implementation is still under development. The school has pioneered online education in the form of the first online degree programme in Estonia and the development of microdegrees (around 20 ECTS credits long).

Areas of development

An area for development concerns the increase of focus on core scientific contributions, not only on applied research or knowledge transfer.

The research groups have a strong track record for developing tools for research and to support industries. While the development of tools for the common good is commended, tool development should be better focussed to address scientific goals and basic research

questions. The level of ambition in research and grant applications should be raised, with the aim of publishing in top level international venues. The PhD supervision load is somewhat uneven among the involved professors and a strategy to solve current load balance issues should be pursued.

Recommendations

The ICT activities would benefit from a clear and focussed roadmap with long-term vision involving the research groups and degree programs. On a research group level there are excellent opportunities for collaborations, however coherence and focus are essential for advancing the level of scientific excellence.

A strategy to consolidate and pursue emerging prominent research directions without losing focus should be developed. More attention should be paid to PhD duration, which is currently around six years, although the recent changes in PhD regulations should help reduce this. Sufficient time available for developing research should be granted to the PhD candidates without distraction from teaching or project commitments; while some actions are already in place, they should be further developed. Some attention should also be paid to lowering the dropout rate at PhD level. Special attention should be paid to the career management programs being developed at university level, also to consolidate good practices and increase collaboration among groups in the future.

3.

ASSESSMENT OF ICT RESEARCH IN PRIORITY AREAS

3.1. Priority area: Artificial Intelligence and Machine Learning; Data Science and Big Data

Of the groups submitting for assessment, 38 list AI/ML as a priority area, 16 of these jointly with Data Science. These are clearly strongly cognate activities, and this report will treat them jointly.

a) Research quality

UniTartu role: There are groups focussing on core AI/ML/Data Science in the areas of Machine Learning, Soft Computing, Natural & Artificial Intelligence, Data Systems, High Dimensional Deep Learning and Natural Language Processing. Additionally, groups encompassing applications are focussed on Software Engineering, Information Systems, Biomedical Computer Vision, Computational Music, Bioinformatics, Intelligent Transportation, Distributed Computing and Autonomous Driving. Work in the Bioinformatics and Information Technology Group is notably strong, with impressive contributions in gene-profiling, bioinformatics and a very promising newly established group in genomics. Another research high point is the ERC Advanced Grant PIX, which is exemplary in raising the institution's profile.

TalTech role: There are groups focussing on core AI/ML/Data Science in the areas of Embedded AI, Data Science, Information Systems and Natural Language Processing. Additionally, groups encompassing AI/ML/Data Science applications are focussed on Intelligent Systems, Biorobotics, Environmental Sensing, Efficient Computing Hardware, Next Generation Digital State, Digital Forensics, Nonlinear Control Systems, High Assurance Software, e-Health, Human Centric Computer Systems, and Applied Cyber Security. Two groups (Digital State and Information Systems) combine work in AI/ML with the Digital Transformation priority area to achieve significant results with impressive levels of private sector funding. The Data

Science group achieves some good quality research outputs at the intersection of AI/ML and Data Science. In the Applied Artificial Intelligence Group, there is some good core work on automated reasoning, but there seems to be a dichotomy between this and the applications oriented project work which produces limited published output. However, overall there seems to be very little forward looking fundamental research, even in the groups where AI/ML is the core focus.

Tallinn University role: There appears to be no significant activity under the AI/ML and Data Science headings.

One characteristic of the three institutions is that they differ strongly in terms of focus and ethos. UniTartu appears to have stronger commitment to core research, TalTech is applications oriented, while Tallinn University is focussed on human-centric computing. One observation underpinning this large body of research is the degree to which AI/ML are now being used in data intensive applications. This is not surprising given the massive global interest in the use of ML, and the impressive recent successes provided by these technologies. Broad areas illustrating this in the above portfolio include natural language processing, health informatics, bioinformatics, neuroscience and e-health.

b) Sustainability

Despite this success in the application of ML/AI in data-intensive domains, there is a noted lack of core research into fundamental aspects of AI/ML resulting in high profile publications in leading journals. This applies to some extent to UniTartu and to a much greater extent to TalTech. This raises questions concerning the sustainability of this research area. This is highlighted by the listed outputs and thesis topics of graduating PhD students. In fact, there are very few publications appearing in core AI/ML journals and selective conferences. There is a need to raise the profile of AI/ML in Estonia through publications in high profile journals and conferences, and through focussing on some core areas of fundamental research.

Another area of concern is the completion time and completion rate for PhD studies. In some cases, the completion times can be as high as five to six years, with completion rates falling below 70%. One commonly cited reason for the high dropout rate appears to be competition with salaries in the private sector. While there have been some institutional efforts to increase the stipend and security of tenure of PhD students, these do not yet seem to have had a tangible impact on these completion numbers.

An action which could improve the profile and sustainability of AI/ML research would be a clear national strategy which identifies priorities in the AI/ML domain, both in terms of application areas and directions for fundamental research, with the goal of achieving a

balanced nationally funded programme with clearly identified priority areas. For instance, at the moment, there is a very limited amount of fundamental work on generative AI, large language models, graph neural networks and other critical technologies, and these should be priority areas. This could be achieved through ETAG or other national funding bodies setting aside funding for a targeted programme in this area. This is not currently achieved through ITA funding, which is distributed at the discretion of individual institutions.

One point that was raised repeatedly in the interviews is the lack of ambition in terms of publications and applications for external funding. One source of externally funded programmes which would support high-quality long-term research and substantially raise the profile in this area is the ERC. Encouraging and supporting suitably qualified staff to apply for such grants could underpin a national strategy of improving the quality and reach of research in this area.

c) Societal impact outside research

UniTartu role: Work on algorithmic bias, assistive healthcare robots, ethical impacts of AI, and standardisation of explainability in AI, gene profiling and COVID tracking have all had significant societal impact. The work is based on strong collaborations with various stakeholders including industry and healthcare providers. Courses have been presented in a wide range of topics including computational neuroscience, computational imaging, Big Data management, neural networks, bioinformatics and Machine Learning. These are available at a variety of levels and seem to provide a good state-of-the-art coverage of the field.

TalTech role: Work on speech recognition, underwater computer vision, underwater sensor deployment, and automatic language captioning have had notable societal impacts. There is strong collaboration with industry, with many industry-funded projects leading to imaginative and enterprising applications of AI/ML and Data Science in a diverse set of domains. There are a number of course offerings covering topics broadly in the AI/ML/Data Science area, including several on the various aspects of robotics and control. However, there seems to be relatively little focus on recent developments in deep learning and recent trends in Machine Learning.

Tallinn University role: NA

Positive aspects

The various groups are to be commended on their agility and enterprise in obtaining funding for a diverse and relevant set of applications of AI/ML/Data Science within the prevailing Estonian economic context. This is highlighted by their engagement with applications involving fisheries and oceanic work. There are also some research highlights in the Machine

Learning, bioinformatics and data-science domains with high profile and high impact publications. Another high point is the award of an ERC Grant.

Areas of development

Although there is fundamental work in AI/ML/Data Science, overall, the bulk of activity is focussed on applications, and this area is viewed as one providing horizontal support for a large number of rather disparate research groups. Overall, to increase sustainability there needs to be a greater focus on core methods, aligned with current and emerging developments in the area, and internationally competitive in terms of its novelty, originality and rigour. This needs to be linked to greater ambition in terms of the publication venue for the resulting research outputs.

Recommendations

Given the large number of groups claiming to work in the AI/ML/DataScience area, there needs to be a greater coherence in planning their joint activities to achieve maximum effect. This could take the form of a national strategy for priority areas in research and knowledge transfer, together with designated and targeted funding. The IT academy could provide a conduit for some of these activities.

Other general comments and recommendations common to all priority areas are listed separately in the report under ICT targeted evaluation: general recommendations on all areas.

3.2. Priority area: robot-human collaboration and Internet of Things in industrial processes; Internet of Smart Things

Robotics and Autonomous Systems, Human Robot Collaborations and IoT of Smart things were flagged with overlapping keywords by 8 groups at TalTech and 10 groups at UniTartu (including the documents provided as Addendum without direct support from ITA). Significant emphasis across both institutions has been on urban mobility, smart cities, and environmental monitoring, as well as on underwater robotics with novel sensing technologies.

a) Research quality

UniTartu role: Most of the Robotics and Autonomous Systems focus comes from the groups hosted in the Institute of Technology, with co-location with the groups associated with the Institute of Computer Science. The Autonomous Driving group is relatively young and ambitious and has achieved some excellent results based on industrial collaborations and significant funding from the likes of ride sharing company Bolt. PI Naveed and research lead Matiisen have developed some interesting projects that sit at the interface of proof-of-concept demonstrations relevant to the industry and autonomy stack development for mobility vehicles at different scales (cars, scooters etc.). An excellent example of use of ITA funding for the retention of promising talent is the hiring of PI Mozhgan Pourmoradnasseri to start up the Mobility Modeling group. In collaboration with PI Hadachi, this is an exciting niche of activity in areas that can be used to exploit the digital infrastructure in Estonia, as well as create impact in monitoring and influencing policy in real-time traffic control, urban mobility and public transportation. The established group of PI Singh (AKS lab) works on core algorithmic research into robot control and planning in unstructured environments with a focus on resource constraint methods. This group has an excellent publication record in good venues (IROS, ICRA, RAL, IJCNN) and good impact (for example in delivering goods in cluttered human centric environments such as hospitals). The group has an excellent track record of grants from Estonian Research and industry. The reviewers have been particularly impressed with the strong collaborations with international teams in the group across US, Europe and Asia, which multiples its impact. PI Kruusamae leads the Robotics at IMS with a good record of EIT projects that form the backbone of the funding.

TalTech role: The Centre for Biorobotics continues to be one of the leading groups in the university in the domain of Robotics and Autonomous Systems and novel sensing technology, with a very strong international presence and research footprint, along with the newly established Centre for Environmental Sensing and Intelligent Sensing, that provides significant added capacity in the domain of Internet of Smart Things through their focus on novel modalities of distributed sensing. PI Kruusmaa has a world leading research portfolio

of research grants (at EU and National level). In general, there is a very strong record of EU and private funding. There is significant evidence of demonstrable impact in key domains of sustainability and environmental monitoring as well as robots in extreme environments. There is evidence of research quality and international visibility. Evidence of research quality and international visibility is also shown by attracting world leading and active researchers and PhD students from countries like Japan. The Centre for Intelligent Systems, under PI Pentlekov, continues to do good work in the domain of complex control systems, with some specific focus on advanced fractional order modelling, mostly under the umbrella of reducing energy footprints in commercial and domestic settings. The framework remains quite traditional and classical, which enables good collaborations with established automation and large infrastructure companies. This cluster of activity had a good mix of national, international, and private funding.

The Internet of Smart Things priority area encompasses several research groups, including the Laboratory of Proactive Technologies led by PI Kaugerand. This laboratory focuses on smart environments, with a special emphasis on proactive systems. A key accomplishment of this group is the implementation of a city-wide sensor network, which provides critical data on air quality, noise levels, and traffic patterns.

To further enhance the publication activity of the group, it is recommended to develop a systematic publication strategy. This strategy should include a thorough selection process for publication forums, ensuring alignment with the group's research focus and the intended audience. By strategically choosing where to publish, the group can increase its visibility in relevant academic and professional communities. Additionally, the group's efforts in organizing significant events like the IEEE CogSIMA conference and a symposium on Situation Awareness are commendable. These activities not only contribute to the group's stature in the academic community but also provide valuable platforms for disseminating research findings and fostering collaborations.

The Centre for Dependable Computing Systems, under the leadership of PI Raik, has established itself as a leading entity in the field of computing systems dependability, with a particular focus on hardware security. This group is actively engaged in several EU projects, demonstrating a strong commitment to collaborative research and innovation at the international level. Their impressive track record includes the successful guidance of numerous PhD candidates to graduation, alongside notable technological advancements. These advancements encompass the development of a mixed-signal integrated circuit and significant contributions to open-source software, showcasing the group's diverse expertise and capacity for innovation.

A standout accomplishment in the group's research portfolio is their pioneering work on incorporating Intellectual Property (IP) protection within FIR filters. This significant research

has been recognised through publication in the prestigious IEEE Transactions on Very Large Scale Integration (VLSI) Systems' journal. The Centre's ability to produce high-impact, practical solutions in the realm of dependable computing systems positions it as a significant player in advancing the field.

The Communications Systems Research Group, under the leadership of PI Alam, stands as a prominent contributor in the realm of radio communication technologies, with a special focus on advancements in 5G and subsequent technologies. The group has been crucial in developing the university's experimental 5G cellular network, marking a significant milestone in practical telecommunications research. Moreover, their leadership in major EU projects, including 5G-TIMBER and LATEST 5G, underscores their pivotal role in shaping the future of 5G technology at both the national and international levels.

This group's research initiatives have yielded considerable achievements, such as filing a patent application and contributing to the standardization efforts of the European Telecommunications Standards Institute (ETSI). These efforts are further supported by their extensive publication record in prestigious journals, including IEEE Transactions. Additionally, the group has successfully mentored a notable number of PhD candidates to graduation during the evaluation period.

Tallinn University role: NA

b) Sustainability

UniTartu role: Several of the Autonomous Driving research groups have a rich stream of public private partnership funding that allows for sustainability of research and autonomy stacks. Proof-of-concept and real-world trials are carried out. There is a concern about how the long-term health of such funding will work, especially when this research becomes mature or the companies start developing most of the core work in-house. The ITS lab and the associated clique mobility modelling research has an excellent mix of industry focussed and core research funded programmes.

TalTech role: At the Centre for Biorobotics, PI Kruusmaa has mentored and helped develop independent leaders in the field including PI Tuhtan, who has directly benefited from some members of his group being financed through the IT Academy funding. This has led to the setting up of the young but extremely agile Centre for Environmental Sensing and Intelligence group, which has successfully collaborated across domains and groups within the university, especially harbouring collaborations in the domain of IoT of Smart Things through joint projects with the embedded systems related hardware groups.

Within the area of complex control systems, there is good evidence of mentoring and suc-

cession planning with senior researcher Tepljakov, as well as the establishment of a new research group of Nonlinear Control Systems under PI Belikov, which has benefited significantly from the ITA funding. The reviewers were impressed with the novel topic emphasis of 'energy informatics' and looking at deployment of theoretically well-founded methods for classical problems advocated through this group, especially for trustworthy XAI algorithms for the energy domain.

c) Societal impact outside research

UniTartu role: Impact is largely focussed around mobility research with several groups contributing to modelling, monitoring and delivery of autonomous mobility solutions for the smart urban city. Software stack Autoware Mini, which is being used for teaching, is an excellent example of using the output of research to develop the next generation of young researchers through evaluated and practical courses and student-led competitions as part of the undergraduate and postgraduate practicals. Robot deployment in cluttered and GPS deprived areas like hospitals was also a demonstrable impact with excellent visibility and coverage. Another impact comes from the development of digital twins for the City of Tartu. The Dashboard for the City of Tartu has been an excellent example of IoT research leading to practical deployable systems.

TalTech role: Much of the research (e.g., Centre for Biorobotics) has demonstrated significant impact in the area of climate and diversity monitoring in remote, inaccessible underwater domains (and continues to be deployed in harbours within Estonia, in Svalbard, Greece, the Arctic circle, Tallinn and the Bay of Riga), as well as on the effects of underwater currents and ship movements for harbour management. There are excellent initiatives towards commercialisation and tech transfer of developed technology and IoT sensors to domains other than underwater – e.g., city scale pollution monitoring. One of the key outputs/impact claimed by the Centre for Intelligent Systems is the open sourcing of some of their control frameworks (MATLAB toolboxes) with clear evidence of usage within the international community – providing demonstrable impact.

Positive aspects

ITA funding has been instrumental in helping grow certain areas within the Robotics and Human Robot Interaction as well as novel sensing and mobility modelling areas including contributing to retaining some promising researchers by providing them with faculty appointments, and by funding places for PhD students and research assistants. The groups have done an excellent job of finding appropriate niche research domains that exploit the strengths of Estonia's digital infrastructure to pursue targeted RAS research - this is particularly important since RAS research is very capital intensive and it is therefore prudent to focus on targeted domains.

There is evidence of cross disciplinary and cross group fertilization, especially in areas of IoT, environmental monitoring and embedded systems along with some work that leverages the excellent high performance computing facilities by several of the robotics and IoT groups. There is also significant buy-in from the industry on several of the projects being carried out in this space.

Areas of development

The reviewers felt that the institutions could aim higher with publication venues in the RAS and Internet of Smart Things domains. There have only been one or two groups in each institution which have tried to maintain a significant presence in large international competitive venues like ICRA, IROS, CVPR, IJCAI, RSS and disseminate in what are considered top tier journals like IJRR, IEEE TRO, RA-L, IEEE PAMI etc. Trying to build up a strong network and participating in significantly more collaborative EU projects will be useful not only to increase the visibility of the work but also to self-direct towards the range of topics and research domains where leadership can be demonstrated.

It would be good to see more effort and funding made available to ensure that PhD students and senior researchers spend more time (i.e. secondments, internships) in leading laboratories outside Estonia so that they can exploit and fill the gaps by doing hands-on projects with infrastructure that may be harder to procure or maintain within the institutions locally. This will create a virtuous circle that will increase collaborations as well as bring back best practices from outside the Baltic areas to benefit the next generation of Estonian researchers.

Recommendations

Specifically in the RAS domain, it would be good to see slightly more fundamental research in planning, sensing and motor control, with industry projects informing core scientific bottlenecks that should be addressed, in addition to a portfolio of proof-of-concept projects that directly address the high TRL levels (there are good numbers of these already).

In the RAS domain, other countries and regions have benefited from strategic grand challenge projects (which necessarily enable closer knit collaborations between research groups) to synergise and maximise existing resources and create outputs that can be more than the sum of their parts. It is a useful exercise to consider what the equivalent grand challenge themes would be for Estonian universities and how industrial co-funding could be recruited to address them, using consortiums that involve more than one group.

In the Internet of Smart Things priority area, several research groups are developing key experimental infrastructures, notably the city-wide measurement system and advanced 5G and beyond testbed. These testbeds are pivotal for interdisciplinary research and enhancing

national and international collaborations. Recognizing their value, we recommend the continued development and strategic expansion of these testbed activities. Additionally, refining collaboration mechanisms is crucial to maximise their potential and to foster effective partnerships. This focussed approach will ensure that the testbeds remain at the forefront of technological innovation and continue to serve as essential platforms for cutting-edge research in the field.

Other general comments and recommendations common to all priority areas are listed separately in the report under ICT targeted evaluation: general recommendations on all areas.

3.3. Priority area: software reliability; security and reliability of hardware and systems

Of the groups submitting a report for the ITA evaluation, six indicated the priority area of software reliability and seven the security and reliability of hardware and systems. There are no groups indicating activity in both priority areas. Software reliability is the sole priority for the Lab for Compositional Systems and Methods (TalTech) and the security and reliability of hardware and systems is the sole priority for the Centre for Hardware Security (TalTech). For software reliability, other groups have also included other priorities. All the groups included Artificial intelligence and Machine Learning and/or Data Science and Big Data as their priorities. For security and reliability of hardware and systems, the groups included Internet of Smart Things, artificial intelligence and Machine Learning, and/or Data Science and Big Data as their priorities.

a) Research quality

Based on the indicated priority areas, the software reliability and security and reliability of hardware systems form two clusters, both building significantly on Artificial intelligence and Machine Learning and/or Data Science and Big Data. Thus, AI and Machine Learning and Data Science with their data infrastructure provide an important methodological and computational basis for the two clusters. The research quality is on a very good level in both clusters. Several research groups at both universities indicated ERC-level ambitions with a track record in publishing at top forums.

ITA funding has been used to establish new research groups in the two priority areas. At TalTech, the Lab for Compositional Systems and Methods was established in the former priority area and the Centre for Hardware Security was established in the latter. At UniTartu, ITA funding supported capacity-building within the two priority areas.

In the software reliability cluster, collaboration across research groups is a rising trend, having significant impact and building on AI and Data Science as well as software capabilities. At TalTech, the new Lab for Compositional Systems and Methods is an example of thinking outside the box. At UniTartu, the software research groups demonstrate excellent research collaborations and synergies. The development and emphasis on open-source software and open results are commendable. The research groups connect education with the research, and research groups supervise M.Sc. theses in an organised manner.

For the security and reliability of hardware and systems priority area, the overall cluster directions emphasise hardware security related topics at TalTech and cryptography and Data Science related topics at UniTartu. Overall, cybersecurity is an interdisciplinary cross-cut-

ting activity with strong connections to the industry and the public sector. The research groups at TalTech demonstrate significant industry/government collaborations. Research carried out in the cluster is high quality, with highlights such as the new Centre for Hardware Security and the Centre for Biorobotics at TalTech and the ERC CerQuS grant at UniTartu in the cryptography area.

b) Sustainability

In all, the two clusters possess strong research focuses, particularly in the software and hardware sectors, alongside numerous smaller, independent research groups. However, the potential synergies within and across these universities are not fully realised. A general recommendation would be to encourage the formation of larger research groups and to foster inter-group collaboration to more effectively harness these synergies. Furthermore, the selection of publication venues would benefit from more strategic, long-term planning, aiming to raise the level of ambition.

TalTech's research groups boast substantial collaboration with industry, engaging in activities that are closely tied to innovation. While some industry projects lean heavily towards applied work and consultancy, there is a risk that they could divert resources away from scientific pursuits with the potential for high impact.

The cryptography area is in a state of change especially at UniTartu, and the sustainability of this important field is in need of further measures to ensure critical mass. To improve the quality and breadth of research, a strategic plan is essential, aimed at elevating the level of research excellence to attract new funding. The existing clusters provide a strong foundation for future developments, particularly in bridging software and hardware research domains.

c) Societal impact outside research

The ITA programme has played a crucial role in augmenting capacity across the two clusters, creating synergies with other initiatives and fostering more robust collaborations with industry partners than was previously possible. Many research groups demonstrate an applied focus with strong industry collaborations. It is essential to establish clear guidelines and mentoring processes to ensure that this applied research is grounded in fundamental studies and contributes to scientific publications. The cluster expertise is reflected in education, and ITA funding was used to support the joint Cybersecurity M.Sc. programme of the two universities. Integrating the M.Sc. thesis process with research activities and publishing related results would be particularly beneficial. This integration would not only improve the quality of scientific outputs but also increase their societal impact.

Positive aspects

At TalTech and UniTartu, the research clusters that are focussed on software reliability and the security and reliability of hardware and systems are well-aligned with contemporary technological trends, particularly in the domains of Artificial Intelligence, Machine Learning, Data Science, and Big Data. The robustness of these clusters is evidenced by the high quality of research output and their clear ambition to compete at an international level. The emerging application of AI and Machine Learning methodologies across both clusters is establishing a solid computational and methodological foundation that supports the institutions' research endeavours.

With the strategic allocation of ITA funding, TalTech and UniTartu have been able to expand their research capabilities through the establishment of new groups and centers, such as TalTech's Lab for Compositional Systems and Methods and Centre for Hardware Security, and the capacity-building measures at UniTartu. These developments are indicative of a continued commitment to advancing research within these priority areas. Additionally, the ongoing collaborations between these research entities and industry partners highlight the applied nature of the research being conducted, which maintains a balance between theoretical exploration and practical application.

Areas of development

Despite the significant strides in research at TalTech and UniTartu, areas for development remain, particularly in terms of maximizing the potential synergies between different research groups. The current landscape, characterised by numerous smaller, independent groups, suggests there is room for greater cohesion and collaboration. Enhancing these connections could facilitate a more integrated approach to research, potentially leading to breakthroughs that individual groups working in silos may not achieve. A more concerted effort towards fostering interdisciplinary collaboration and streamlining research efforts could also amplify the impact of the work being done, especially in fields that naturally intersect, like AI and Big Data, within the core research areas of software and hardware reliability and security.

The sustainability of these research clusters is another aspect that warrants attention. The rapid pace of technological change and the shifting priorities in the academic and industrial landscapes mean that continuous evaluation and adaptation are necessary. For example, PhD student recruitment poses a challenge, especially in the field of hardware security. The cryptography sector at UniTartu is experiencing changes, necessitating strategies to maintain and enhance the critical mass of expertise. Additionally, the balance between industry-led applied research projects and fundamental scientific inquiry needs careful management to ensure that both are pursued without one compromising the other. Sustaining the

momentum of high-quality research output, while nurturing the next generation of scholarly pursuits, is critical for maintaining the competitiveness and relevance of both TalTech and UniTartu in the global research community.

Recommendations

The priority areas would benefit from fostering interdisciplinary collaboration among the various research groups, which could significantly enhance the overall research output by tapping into the diverse strengths and perspectives of different disciplines.

The selection of publication venues would gain from being underpinned by a strategic, long-term approach that sets higher ambitions. The sustainability and development of dynamic fields such as cryptography at UniTartu would benefit from targeted support measures designed to nurture and retain expertise in these critical areas. A balance should be struck between applied, industry-led projects and fundamental research activities to ensure that the institution continues to contribute meaningfully to both immediate industry needs and the broader scientific community. Educational initiatives at both institutions would benefit from a closer integration with ongoing research projects, particularly at the M.Sc. level, to foster an environment where academic pursuits complement educational outcomes, enhancing the quality and impact of both. The attractiveness of the hardware security field could be significantly enhanced by increasing its visibility, emphasizing its importance in the digital landscape, and offering tangible incentives like scholarships and internships to potential students. Other general comments and recommendations common to all priority areas are listed separately in the report under ICT targeted evaluation: general recommendations on all areas.

3.4. Priority area: digital transformation and lifelong learning

Of the groups submitting a report for the ITA evaluation, 12 indicated the priority area digital transformation and lifelong learning, however only in three groups was this mentioned as the sole priority. In Tallinn University, the Digital Transformation and Lifelong Learning group (DTL3) was created as a new group within the ITA programme, and the Technology Enhanced Learning and Human-Computer Interaction groups were partially supported by the ITA Programme through some PhD positions.

The other groups in the other universities indicating this priority have a major focus on other priorities. All these groups also include Artificial intelligence and Machine Learning and/or Data Science and Big Data as their priorities, and in many cases robot-human collaboration and Internet of Things in industrial processes and/or Internet of Smart Things are also indicated.

a) Research quality

Within this priority two main research directions can be identified.

The first direction concerns fields in the area of didactics and enhanced learning. In the case of the University of Tallinn, the previous consolidated research experience in educational software and for teaching evaluation has been extended through the ITA programme to further research directions. As Tallinn University was included in the programme only in a later phase (in 2019) and the new group focusing on this priority was actually started in 2021, the period covered by this evaluation is too short for a clear assessment of the results. The call for positions at Tallinn University was designed to recruit new professors from outside the university and resulted in new competences being acquired in this area and the creation of a new research group.

In TalTech the Creativity Matters IT Didactics Research Group is a multidisciplinary team focussed on higher education IT didactics.

The second direction addressed by groups including this priority considers digital transformation in general, and the fields of investigation are typically inter/multidisciplinary. New directions are emerging in the areas of creative industries and manufacturing in the newly created group. Tallinn University is leading a European project to expand the creative possibilities for contemporary dance performance and audience experience, which was approved in 2022, and it is currently ongoing, showing a rising international visibility of the research group. While the single initiatives are promising and interesting, there is still a need for a

better strategic integration of these themes in the research directions in this priority area.

Other groups in the other universities, in particular those active in the areas of Artificial intelligence and Machine Learning and/or Data Science and Big Data, have research activities mainly characterised by a focus on application areas and not on specific research topics. As a result, while the amount of self-funding is increasing, the level of publications should be more ambitious to achieve a good international reputation in the field.

In general, within this priority area, an effort should be made to raise the intensity and the level of publications to disseminate the research work internationally.

b) Sustainability

Involvement of PhD students in teaching and projects has an impact on the duration of the PhDs in particular in this area, which is characterised by practical research. While the new regulations on PhD studies are likely to improve this aspect, special attention must be paid to the type of activities performed by PhD candidates to improve the sustainability of the doctoral educational path in this area.

There is a strong dependency on funding and projects, which can be critical for the further development of research activities and for establishing long term research goals.

c) Societal impact outside research

Involvement of external institutions and industry is high, in particular in focussed projects.

In Tallinn University, several initiatives are present, such as thematic workshops, microdegrees of 20 ECTS credits, involvement in industry associations, Summer and Winter Schools, Creative Camp, and hackathons, which contribute to the involvement of external institutions and companies, and technology transfer. Cooperation via ERASMUS projects has focussed on digital education and online tuition. Several courses at M.Sc. level are organised in relation to this priority area in the university, as well as some PhD level training initiatives.

In TalTech, six groups include this priority together with other ones, on topics ranging from control systems, to security, energy informatics, e-government, and robot-human collaboration in higher education, in general with a good level of activity and contracts with external organisations.

In UniTartu, three small- to medium-sized groups mentioned this priority area, focusing on Virtual reality (in which a new group has been established in 2020), supporting human-work processes, and extended reality and IoT in educational contexts. In these groups, funded

activities involving external actors are mainly in collaboration with other research groups.

Positive aspects

New directions for interdisciplinary projects are being opened in this field.

In particular, the ITA programme contributed to creating new research directions and to attracting research staff at all levels to create new interesting initiatives.

Areas of development

A strategic development of this priority area should be pursued, relying not only on bottom-up research efforts.

A clear definition of the role of PhD candidates in projects should particularly be addressed in this area. PhD candidates should not focus too much on project deliverables, some freedom in research should be retained. In addition, intellectual property rights should be clearly defined.

The number and level of publications should be increased. Particular attention should be paid to training newly hired PhD candidates towards designing their personal research goals and in writing high quality research publications.

Recommendations

This is an important priority area, and it follows current trends of interdisciplinarity of IT research, but in the future, it should be better characterised in terms of interesting research directions.

Some focussed funding could contribute to its development.

In addition, a closer connection to the educational industry should be pursued, focusing on long term goals and new research directions in this area.

Other general comments and recommendations common to all priority areas are listed separately in the report under ICT targeted evaluation: general recommendations on all areas.

3.5. General recommendations on all areas

Research quality

New groups were started on new themes creating new research directions. In particular, exciting new and interesting research developments emerged in the areas of Communication Systems (TalTech), Hardware Security (TalTech), Mobility Modelling (UniTartu), Collaborative Robotics (UniTartu), Health Informatics (UniTartu), Environmental Sensing (TalTech), Bioinformatics (Alasoo, UniTartu), Compositional Systems (TalTech), Distributed and Pervasive Systems (UniTartu), and Nonlinear Control (TalTech). In spite of a later start, the Digital Transformation and Lifelong Learning group (Tallinn University) is showing good promise.

In addition, some existing groups were strengthened, benefitting directly or indirectly, from the ITA, mainly through new PhD positions, interactions with the newly started groups, or by helping spin off new groups from existing groups towards new directions.

The ambition level in the quality of publications, with some few notable exceptions, should be increased, targeting not only Q1 journals, but also the top level venues in the area (e.g., ICRA, ICML, RSS, VLDB, IJCAI, AAAI, established IEEE and ACM Transactions, NeurIPS). Within Q1 journals, the reputation of the journal in the community should also be considered.

Sustainability

While funding levels have been increasing over the evaluated period, many research activities are linked to rather short projects with an applied focus. A longer-term focus for research should be developed to guarantee sustainability, concentrating not only on applied challenges but also on more fundamental research.

Funding instruments and support for ensuring the sustainability of newly recruited international professors and their groups are needed. It is essential that integration of new professors is also supported through guidance regarding funding.

In general, the planned PhD intake (at a national level) to meet the goals is not very realistic (e.g., based on the Tartu report and from available general country-level information), in particular due to the strong competition from industry.

Societal impact outside research

A significant number of the ITA supported research groups demonstrate collaboration with the industry in terms of joint research projects and industry mentors for theses. In some

cases, research has resulted in university originated startups.

Some specific training, dissemination initiatives, and university-level courses have been started on the topics of the priority areas. Some short degrees (e.g., microdegrees) have been started on priority themes.

Positive aspects

In several cases, the ITA Programme facilitated the recruitment of international professors in key ICT areas and it increased the number of PhD candidates and facilitated the offering of better positions (i.e. hired positions). In general, the ITA programme helped increase external funding.

Areas of development

Some possible suggestions for new research directions:

- Increase core algorithmic research in fundamental AI/ML and Data Science as a basis for the excellent volume of applied research in this sector;
- Strengthen e-Estonia excellence in new research directions;
- Develop sustainability SDGs (present now only marginally in some research in green IT, climate change, smart cities, and urban mobility).

In general, research focus should be improved, and not only follow applied project needs.

PhD candidates should not focus too much on project deliverables, some freedom in research should be given.

There is some concern about the high levels of student dropouts, in particular in TalTech in B.Sc. and M.Sc. degrees and in UniTartu at PhD level.

Recommendations

Significant emphasis should be placed on fundamental research as an enabler for scientific excellence and the renewal of science. Many research groups demonstrated solid application-oriented research; however, fundamental research is a crucial necessary enabler that needs to be connected with the more applied use cases. For example, fundamental research in Machine Learning and cybersecurity would need to be strengthened to support the more applied activities and address the growing need for expertise.

Merging of research groups to create larger research units with better synergies in address-

ing difficult scientific challenges should be explored. For many scientific challenges, a critical mass and momentum are needed in terms of expertise and infrastructure, motivating the creation of larger research units and also collaboration between the units within and across universities.

Developing Grand Challenge driven research questions that will bring together theoretical research groups with expertise in core algorithmic expertise (this needs to develop across institutions) with groups that focus on hardware development, system methods and last mile (trials, high TRL level); this will enhance synergies as well as allow specialisation.

Some additional criteria for research evaluation in general are suggested:

- Insert equality as one of the criteria;
- Quantify the impact of research, in particular in teaching.

Answers to questions from the Board: “According to the Expert Panel, was the IT Academy a worthwhile venture? Can the activities undertaken within the IT Academy be considered reasonable in the world context? Could there have been any alternatives?”

The panel received a very positive impression on the effects of the initiative. There was evidence that ITA resulted in new research groups in priority areas which were not sufficiently covered before the inception of the programme. The ITA programme has also been pivotal in fostering interdisciplinary collaboration.

On the other hand, as the granted funds are somewhat limited, in particular compared to European and potential industry funding, the potential for steering towards new directions is also limited. However, although the financial contribution of the IT Academy is relatively small in terms of the total financing of universities, it is crucial for the creation of new activities and structural units.

In addition, the allocation of funds was to the universities and not to specific projects, so the impact is rather indirect. Possible alternatives are in the direction of programmes focusing on specific priorities, with calls to start new projects.

Another comment is on the type of funding, which focussed mainly on positions for PhDs and staff. A more complete funding scheme for projects, including additional expenses, could be helpful in driving research. One potential model to consider is to have 50% of (an increased) overall ITA funding reserved as matching funding for externally procured or competitively won grants, to encourage young faculty to develop grant writing capability while ensuring that they secure longer term and slightly more substantial funding than that has currently been possible with the scale of the ITA funding.

4.

OVERALL ASSESSMENT OF THE IT ACADEMY PROGRAMME

The questions in the following section were raised in the Minister's Directive No. 1.1-2/22/348. The Expert Panel was assigned to answer questions 6, 9, and 11. They were also tasked by the Steering Committee to add comments to question 4 (Do the evaluated institutions themselves consider the IT field research area important or not? What is the focus of the organisation itself and are the IT topics in the organisation aligned with the priority topics or not?). The rest of the questions were answered by the Steering Committee. The answers refer to IT Academy programme in general, for all evaluated institutions.

4.1. To what extent has the ICT research measure of the IT Academy achieved its goals? What is the change in the level and sustainability of selected research directions?

The goals of the IT Academy programme were to ensure that Estonian IT education is internationally competitive, that the number of graduates corresponds to the needs of the society, that Estonia is engaged in international collaboration, and that the graduates of IT programs are equipped with the necessary knowledge and know-how. These goals were to be achieved by enhancing the research capabilities and outputs of the universities which, among other results, would generate the required number of people with PhD degrees to provide the education and industry support needed by society.

As a result of the IT Academy programme, there has been a positive change in the level and sustainability of the research areas. In some areas, a significant positive change can be observed (e.g., in health informatics, and in smart and sustainable mobility) and some new research directions have been started (such as quantum software, software reliability methods and trustworthy AI, and applied aspects of hardware security). So, in general it can be said that the IT Academy has reached its goals. In certain areas the positive impact generated by the IT Academy is observable but, in some areas (such as fundamental research in AI/ML) longer term strategic prioritization (combined with appropriate additional funding) is required to create a positive change. Although the launch of the IT Academy was delayed, Estonian IT research has reached a new level thanks to the programme.

The fact that the IT Academy programme has been successful is demonstrated by the additionally secured external research funding as well as the number of projects in IT Academy priority areas.

The number of senior researchers as well as junior researchers has been increased.

A major challenge is the sustainability of the research in the domain. There is no certainty that Estonian IT research is able to cope with the highly competitive nature of international as well as Estonian research funding. There are clear risks that the improvement of the quality and the scope of the ICT research might not be sustained when the targeted funding of the IT Academy programme is reduced. High expectations have been set for the research groups as they must navigate autonomously in the complex scientific and funding landscape. One of the challenges is also the funding for the PhD students. Despite the measures introduced by the state for the PhDs, such as salary support for the junior researchers, the income gap between academic positions and ICT specialists in the private sector is still huge and the ICT research domains might not be attractive enough to new PhD students. The significant salary gap between the private sector and the academic staff at all levels is a threat to the sustainability of ICT academic staff in general.

Sustainability is ensured to some extent by the fact that many companies are collaborating with the research groups supported by the IT Academy, so the sustainability is partially ensured by private funding. Over half of the research groups are engaged in such collaboration. In addition, the research groups have increased their activity towards international funding schemes including the EU framework programme which adds to the diversification of the research funding.

4.2. To what extent are the selected research directions aligned with the national priorities, global development trends, business sector and societal needs identified in the overview of the field? To what extent do research directions need to be changed or supplemented in the light of this?

The current research directions are in general aligned with the national priorities, global development trends, and needs of the society. Although the general directions are aligned, there is a lack of focus in some cases. With limited resources available to a small nation like Estonia, a clear focus is indispensable for achieving positive results.

The researchers were not always sufficiently incentivised to collaborate with industry in the context of the IT Academy. While the importance of industry collaboration is clear for the institutions, it is not always a high priority for researchers. Some progress was made in this area, however there is still room for improvement. There are multiple reasons for the lack of motivation for industry collaboration, among them the fact that industry collaboration

limits academic freedom and pressures researchers to focus on the priorities of the client. Also, typically industry collaboration projects yield fewer research papers, which may limit the research funding opportunities for research groups from pure research funding sources.

There is a challenge in terms of prioritization between fundamental research and the needs of society and industry. There needs to be alignment between fundamental research, applied research and the real needs of the society at large.

One of the objectives for the research institutions should be to create mid- to long-term strategic research agendas in close cooperation with private sector where fundamental research is combined with applied research. The amount of fundamental research should be increased, as if the research is too application focussed, the universities risk becoming underpaid contractors. However, it must be ensured that the fundamental research carried out in research institutions is aligned with the priorities of the private sector. This can be achieved through close collaboration with companies at all levels of research.

4.3. Whether and to what extent has a significant developmental leap taken place with the help of ICT research measure in selected research areas (compared to the rest of the advances in IT research and development activities)?

There has been a clear and observable developmental leap in the research institutions.

New capabilities have been created, which is demonstrated by the fact that new centres of excellence are being created, the AIRE programme has been started and Teaming for Excellence proposals have been submitted. So, there is some confidence that sustainability exists.

4.4. What is the institution's contribution (both financial and non-financial) to support the research directions of the support measure?

The research institutions and their research groups have succeeded in securing additional external funding for their programs, which is positive. This shows that the IT Academy focus areas are aligned with the priorities of the research institutions. In the past, there has been an expectation for the research groups to mostly secure additional funding themselves. While some changes in this trend can be observed, more systematic support for the focus areas would be beneficial at the organization levels of research institutions.

Answers to the questions "Do the evaluated institutions themselves consider the IT field research area important or not? What is the focus of the organisation itself and are the IT topics in the organisation aligned with the priority topics or not?"

It was evident in all universities, and in particular TalTech and UniTartu, that ITA funding

enabled retaining and promoting junior staff to more permanent posts with independent lines of research while being mentored by senior established chairs.

On the basis of the university reports it is difficult to answer in detail the question on whether the evaluated institutions themselves consider the IT field research area important, as we do not have a complete overview of the universities as a whole. As a general consideration, the IT faculties at both UniTartu and TalTach are among the largest. Consequently, the IT field is a priority in the eyes of university management. This also corresponds to the Estonian Digital Agenda 2030.

Considering the received reports the following can also be considered:

- UniTartu: there is a clear interest in IT as demonstrated by the impressive new building in the centre of town, the advanced High Performance Computing facilities and the very active research groups present in the university. As a whole, University of Tartu has an active IT roadmap with focus also on the infrastructure. IT development with respect to priority areas and use of funds from the ITA seems rather organic, building upon existing strengths and being opportunistic with research funding bids as opposed to a systematic alignment with IT priorities. We did note that the focus is mainly on interdisciplinary research and applications and there is limited attention to theory.

- TalTech: the university has a considerable emphasis on IT; however, the field is somewhat fragmented. The research priorities of the university are aligned with ITA priorities. TalTech has a clear roadmap of how the capacity building, teaching pipeline and additional research resources can be directly aligned with the ITA priorities.

- Tallinn University: the evaluated School has a narrow but well-defined remit on educational and upskilling aspects of the IT domain in collaboration with educational providers and industry. The focus of the university is not on IT, but the measure helped start new activities in the direction of leveraging IT in advanced learning and educational aspects.

Concerning the priority areas, in the evaluated universities Artificial intelligence and Machine Learning and Data Science and Big Data are considered mainly as horizontal topics, and are present in most if not all the research groups. As a consequence, research related to these areas is mainly applied and attention to fundamental research is lacking.

4.5. To what extent has the support measure promoted cooperation between institutions, how much does duplication occur?

There is a positive trend of increased collaboration between research institutions, however this could be further improved, especially internationally. Many research groups are rela-

tively small, resulting in limited results and very limited impact. There are many fragmented groups that are not collaborating with each other. The universities should support the creation of larger research groups, which cover a larger scope and that could have multiple focus areas. Also, collaboration between groups should be encouraged, supporting the sustainability of the groups.

Duplication occurs to a significant extent within research institutions as well as across research institutions.

4.6. How are the priority research areas of the ICT support measure related to higher education? To what extent and how do researchers (including involved foreign and external researchers hired using the means of the measure) participate in teaching?

In general, all researchers participate in teaching in courses which are related to the ICT priority research areas in which they are involved. There is no problem with teaching at Master's level for international researchers, as in this field education is mostly in English. In addition to traditional education, other forms of education through short courses, Summer camps, and other initiatives have been developed.

Ways of mapping teaching resources to degree programs in a systematic and fair manner, helping connect research and education should be developed. Ideally, degree programme course offering would be balanced (i.e. not having too few or too many options for the students given the intake size). Specialist (and/or advanced) courses should be offered as seminar offerings rather than standalone courses - this is likely to reduce the overall scatter of courses and consolidate student numbers. It will reduce teaching load on PIs and indirectly, on research active PhD students.

4.7. What has been the measure's contribution to doctoral studies? How has the measure affected admission and graduation of doctoral students?

There has been a significant contribution to doctoral studies as the enrolment to PhD studies was increased by tens of PhD students when the IT Academy funding was started and it was decreased when the programme ended.

While the IT Academy programme has had some positive effect on the total study time of the PhD students, in many cases the study time is still too long as it is typically between five and six years. Decreasing the time for the PhD studies should be a target for the institutions. Also, the successful completion rate of the PhD studies should be increased.

While the number of PhD students was generally increased, the low percentage of Estonian PhD candidates is a concern as it affects the quantity of future academic staff able to teach

in Estonian. Without PhD degree holders fluent in Estonian, the research institutions cannot fulfil their national obligation to conduct bachelor studies in Estonian. A consideration for the policy creators and research institutions would be to set Estonian language requirements or possibly a specific ratio for admission of international/Estonian PhD students, limiting the percentage of international PhD students admitted. The first step would be to make the PhD student positions more attractive to potential candidates.

4.8. What are the main outputs of knowledge transfer of the ICT science support measure and how is support for knowledge transfer organised in institutions?

While collaboration and knowledge transfer have somewhat improved, many researchers are not collaborating with industry, which may be for several reasons, such as lack of motivation, type of the research field or individual traits of the person. Naturally, to some extent industry collaboration is also limited because of lack of visibility and awareness from both sides – i.e. researchers' and industry's knowledge of each other's focus areas and capabilities.

The individual research institutions have their programs for knowledge transfer (such as ADAPTER) and the process for knowledge transfer was observable in the programme, however the IT Academy programme lacked a process and targets to support knowledge transfer. Collaboration with industry was carried out in individual research institutions at different levels and it was observable. Clearly knowledge transfer processes employed at research institutions should be universal across all research fields, so the lack of effective knowledge transfer processes is not so much a shortcoming of the IT Academy programme but a more general challenge prevalent in the Estonian research institutions.

It must be noted that there were very few spin-off companies, defendable IP and ideas originating from the research groups. It must be noted that it is not always clear which startups have originated from which research institutions and what the ties are between individual startups and research institutions. The research institutions and research groups should educate and encourage their researchers to recognise and create defendable IP and to also evaluate the commercialization opportunities for the IP created.

Knowledge transfer is a complex topic and it cannot be forced on the industry nor on the researchers. In some cases, conferences and events that the research institutions consider to constitute knowledge transfer are not utilised to the maximum extent. This illustrates the attitude from the research institutions towards industry collaboration – in some cases it is viewed as an inconvenience, rather than an opportunity. It is clear that successful knowledge transfer requires both sides to work together so that all parties may benefit.

Better methods and approaches to knowledge transfer between research institutions and industry should be devised. Knowledge transfer could be further supported via increasing

the contacts and improving the interaction between interested parties, both from research institutions and industry, to define mutual interests and possible areas of cooperation. Communication between organizations and people as well as the management of the process are important. It would be useful to assess the utility of the advisory bodies to the research support instruments. If the activities of the advisory bodies are continued, their role and mode of operation should be reviewed. Until now, the main task of the advisory bodies has been to share information on the activities carried out at the research institutions rather than to perform an advisory role. The research institutions must focus more and commit more resources to supporting researchers in establishing contacts with the Estonian industry. It would be important to hold more events involving both research institutions and industry, where the researchers can present their activities and results to the industry, industry could provide feedback on their priorities, and potential collaboration areas could be explored together.

We also recommend introducing the research areas of individual research groups to existing networks (for example industry associations). The goal should be to increase the dissemination activities to a broader scale and increase awareness in the society, enabling the industry to identify relevant areas and establish contact with the relevant research groups.

4.9. To what extent have foreign researchers and external researchers hired using the means of the measure been involved in the institutions, what kind of support do the institutions provide to integrate them into the higher education and research landscape of Estonia?

International researchers, at professor and junior researcher level, have been engaged through the ITA Programme, focusing on new research directions indicated through the priorities. General support for integrating the new professors and their families is usually provided at university level, including language courses and support for the administrative aspects. As a suggestion, systematic support for career development for new hires (i.e. training and mentoring) should be increased.

4.10. How relevant has been the management, implementation and financing model of the measure to achieve the intended goals?

The funding model succeeded in attracting new researchers, increased the number of PhD students and also supported the establishment of some new research directions. So, it can be concluded that the funding model of the IT Academy is adequate and it functioned well during the programme.

There is an expectation of a follow-on programme, which could continue in a similar manner. While the aim of the funding model in the IT Academy programme was to instigate a developmental leap – by attracting new researchers – the next funding model must be aimed at

sustainability, supporting the consolidation of the competence areas. The research institutions welcomed the ability to apply the funds as they saw fit, which helped them to address their priorities.

A strategic development plan is needed to develop the IT domain by combining multiple funding mechanisms. The research institutions should have longer vision on priorities and focus research areas, which are communicated within the research institutions as well as externally. These long-term strategic plans would enable the research institutions to better plan participation in research projects and also plan the hiring of key staff members (i.e. to identify which people in which areas are needed). Hiring new staff is time consuming and it must be approached strategically, having a long-term view. Also, the advisory bodies should be involved to a larger extent.

4.11. What are the recommendations for follow-up activities of the ICT research support measure? (launching new topics, changing procedures and/or conditions, starting cooperation mechanisms etc.)?

The opinion of the experts is that if IT is a priority in general for Estonia, funding in ICT should be proportionally increased and a sufficiently stable funding environment should be guaranteed. One possible recommendation is to consider a pool from the Estonian Research Council for matching funding of core research that is proportional to the external (potentially more applied) research funding attracted by the department.

Some new research directions are suggested for consideration. On one end, fundamental research is needed to provide the background for applied research. In particular, there is a need to increase core algorithmic research in fundamental AI/ML and Data Science as a basis for the excellent volume of applied research in this sector.

Some strengths could be further developed. In particular, ways should be identified to strengthen e-Estonia excellence in new research directions. Sustainability topics such as the ones defined in the UN Sustainable Development Goals (SDGs) are currently present only marginally in some research in green IT, climate change, smart cities, and urban mobility.

The priority areas would benefit from fostering interdisciplinary collaboration among the various research groups, which could significantly enhance the overall research output by tapping into the diverse strengths and perspectives of different disciplines.

The current move of incorporating PhDs as staff is positive. The recommendation is to sustain PhD salaries in line with inflation. This is essential in this area due to high competition from industry and from abroad.

The time to complete the PhD degree is, on average, quite high at all three universities. Measures to ensure the timely completion of degrees are needed, for example the use of top-ups to the basic PhD salary to keep students working at the university, mentoring support, and an analysis of the degree process including degree requirements (for example, the publications needed for the thesis). The new PhD regulations are heading in this direction, but specific attention is recommended on this aspect.

The Principal Investigator (PI) model should be uniform across universities with the expectation that a PI would have a PhD degree and competence to manage research projects and research funding at the university.

5.

EXPERT PANEL BIOGRAPHIES

Chairperson Barbara Pernici, full professor, Politecnico di Milano, Italy

Barbara Pernici is a full professor in Computer Engineering at the Politecnico di Milano since 1993. Her research interests include adaptive information systems design, data and information quality, IS energy efficiency, and social media analysis for emergencies. She has published more than 70 papers in international journals and about 350 papers at international level. She has led the information systems group of Politecnico di Milano in many projects, among which the European H2020 Project Crowd4SDG (Citizen Science for Monitoring Climate Impacts and Achieving Climate Resilience, 2020-2023), FP7 projects on energy efficiency ECO2Clouds and GAMES (Green Active Management of Energy in Service Centers, where she was scientific leader). She was an elected chair of TC8 Information Systems of the International Federation for Information Processing (IFIP) and of IFIP WG 8.1 on Information Systems Design. She has chaired or cochaired major conferences, as general chair or programme chair, including CAiSE, ER, BPM, ICSOC, Coopis, tracks in ICSE and ICIS, and IFIP conferences and workshops. She is in the editorial board of ACM Trans. on the Web, IEEE Trans. on Services Computing, Business and Information Systems Journal (BISE). At Politecnico di Milano she was Director of the PhD School of Politecnico di Milano and Member of the Academic Senate. She participated in research and project evaluations in many countries, including Norway, Denmark, The Netherlands, Estonia, Austria, Australia, and Switzerland.

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Vice Chairperson Edwin R. Hancock, Emeritus Professor (Computer Science), University of York

Edwin R. Hancock received the B.Sc. degree in physics, the Ph.D. degree in high-energy physics and the D.Sc. degree from the University of Durham, Durham, U.K., in 1977, 1981, and 2008, respectively, and the Doctorate Honoris Causa from the University of Alicante, Alicante, Spain, in 2015. He is currently an Emeritus Professor with the Department of Computer Science, the University of York, York, U.K., an Adjunct Professor with Beihang University, Beijing, China, and a Distinguished Visiting Professor with Xiamen University,

Xiamen, China. His research interests are Machine Learning with graph, trees and strings, physics-based vision and complex networks. He has authored or coauthored about 220 journal papers and 650 refereed conference papers on these topics. He was elected Fellow of the Royal Academy of Engineering (the U.K.'s national Academy of Engineering) in 2021, a Fellow of the IEEE in 2016 and Fellow of the International Association for Pattern Recognition in 2000. He is currently the Editor-in-Chief of the journal Pattern Recognition, and was founding Editor-in-Chief of IET Computer Vision from 2006 to 2012. He has also been a Member of the Editorial Boards of the Journals IEEE Transactions on Pattern Analysis and Machine Intelligence, Computer Vision and Image Understanding, Image and Vision Computing, and International Journal of Complex Networks. He was the recipient of the Royal Society Wolfson Research Merit Award in 2009, and named BMVA Distinguished Fellow in 2016 and the IAPR Pierre Devijver Award in 2018. From 2016 to 2018, he was the second vice President of the IAPR. He is currently an IEEE Computer Society Distinguished Visitor. He was a member of the UK REF Panel in Computer Science and Informatics in 2014 and 2021, and Chaired Evaluation Commissions for the Czech Academy of Sciences in the areas of mathematics and computer science in 2015 and 2021. He currently serves on the Royal Society Research Appointments Panel Aiii responsible for appointing University Research Fellows and the Royal Academy of Engineering Membership Panel in Computer Science and Communications.

Member: Professor Sethu Vijayakumar FRSE

Sethu Vijayakumar is the Professor of Robotics at the University of Edinburgh, UK, and the Founding Director of the Edinburgh Centre for Robotics. He has pioneered the use of large-scale Machine Learning techniques in the real-time control of several iconic robotic platforms such as the SARCOS and the HONDA ASIMO humanoids, KUKA-LWR robot arm and iLIMB prosthetic hand. One of his projects (2016) involved a collaboration with NASA Johnson Space Centre on the Valkyrie humanoid robot being prepared for unmanned robotic pre-deployment missions to Mars. Professor Vijayakumar, who has a PhD (1998) from the Tokyo Institute of Technology, holds the Royal Academy of Engineering (RAEng) – Microsoft Research Chair at Edinburgh and is also an Adjunct Faculty of the University of Southern California (USC), Los Angeles. He has published over 250 peer reviewed and highly cited articles [H-index 45, Citations > 11,000 as of 2023] on topics covering robot learning, optimal control, and real-time planning in high dimensional sensorimotor systems. He has been appointed to grant review panels for the EU (FP7, H2020), DFG-Germany and NSF-USA. He is a Fellow of the Royal Society of Edinburgh, a judge on BBC Robot Wars and winner of the 2015 Tam Dalyell Prize for excellence in engaging the public with science – including his role in the UK wide launch of the BBC micro:bit initiative (2016) for STEM education. Professor Vijayakumar helps shape and drive the national Robotics and Autonomous Systems (RAS) agenda in his role as a Programme Director (AI) at The Alan Turing Institute, the United Kingdom's national institute for Data Science and Artificial Intelligence.

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Member: D.Sc. Ülo Jaaksoo, Advisor to the CEO of Cybernetica

Ülo Jaaksoo received the Candidate of Sciences (corresponds to PhD) degree in adaptive control systems in 1969 and the D.Sc degree in computer aided design of control systems in 1982. He has 50 publications. He is currently an advisor to the CEO of Cybernetica. From 2013 to 2023 he was a Chairman of the Supervisory Board and from 1997 to 2013 a Chairman of the Management Board of Cybernetica. From 1989 to 1997, he was Director of the Institute of Cybernetics at the Estonian Academy of Sciences. He was elected a Member of the Estonian Academy of Sciences in 1986. From 1990 to 1994, he was a Vice President of the Estonian Academy of Sciences. From 2002 to 2005 he was an Estonian representative at the NATO Science Committee. He is a Life Member of the IEEE.

Member: Sasu Tarkoma, Professor, Dean, Faculty of Science at the University of Helsinki, Director of the Nokia Center for Advanced Research (NCAR)

Professor Sasu Tarkoma is Dean of the Faculty of Science at the University of Helsinki and Professor of Computer Science. He is Chairman of the Scientific Advisory Board for Finnish Defence (MATINE). He has authored 4 textbooks and published over 240 scientific articles and 10 granted US Patents; his h-index is 47. He is Fellow of IET and EAI, and Senior Member of IEEE and ACM. His research interests are Internet technology, distributed systems, data analytics, and mobile and ubiquitous computing. His research has received several Best Paper awards and mentions, for example, at IEEE PerCom, ACM CCR, and ACM OSR. He is actively involved in the Helsinki Institute for Information Technology (HIIT), the Finnish Center for AI (FCAI) flagship, Helsinki Center for Data Science (HiDATA), and the Allied ICT Finland network. His flagship MegaSense research programme aims to elevate air quality and environmental monitoring to the next level by providing a real-time and accurate view to the chemical cocktail and the micro climates of mega cities. MegaSense involves a novel hierarchy of distributed air quality sensors, in which more accurate sensors calibrate lower cost sensors. Current low-cost air quality sensors suffer from measurement drift and they have low accuracy. This significant open problem is addressed by a new AI-based calibration scheme. MegaSense integrates with the 5G cellular network and leverages mobile edge computing for sensor management and distributed pollution map creation.