Estonian Centre of Excellence in ICT Research

EXCITE

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CYBERNETICA

Dear reader, we are pleased to present this Estonian Centre of Excellence in ICT Research (EXCITE) publication that has been prepared as a collaborative effort between researchers aiming to provide insight into the activities of the centre.

EXCITE's leading researchers would like to use these stories to communicate with those in society who are influenced by the future of information and communications technology (ICT) – entrepreneurs, (research) policy designers, as well as researchers in various fields and "smart clients" at both the national and the individual level. But why shouldn't it also be a book for mothers and fathers, grandmothers and grandfathers to read to themselves or their children and grandchildren – our future digital world citizens – before bed? When attempting to look at the world in a broader sense, it must be recognised that ICT has not been a "thing-in-itself" for a while, it is rather an "objective inevitability". The recent pandemic has shown this as well, when the reliability and accessibility of information were often primary factors in difficult circumstances, in both decision-making and behaviour. All of us live in a modern information society that is becoming increasingly more globalised and our daily routines are closely integrated with ICT – often without us even noticing, it influences almost all of us to a greater or lesser extent. Including Toomas, the 30-year old father and his 5-year old daughter Emma, who will be your guides in this journey into that futuristic digital society.

In these stories, top researchers have written about their joy and excitement regarding exciting research topics and challenges, given insight into the inner workings of the digital world, the glamour and pain of scientific collaboration with colleagues in research teams as well as with companies, but also of their concerns regarding digital society and its members' safety, privacy, mental health and the future of science. Hopefully, the many different aspects of ICT top research in this publication will surprise readers. Perhaps they will sense the socio-economic dilemma of limited resources and the inevitability of high-level research and maintaining sustainability in a future society based on innovation.

This publication is also a humble expression of gratitude to Maarja Kruusmaa, one of EXCITE's passionate founders and coordinators, who managed to successfully start the Centre of Excellence with research groups involving joint doctoral candidates in its first four years of operation. Additionally, we want to thank EXCITE council member Marlon Dumas, who came up with the idea for the publication, as well as other members of EXCITE's council who have supported this idea, Peeter Laud, Tarmo Uustalu, Jaak Vilo; and to the people from TalTech who helped make the idea a reality, Anne Muldme, Epp Joala, Jaanus Joasoo; and finally, all the EXCITE researchers who contributed to the texts and photos and the diligent team at AS Ekspress Meedia.

It's certainly worth seeking out visionary insights into the challenges of digital society from the articles. Perhaps some people will be surprised to find that there are regular people of flesh and bone living in our digital society – at least for now – who have attempted to extend their sentient and keen minds into those deep problems of the digital world and tried to envisage an answer to the following question: "What is in store for us 50 years from now and how might it affect the lives of our children?"

We wish you a fascinating and an informative read!

Ivo Fridolin
Coordinator of EXCITE

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Print: Printall AS
Issued: 2021
Special thanks: Jaanus Joasoo, Diana Aljas, Henry Narits, Anne Muldme

www.excite.it.ee

EXCITE is funded by the European Regional Development Fund

European Union
European Regional Development Fund

Investing in your future

This small nation's ICT sector intends to grow tenfold in the next ten years

Based on earlier analysis, we can presume Estonia's future prosperity will come from the tenfold growth of the ICT sector in the next ten years.

The ICT sector and its importance for Estonia is ever increasing. It has been the most important aspect of Estonia's economic growth over the last decade. The ICT sector has brought an amazing 30% growth in added value to the total economy.

There were more than 6000 companies operating in the ICT sector in 2019. Estonia is Europe's fastest growing nation when it comes to establishing technology companies. The growth of our startup companies has been stable at 20–30% for over five years, whether measured by revenue, the number of employees or investments.

Technology companies are providing the most significant increase

According to the data from the Estonian Founders Society, the total turnover of Estonian technology companies in 2020 is one billion dollars – equal to the size of the Estonian agricultural sector. That billion indicates the amount of money clients all over the world have paid for the goods and services provided by our companies.

"Both sectors are serious industries, but the noticeable difference comes from the speed of growth," they said. "Agriculture was still as large as it is now a few years ago, but startup companies back then were less than half the current size."

The second factor is the specific nature of the technology sector, where a few smart employees can create a huge amount of value. The 6300 employees or 1% of Estonia's total workforce in the technology sector make up 2-3% of Estonia's total economy. The Estonian Founders Society members state that this is the perfect model for a small nation where there is always a shortage of workers – the more prosperity we can cultivate with fewer workers, the better.

Estonian startup companies are world-renowned. In 2020, they were able to raise a record number of 450 million euros from both domestic and foreign investors.

The balance of trade is (meur) increasingly more positive

It is quite evident when looking at the export and import numbers how the ICT sector is beneficial for our economy and our country.

	2014	2016	2018	2020
Export	514,7	612,1	916,5	1286,6
Import	292,1	316	469,3	585,9
Balance	222,6	296,2	447,2	700,8

Source: Statistics Estonia

The ICT sector's significance has increased considerably

We can see considerable growth in three main indicators when compared to 2010. Only gross profit was lower in 2020 compared to 2010.

	2010	2012	2014	2016	2018	2020
Average number of persons employed	15 585	18 858	21 356	21 635	25 727	31 561
Revenue, in thousands (euros)	2 082 736	3 303 465	3 685 956	3 458 874	3 519 520	4 193 434
Gross profit (-loss), in thousands (euros)	220 391	208 024	176 919	125 107	138 502	188 518
Net added value, in thousands (euros)	504 352	598 055	655 426	683 329	877 685	1 191 697

Source: Statistics Estonia

The movement is towards a higher added value

In the study entitled "Overview of the ICT sector economy, vocational and higher education and research and development activities, 2020" (IKT valdkonna majanduse, kutse- ja kõrghariduse ning teadus- ja arendustegevuse ülevaade, 2020) it shows that the sector has been on an upward trend for a while, but there has also been a decline in some parameters.

The Education and Youth Board of Estonia commissioned a study which stated that the subsector of programming still has the most positive development, where turnover, export capabilities, added value as well as revenue have all rapidly increased.

There are a few noticeable interesting developments in the ICT manufacturing subsector when compared to 2016 and 2017 – turnover has greatly decreased because there has been less foreign demand.

However, it is still noticeable that despite the decline in turnover, added value and revenue in the ICT manufacturing sector has increased greatly. It is an extremely interesting change and the conductors of this study are glad to report that we are moving in a positive direction – producing higher added value products should be the objective for every company.

Researchers have observed during their examined period that ICT sector companies have seen their added value grow. The growth has been significant when compared to 2012 – 64% in total, while the added value in programming has nearly doubled. Value added per employee has also grown (7% in 2018), as have the number of employees (5%) and overall wages (13%), which has brought along a situation where company profits have decelerated. The most qualified ICT sector companies are mostly large enterprises with between 100–249 employees and an average salary of 2578 euros a month, which is 31% higher than the average salary in that field.

- The ICT sector's percentage in the number of people employed in business – 5.8%
- Added value created in business – 8% and more
- All taxes received from Estonian businesses – 6.6%
- Percentage of export – 10.1%

Should that same growth continue, then ...

The sector's average growth will be 25%. Although it is difficult, keeping up the same pace would mean that more than 50,000 people will work in the technology sector ten years from now. The people working in the sector are hoping for that and working towards that future. That number would represent 10% of all working people in 2030.

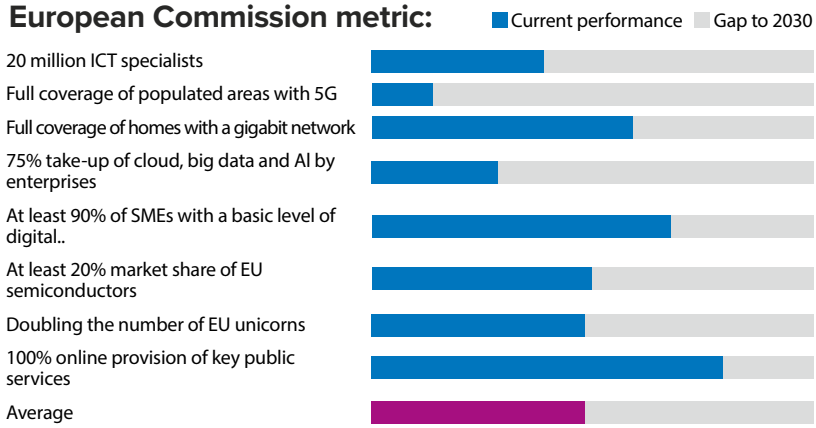
The more impressive part of the sector's plan is the part where IT companies would carry on with the current efficacy and contribute ten billion dollars to the Estonian economy every year. That would be around 30% of Estonia's GDP.

"This is the long dreamed of knowledge-based economy and export of goods from Estonia's best and brightest to the world," says the Estonian Founders Society, which unites the strongest people in Estonia's IT sector.

Europe has set certain digitalisation objectives

The European Commission must observe the state member countries have reached by creating a sustainable and inclusive digital society. There are eight total targets and the target date for those is 2030. The gauge shows the current situation and the difference that they hope to reach by 2030.

European Commission metric:



How does Estonia benefit?

Different studies have shown that one high-paying and directly exporting job contributes to five different jobs in its vicinity. Which means that every programmer, designer, technologist or product manager creates other jobs in restaurants, barbershops, manufacturing, law firms and various other places. Moreover the additional revenue will aid in paying a higher wage to doctors, teachers, firefighters and police officers in the future. It also has a part to play in paying out pensions.

In the interest of developing Estonian science, economy and society as a whole, including information society, it is important to cultivate the capability of Estonian top level ICT research and development, apply it to the interests of Estonian society and economy, while emphasising the introduction of science-based and innovative solutions in all areas.

How will these developments influence jobs in Europe?

McKinsey & Company's 2017 study "Digitally-enabled automation and artificial intelligence: Shaping the future of work in Europe's digital front-runners" observed how automation and artificial intelligence are changing the labour needs in various sectors. It is rather likely that more jobs will be created in the fields of ICT, communications and health care service providers. Meanwhile, the construction, travel and tourism, industry and transportation fields require a smaller labour force. It is already evident now and digital technology only accelerates those processes. Therefore, digital innovations may keep the number of jobs in a sector at the same level or increase it. Jobs can mainly be replaced in areas where workers have been brought in from someplace else. Bringing them back to their home country will provide jobs for locals.

Automation will accelerate the change in sector structure

Share of total employment base, digital frontrunners, midpoint scenario (%)

Sector	Employment 2016	Employment 2030	Employment growth yearly
Information and communicators technology (ICT)	3,7	6,8	5,9
Education	8,8	9,5	0,6
Human health and social services	16,1	17	0,5
Public	6,6	6,9	0,5
Professional services	13,1	13,5	0,3
Financial services	2,9	2,9	0,2
Other services	5,1	4,9	-0,2
Trade	13,9	13,2	-0,3
Utillies	1,1	1	-0,7
Manufacturing	11,2	9,8	-0,8
Primary	2,3	2	-0,8
Construction	6,2	5,4	-0,9
Transportation	4	4	-1,4
Holers and restaurants	4	3,1	-1,5

Source McKinsey analysis

Estonian Centre of Excellence in ICT Research (EXCITE) unites the pinnacles of Estonian IT research

EXCITE has been created with the purpose of filling an important role on the global IT research landscape, where people are trying to find solutions for current issues as well as future challenges.

EXCITE has been active since 2016 and unites 16 Estonian research teams in order to research and develop ways for developing secure and dependable IT systems and services. EXCITE operates on an activity matrix principle where common research topics that were previously operated separately by different research teams are brought together and PhD students and postdoctoral researchers are jointly supervised. TalTech, the University of Tartu and Cybernetica AS are our partner institutions. EXCITE is funded by the European Regional Development Fund.

TalTech's Professor Maarja Kruusmaa is the person who kick-started EXCITE during its early years. TalTech's Professor Ivo Fridolin took over her role in 2020. He begins by saying that a researcher in EXCITE is never alone. All top Estonian IT researchers can help and support them.

"We have joint PhD students across research teams in order to be better organised as well as financially supported. In a sense, researchers are required to collaborate, even if their personality traits suggest that they would be better off working quietly on their own," says Fridolin.

Nevertheless, this is certainly not the only reason why EXCITE was created. It also provides a more constant and sustainable funding for researchers, who according to him have "crazy ideas", which may not find immediate application. The research funding system in Estonia is extremely competitive and EXCITE provides a degree of certainty that even if a researcher and their team may not get funding during the call for proposals this year, they are not going to have to leave the university to take a different job.

EXCITE researchers utilise scientific methods in order to develop dependable and reliable ICT systems and apply them everywhere – health care, safety (hardware and work environment), environmental protection (water quality), banking and other fields.

Top research challenges

EXCITE is not only an umbrella organisation for top researchers. All researchers concerned about research and its future have gathered here. Whether it be young talent or resources – the two are clearly intertwined. Fridolin says that you might believe a top researcher can find ideas out of nowhere, but there to actually a complex causality linked to it.

"Throughout history, the brightest members of society have been excited by unexplored areas or depths that regular minds have not been able to make sense of," says the EXCITE coordinator. "In ideal situations and during the best times, EXCITE researchers are able to work on these unexplored areas. IT is completely intertwined with all areas of life and because of that, the variety of challenges is broad and is only expanding further. It must be noted that high tech discoveries have made mankind rather powerful. So powerful in fact, that it is not the imagination of top researchers that is limiting, but rather man's own imperfections and our ability to maintain that delicate balance between our wishes and actual possibilities."

Complexity and intrigue work hand in hand here, but the former means time and resources. As a consequence, research is expensive, especially top research. Fridolin recalls 19 December 2018, when Estonian researchers, politicians and business organisations signed a social contract with the president as witness in which the focus was to increase public funding for research and development as well as innovation to 1% of the GDP and at least keep it at that level.

"Unfortunately, this was not carried out. The new national budget foresees an increase for research funding to 1% of the GDP, but that may no longer be sufficient anymore."

The Estonian Employers' Confederation annual conference entitled "Tulelohe lend – Who are the winners in a changing world?" was held in late March 2021, and the President of Estonia as well as the Chairwoman of the Estonian Employers' Confederation Council Kai Realo signed a contract to establish a club for innovation intensive companies. The Estonian Employers' Confederation initiative brings together companies that invest at least 2% of their turnover into research and development. Fridolin says that this is a worthy initiative which clearly states that there is no growth in prosperity without innovation.

"Aligning the national aggregate indicator to 2% of the GDP requires an increased number of companies investing in research and development" says Fridolin.

Researchers at EXCITE (Professor M. Dumas' research team) are devel-

oping ways for monitoring business processes in order to predict the future states of those processes, e.g. the probability that a process instance will end with an unsatisfactory result.

"Highly stressful and competitive conditions for research funding is the current reality, and it is difficult for young people to see a career as a researcher as a viable life goal. However, true innovation is based on high-level basic research and an adequate number of specialists with university degrees. Will society sense this requirement?" asks Professor Fridolin.

Top researchers are dedicating themselves to the future

It is thanks to top bioinformatics researchers (Professor J. Vilo's research team) that we were able to monitor and represent the spread of COVID-19 so quickly and successfully. Meanwhile, we are faced with a number of other extremely important topics that humanity needs to deal with and find solutions to. If we don't, the consequences may be fatal.

Let us start by making technology more environmentally friendly. IT has a huge part to play in this. For example, EXCITE's research areas include simulations of energy network process optimisations, contributing to the development of innovative energy services and offering versatile products for managing energy consumption (Professors J. Raik's and Ü. Kotta's research teams).

EXCITE's research areas also include developing algorithms and methods that enable the use of new and reliable equipment and information sources in order to analyse the impact of floods caused by extreme climates and weather conditions on infrastructure and to assess the conditions of ecosystems (Professor M. Kruusmaa and her research team). Guidance systems have to be modelled in order to do this (Professor Ü. Kotta's research team). Testing the hardware of IT components and systems for fail safes and reliability (Professor J. Raik) helps ensure the sustainable performance of all this equipment.

"We cannot ignore the contradictions," Fridolin says. Extracting Bitcoins requires a colossal amount of energy – is that in accordance with the fact that about 2.2 billion people, or one in four people on our planet, do not have access to clean drinking water? Who will decide where energy is best spent and how? Is that an ICT issue?"

Complex and significant topics

The opinion of researchers in mass media regarding the COVID-19 pandemic has become an inseparable part of everyday life. Government decisions are made in collaboration with the Scientific Advisory Board. Fridolin thinks that's wonderful. That is how it should work in an innovation-based and sustainable society. Society realises the significance that education provides in determining the future of people themselves. However, there is still a long way to go.

> *EXCITE unites 16 Estonian research teams and operates on an activity matrix principle in order to research and develop ways for developing secure and dependable IT systems and services.*

"Everything that may seem simple is not so in reality. We live in an extremely complicated world. The COVID-19 pandemic is great proof of this. EXCITE research teams that are working on developing new theoretical models and new algorithms prove this as well, using functional programming, transforming programs and constructing methods and modal logics computer science applications (Professor T. Uustalu's and N.Veltri's research teams)."

Estonia is rapidly developing its own high-speed Internet network across the country, including in sparsely populated regions. This would ensure that every Estonian resident has access to ICT services. When compared to other developed nations in the world, we are spearheading Internet connection speed and availability. A solid and high-quality data network enables remote work, homeschooling and also the simplified use of public services. Cloud computing and the Internet of things will join our everyday technological life in the future, and EXCITE researchers are heavily involved in making this happen (Professor Y. Le Moulec's and Professor S. Srirama's research team).

Cyber security and human health

Mass media also uses high-speed internet. The positive aspect is that people can continue working and communicating even during the restrictions brought by the state of emergency during a pandemic. However, opportunity and freedom also require responsibility. EXCITE's cyber security research topics dedicate their strength and knowledge to making people feel secure while they socialise in cyber space. To keep their identity and personal data free from exploitation. Developing secure e-Estonia applications (e-voting, secure data exchange protocols) is conducted by EXCITE research teams from Cybernetica AS (Professor P. Laud's) and the University of Tartu (Professor V. Skachek's research team).

ICT-solutions based on quantum computing will increase security in the future. These are studied by EXCITE's top researcher D. Unruh and his research team.

ICT is one of the causes of smartphone addiction. It has been assessed that the biggest risks to our health in addition to infectious diseases (COVID-19 and influenza) and non-infectious diseases (cardiovascular, respiratory and lung diseases and cancer) are soon going to be addiction, mental disorders and related diseases, which will have a monumental psychological and economic impact. Several EXCITE research teams are working on improving our health – both physical health (Professor A. Aabloo, Professor I. Fridolin, Professor M. Min, Professor Y. Le Moullec, Professor J. Vilo) and mental health (Professor M. Bachmann, Professor R. Vincente Zafra).

"We hope humanity has the intelligence to support their top researchers and apply their creations to the benefit of everyone" concludes Fridolin.

Ivo Fridolin:

Living a healthy life is a challenge. Science does not fight death.

When looking to the future, health technologies will be a key area for the field of science as a whole. Ivo Fridolin and his teams are working to extend the span of people's quality of life, in terms of both prevention and treatment.

An analysis carried out last year showed that Estonians are living longer today than ever, but as much as a third of this time can be spent battling health issues. This is clearly below the European average. "The number of years we spend living healthily in Estonia is an area that needs to be addressed," Fridolin says. This concerns people's physical and mental well-being alike.

One of the main goals of health technology research is to find ways of detecting changes in physiological systems and in their functions at an early stage, before the development of disease symptoms and pathological changes.

"Information technology, especially signal-processing, has a significant part to play in our research and is needed in order for us to develop new methods and devices," Fridolin explains, adding that the widespread

use of activity monitors and sports watches shows that people like to be constantly informed about their health. At the same time, the world is moving towards personal medicine and a people-centric approach.

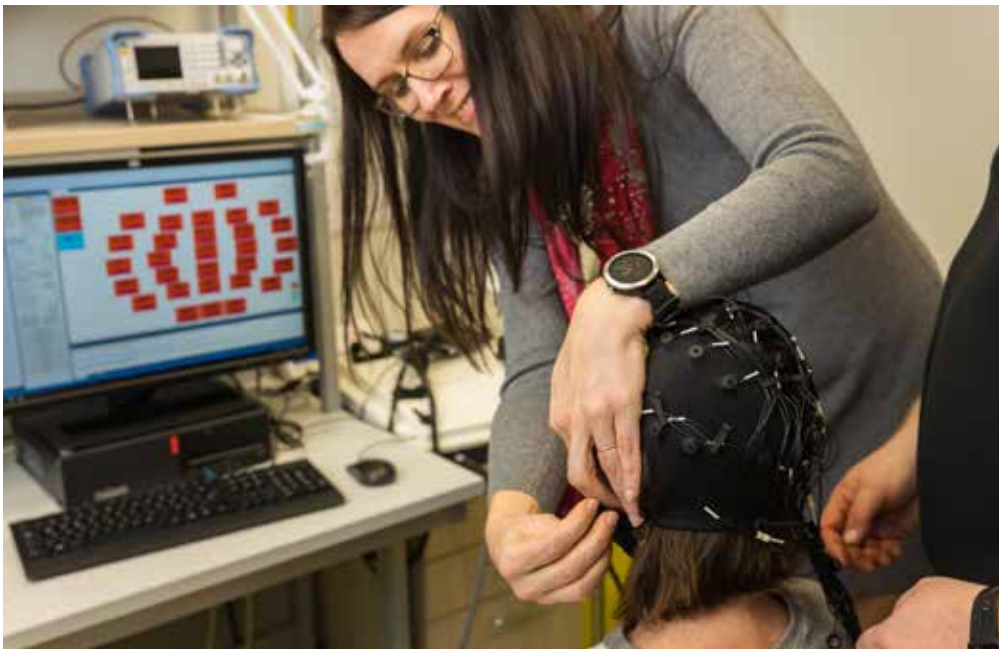
The key element is mental well-being

The number of people suffering from depression has increased 40-fold in the last decade and now affects more than 6% of the population. Being impaired by depression is mainly caused by years of living with ill health.

The group researching the brain's bioelectrical signals at the Department of Health Technologies at TalTech (Professor Maie Bachmann, senior researchers Hiie Hinrikus and Jaanus Lass, researcher Laura Päeske and doctoral students Toomas Põld and Tuuli Uudeberg), are working to develop an objective method for assessing the mental state of the brain that allows for the detection of mental disorders before the onset of subjective symptoms and that can be used in regular medical examinations among workers with high levels of responsibility (police, rescue workers and military personnel) and the general population.

These signals are measured from the scalp. It is like taking measurements from the shell of a computer to find out how the computer is performing. Electroencephalography (EEG) provides an overview of the bioelectrical processes in the brain without interfering with those processes, which would be impossible in an invasive study. The disadvantage of EEG is its low spatial resolution, as the signal at the surface electrodes reflects the fields generated by many neurons. At the same time, the great advantage of EEG is its temporal resolution, which enables the monitoring of ongoing bioelectrical processes to an accuracy of more than a millisecond.

Mental disorders, including depression, are mostly diagnosed at present based on subjective methods (tests and questionnaires). "One of the main goals of the research group that's being led by Professor Bachmann is to find an objective method, based on the assessment of brain signals, for the early detection of mental disorders," Fridolin explains.



Electroencephalographic analysis are performed by Maie Bachmann.

To characterise the EEG power balance, the working group introduced the SASI spectral asymmetry index, which characterises the power balance above and below the average frequencies and is calculated as the relative difference between these powers.

> *The group researching the brain's bioelectrical signals is working to develop an objective method for assessing the mental state of the brain that allows for the detection of mental disorders before the onset of subjective symptoms and that can be used in regular medical examinations among workers with high levels of responsibility and general population.*

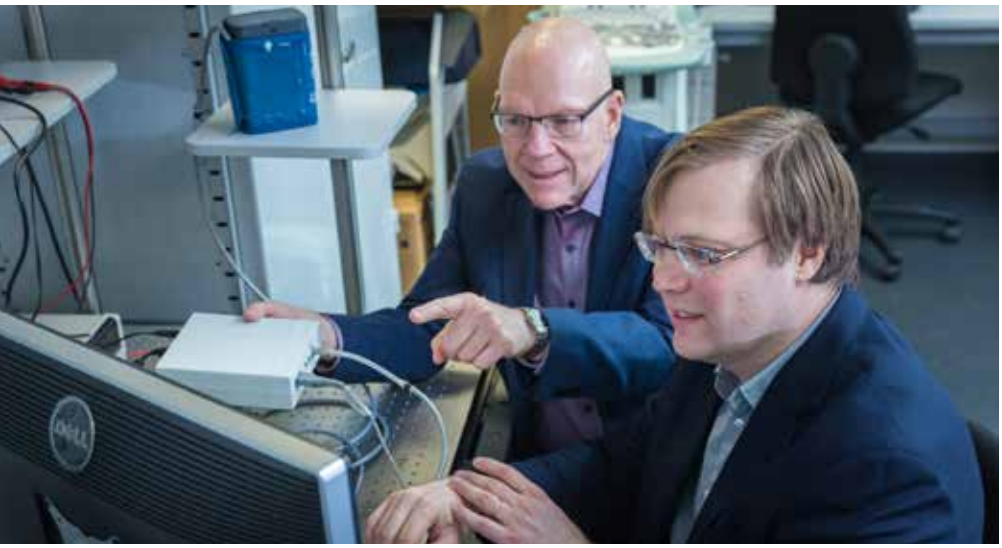
"Professor Bachmann's team made an interesting discovery that the power balance in the frequency bands selected above and below the maximum frequency changes in patients diagnosed with depression," Fridolin says. "SASI was positive in the group of depressed patients, while in most healthy subjects it was negative. Laura Päeske defended her doctoral dissertation in March on the basis of her research in this very field."

Päeske's dissertation, which was partly based on the collaboration that took place within the EXCITE framework between the research group into the brain's bioelectrical signals and the Department of Computer Systems (under Professor Jaan Raik) at TalTech, concluded that a signal from a single EEG channel provides comparable results to combining multiple channels, and it was suggested that the brain compensates for a poor functional network with stronger connections. In addition, EXCITE cooperation is ongoing with TalTech's Department of Software Science (under Professor Yuri Belikov), where doctoral student Tuuli Uudeberg combines traditional EEG signal-processing methods with those used in data science to develop personal brain condition markers.

Fatigue and mental disorders go hand in hand. Fatigued workers are at a much higher risk of becoming depressed. One of the outputs of the research collaboration between

Brain's bioelectrical signal research group (from left to right) Toomas Põld, Hiie Hinrikus, Laura Päeske with son, Jaanus Lass, Maie Bachmann and Tuuli Uudeberg.

the research groups of the EXCITE Department of Computer Systems (Professor Gert Jervan and senior researcher Mairo Leier) and the Department of Health Technologies (Professor Ivo Fridolin, senior researcher Kristjan Pilt, researcher Moonika Viigimäe and doctoral student Ardo Allik) is the automatic measurement of worker's physical fatigue and stress, for which the first steps have been taken with the development of algorithms based on artificial intelligence (AI) machine-learning methods. The initial focus will be on the assessment of physical fatigue using non-invasive real-time recordings of physiological signals. A doctoral thesis on the topic, entitled 'Assessment of physical fatigue based on portable devices', is currently being written. In the future, one of the outputs of the EXCITE research could be boosting work safety and comfort through the development of systems hidden in workwear and the algorithms that operate within them. This kind of smart workwear would give workers the opportunity to be aware of their work and movement habits, which could be used as input for planning a more efficient time management system and safer work environment, or for automatically identifying patterns that could prevent accidents among workers in hazardous conditions.



Non-invasive measurement of vascular parameters. From left to right: Kristjan Pilt and Margus Viigimaa.

A major killer can be identified early

Cardiovascular diseases such as atherosclerosis are among the leading causes of death around the world. Early detection of atherosclerosis and proper treatment can prevent the progression of the disease. Atherosclerosis and the formation of plaque on the walls of blood vessels are associated with the ageing of the arteries. In various diseases, including diabetes, the ageing process of the arteries is accelerated. Vascular calcification increases the stiffness of the blood vessels, which causes strain on the heart due to the greater resistance exerted by the blood vessels, making it more difficult to pump blood through them. This leads to cardiovascular diseases such as hypertension and coronary heart disease.

"A person's vascular condition can be assessed non-invasively using pulse wave analysis," Fridolin explains. "The pulse wave, which results from the wave of pressure changes caused by the pumping of blood by the heart, travels along the aorta to smaller arteries, eventually reaching the peripheral blood vessels. The speed and shape of the pulse wave depend on blood pressure and the elasticity of the blood vessel, therefore providing use-

ful information about ageing and the condition of the person's vascular system. As the elasticity of the blood vessel decreases, the velocity of the pulse wave increases and its shape changes."

It is important to choose a non-invasive method to assess the parameters of the vascular system that does not affect the blood vessels or blood flow. A good option is the photoplethysmography (PPG), which can be used to record volumetric changes in blood. The method has already been integrated into many activity monitors and smart watches, which are finding increasing use.

Senior researcher Kristjan Pilt has developed a novel algorithm to analyse the PPG signal using the pulse waveform index PPGAI, which provides reliable information about the condition of the blood vessels. This algorithm was compared with the methods used in clinical practice in cooperation with North Estonia Medical Centre cardiologist and Taltech Professor Dr Margus Viigimaa, and the results showed the advantage of the new method in distinguishing subjects with normal arteries from subjects with increased arterial stiffness.

"Kristjan's algorithm also has the advantage of suppressing noise in PPG signals by using adaptive filtering, and linking pulse waveform analysis to heart rate," says Fridolin. Mairo Leier, a senior researcher at the Department of Computer Systems, has worked with EXCITE to develop an optical sensor for recording the PPG signal from arteries at different depths in the body. This enables the signal measurement locations on the body to be expanded and the accuracy of the method to be enhanced.

This novel approach, combined with an optical pulse wave recording system, is a promising method for use in assessing the elasticity and age of arteries in the early diagnosis of cardiovascular diseases.

Chronic diseases are a major concern

If preventive measures are delayed, a disease can turn into a chronic illness. The growing spread of chronic diseases is an inevitable process in an ageing society. The spread of chronic illnesses is approaching epidemic proportions, especially in more developed countries. Approximately 70% of public health funding is spent on combating chronic diseases in the European Union. Epidemiological studies have shown that 14% of people aged 65 or older have six or more chronic diseases. In addition, COVID-19 poses a serious challenge to people who are in risk groups due to the chronic illnesses from which they suffer.

"This novel approach, combined with an optical pulse wave recording system, is a promising method for use in assessing the elasticity and age of arteries in the early diagnosis of cardiovascular diseases.

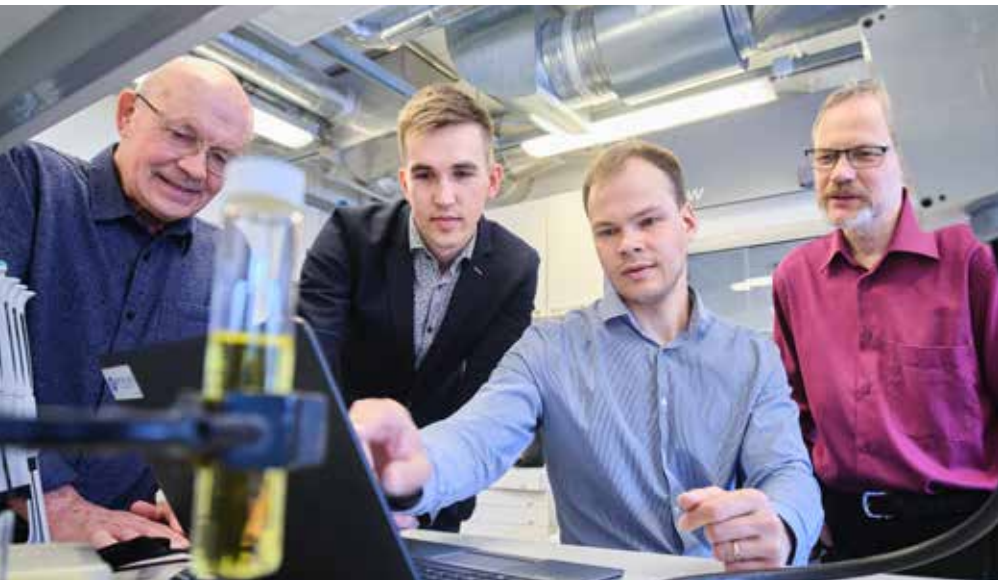
"Final-stage kidney disease is one example of a serious chronic disease," says Fridolin. "There are about 850 million people in the world suffering from various types of kidney disease, which is why it's estimated that chronic kidney disease will be the fifth most common cause of shortened life expectancy by 2040."

The kidneys cleanse the blood by filtering out metabolic residue, including toxic residue like uremic toxins. In the final stages of chronic kidney disease, the only option is to use renal replacement therapy: a so-called artificial kidney, which filters harmful substances out of the blood during haemodialysis. Renal replacement therapy is a vital but time-consuming and uncomfortable procedure for the patient. The treatment is very expensive, one of the most expensive among all chronic disease, but without it the patient would die. As such, it is very important to ensure the effectiveness of haemodialysis. Patients with severe COVID-19 are also at high risk of experiencing irreversible renal damage and therefore becoming dialysis patients.

The quality and effectiveness of renal replacement therapy have traditionally been monitored chemically, using periodic blood tests. The disadvantages here are the loss of valuable blood for the patient, the use of chemical reagents and the complicated measurement procedure.

The group researching biofluid optics includes Professor Ivo Fridolin, senior researchers Jürgen Arund, Jana Holmar and Risto Tanner, researcher Sigrid Kalle, doctoral student Joosep Paats and engineers Rain Kattai and Deniss Karai. The group has proposed a fundamentally new approach to monitoring haemodialysis and providing quality control in collaboration with North Estonia Medical Centre nephrologists Dr Merike Luman, Dr Annika Adoberg and Dr Liisi Leis and biochemistry laboratory quality manager Kai Lauri (SYNLAB Eesti OÜ).

Physiological signals recording laboratory, (from left to right) Ivo Fridolin, Mairo Leier, Moonika Viigimäe, Kristjan Pilt and Ardo Allik.



Optical signals from biofluids are studied by (from left to right) Risto Tanner, Joosep Paats, Jürgen Arund and Ivo Fridolin.

This approach uses optical radiation, in particular the absorption and fluorescence properties of the respective marker molecules. By measuring the absorption and fluorescence spectra of various molecules in the effluent dialysate using this optical method, it is possible to estimate their concentration and thus monitor the renal replacement therapy in real time.

Effluent dialysate is a fluid which carries away the waste products filtered out of the blood, usually into the sewer. The advantage of the optical method is that the measurement takes place on the effluent dialysate, thus providing the easiest way to connect the monitor without disturbing the haemodialysis process in any way. There is no need for blood tests or the use of chemical agents. By varying the optical frequencies and the absorption and fluorescence spectra, it is possible to record molecules both large and small. As a result of this research project, a real-time measurement sensor – the so-called Multicomponent Monitoring (MCM) concept – is being developed. It uses an optical method developed by the research group to monitor the removal of toxic residue from the blood. Cooperation with Professor Artur Jutman from Testonica Lab OÜ to test the hardware and software reliability of the MCM sensor developed for the implementation of On-Chip Health Technology at EXCITE is a continuation of previous joint projects with Professor Raimund Ubar's research group.

> *Our e-health system is no longer a success story and has not been for many years now. Our data are fragmented and unsystematic, and there are no big data, which medicine desperately needs.*

More high-quality information for the digital health system

The Estonian Health Insurance Fund will soon find itself in a situation where there is not enough money for everyone. Accessing medical care is becoming more difficult. People need to take into account that if they do not look after their own health, their quality of life will decline prematurely.

"This is something that people are afraid of more than anything else," says Fridolin. "That you would otherwise be able to enjoy life but you can't because of poor health. It's a great motivator to get people to change their behaviour." This leads to the question of whether society should pay for the treatment of people who, despite simple, widely known health facts, do not follow them and refuse to take care of their health. Would having sufficient personalised health information help in such situations?

Fridolin is convinced that the e-health systems in Estonia should feature more high-quality information. People should be assessed and then informed of the results. Take, for example, classic parameters such as blood pressure or blood markers: indicators that are related to some of our biggest health risks. There are nor-

The quality of renal replacement therapy is assessed by (from left to right) Annika Adoberg, Liisi Leis, Merike Luman, Jürgen Arund and Joosep Paats.

mative values available based on gender and age, and you can check how you compare to them at any time.

"If the values are in the red zone, it's important to step in and intervene," Fridolin advises. "We should be creating a timeline to gain an overview of trends. When people are young, before they become adults, all key personal indicators should be measured so that trends can be projected."

Fridolin concedes that our e-health system is no longer a success story and has not been for many years now. In particular, this is because there is no simple, user-friendly way to enter data in a high-quality manner that enables doctors to listen to their patients. Additionally, there are technological compatibility issues between systems. Partly because of this, doctors are unable to obtain an overview of a patient's vital indicators and risk factors and of the results of analysis on a timeline that would provide a snapshot of the patient's condition. Our data are fragmented and unsystematic, and there are no big data, which medicine desperately needs. Moreover, machine-learning and artificial intelligence are of no use in such a situation. "If the information that's entered is poor or incomplete, the results will be the same," Fridolin remarks. Incorporating doctors in the process as a whole is also very important.

Finally, it is worth noting that the development of health technologies is not leading us closer to immortality, but instead to the knowledge that death is inevitable. This is why it is especially important that the years we are alive are lived as healthily as possible. For this to happen, people need to do a lot of work themselves – precisely because the closest sensors are located in and on ourselves.

WHAT DOES THE FUTURE HOLD FOR THIS FATHER AND HIS DAUGHTER?

Toomas (30) and Emma (5)

The challenge for mankind in the next couple of decades will be how to live more health-consciously. This means that a healthy, nature-friendly lifestyle is important to Toomas and Emma, who are constantly improving their health literacy. But health technologies can boost health awareness. Virtual consultations have become commonplace in Toomas' lifetime. There are intelligent applications in the e-health system that inform both father and daughter about the level and risks of their health behaviour. Even if it turns out they have the 'obesity gene', they will not succumb to depression if they are health-conscious. They are aware that weight depends very much on lifestyle, and genes are just an evolutionary possibility that may never materialise. Knowing this, together with technology, they can create conditions that support achieving a normal weight, as well as conditions that create and maintain motivation.

Activity monitors and smart watches, together with artificial intelligence, help them monitor their movement habits and quality of sleep. They offer personalised daily plans and exercise plans. Nutrition applications register Toomas and Emma's eating habits, food and calorie intake and taste preferences and offer personalised diets. But they are also monitored by smart scales, blood pressure monitors, thermometers, pulse oximeters and glucometers. Health fanatics and patients with particularly complex cases may be prescribed sensors that are implanted directly in their brains. These sensors are connected to the respective brain centres and send information from there, such as "Stop, there's enough sugar in your body!"

Good mental well-being means, first and foremost, raising awareness: developing awareness of body, speech and mind through mental exercises and assistive technologies – for example, using the stress and fatigue monitors that are currently being developed at EXCITE. These monitors provide feedback on fatigue levels so that Toomas can stop himself from overdoing it at work and prevent accidents in the workplace. Stress monitors indicate high stress levels. This information should be followed up with appropriate support services: (virtual) support groups, (virtual) social counselling, targeted health games (gamification) and (virtual) storytelling.

The public and private sectors can also do a lot to ensure mental well-being by creating supportive and preventive conditions, using big data and their processing to protect personal data and to model and implement appropriate services, benefits and more.

Emma should know that in 100 years' time, information hygiene will be a daily part of healthy people's lives. Just as we brush our teeth and wash ourselves daily, members of the modern information society, being constantly flooded with information, need information hygiene as well. And just as we go to the sauna to scrub our bodies from head to toe, health-conscious Emma will regularly clear her brain of excess information in the future. This will be taught as early as in kindergarten. Consumption of information could be compared to eating. It is unhealthy to gobble up too much information. Information diets may be necessary, much like ordinary diets. There may also be fasting camps for information overload. Time-planning technologies could be of help here. There future health technologies will remind Emma to have a break and take time off by herself without any stimulation. Simpler living and being more aware of one's own body, mind and thoughts can bring great satisfaction. This is beneficial to both physical and mental health.

Jaak Vilo:

Data analysis greatly influences the understanding of biology and health care in general

Health science and data analysis are becoming increasingly more intertwined. Jaak Vilo is a Professor of Bioinformatics and his research teams help compile and analyse biological data and health data, which will help humanity in several aspects.

We are living in an age where data collection is constantly getting faster, where the abundance of information gives us significant advantages to help combat serious diseases and make important decisions. Therefore, bioinformatics has developed into a powerful weapon with which we can combat the coronavirus by both understanding the virus as well as developing vaccines and also developing epidemiological computations. Data researchers are a necessity in any field and company that wants to be both competitive and successful in the future. Jaak Vilo is pleased to note that Tartu University's recent data science Master's programme has grown to admit 75 students per year. This inspires hope that ten years from now we will have between 500 and 600 more capable data researchers. They are needed in various companies in the commerce sector, in manufacturing, in banking, in the pharmaceutical industry and in other fields.

"Biology as a whole has changed because of large-scale data analysis," says Vilo. "Similar analysis methods are also applicable in other fields where the volume of data has increased rapidly."

As a result of bioinformatics, a collection of medical data is created that helps researchers make important conclusions and decisions. Professor Vilo cites his first example from the work of his own research team. Large-scale data analysis allows us to decide which medication and which dose is best suitable for a specific patient. Every once in a while, doctors will prescribe medication to a patient that is actually unsuitable for them. This happens because our genetics play a crucial role in administering medicinal products.

It may seem counter-intuitive, but in order to make a decision for an individual, it is often necessary to first analyse data from hundreds of millions of people. Therefore, data only from Estonian, Latvian, Lithuanian and Finnish researchers is not enough. Researchers all over the globe must work together. Jaak Vilo's research team is actively involved in this type of international collaboration in both the biological

field as well as in the field of health data.

Correct administration of medication and biologists' tools

"Anyone can buy aspirin or a similar type of medication that should be suitable for everyone, or a doctor can prescribe one of several possible antidepressants. This might not be an apt solution, because a person's genetical nature might digest that specific medication either too slowly or too rapidly. So the medicine will either accumulate in high numbers, creating side effects, or it may not have any effect at all. When dealing with new anti-cancer medicine, it is first necessary to identify the exact type of cancer that the new medicine may influence. When administering medication you have to also think about the dosage, the procedure and the suitable combination of medications that the patient is going to take. All of this has to also be suitable for the individual genetics of that person and sometimes also the disease (such as cancer or a virus).

This requires knowledge about the biology of a healthy and a sick person, the targets of possible new medication and the specifics of medicinal products. Evidence-based medical science requires approved data-driven approaches and more precise targeting of medicinal products to correct target audiences in the future." Vilo states that a lot of medications have been forgotten about over the course of time. But some group of patients might substantially benefit from these medicinal products. This requires analysis of data from biological experiments and genetic data, as well as the tools to study these phenomena with.

Vilo's research team has contributed significantly to the study of stem cell development, cancer, immunology and nervous system diseases.

> *Evidence-based medical science requires approved data-driven approaches and more precise targeting of medicinal products to correct target audiences in the future.*

They research the probable functions of genes, DNA and its modifications, occurrence of proteins under various conditions etc. They develop tools mainly on their own and work with molecular biologists and doctors in different fields.

These highly demanded programmes have cool built-in web interfaces and are routinely used by thousands of researchers across the globe. Estonian computers receive millions of requests every month that aim to help researchers and companies by enabling easier analysis of their data. ELIXIR is an international bioinformatics infrastructure collaboration that is used to create shared databases, ensure their compatibility with each other and with different tools and also educates researchers who have a need for data analysis. Vilo and associate Professor Hedi Peterson collaboratively lead Estonian activities in this field.

Health care needs to be data-driven in order to be evidence-based

From the study of biological mechanisms we soon arrive at the use of medicinal products and the analysis of their effects. As more information becomes readily available regarding

human DNA alongside health data, e.g. what types of illnesses someone is suffering from at a certain age, we can also search for fragments of information in the DNA that specifically influence these processes.

In the world of health science, the trend is prevention and bioinformatics as well as pharmacogenetics offer up intriguing opportunities in this field. In the future they can be used to clarify a person's predisposition to some disease, e.g. it may be possible to prevent heart disease by taking the necessary medicine pre-emptively. "These types of treatment regimens are on their way," says Jaak Vilo. "At the moment, cynics can say that pharmaceutical companies are imposing these medicinal products on us, but taking care of your own health is a long-term process and sometimes people with high genetic risks have to keep their cholesterol or blood pressure low."

Now our discussion reaches the current hottest topic in the world – the coronavirus. Thanks to the competence of Estonian researchers, they were very quickly able to create local data analysis workflows and visuals for the public which helped predict the spread of the virus more clearly and use that to make decisions. "This is not necessarily difficult data science, but it was because of our previous experiences we were able to rapidly create them," says Vilo.

The key topic – data standardisation

When considering unique genetic features, researching the coronavirus or whatever other topic related to health research, you need data that can be compared as well as possible. Only then can you make high-quality conclusions from them. The quantity of data is also vital. Analysing the data of a thousand people in Estonia may not necessarily be enough to make definitive conclusions about a disease, e.g. which medicinal products may be suitable for them or predicting any health risks they might have. Often enough, the main genetic tendencies will not emerge in a reliable way, therefore the results need to be compared to corresponding data from other nations. When the same characteristics are determined in tens and hundreds of millions of data items, then it has true value for the entire human race.

"The analysis in different countries should be comparable to each other, regardless of language or the special features of that health care system," says Vilo." "There are many reasons why it is not possible or feasible to bring all health data into one collective system. Therefore, all locally collected data must be the same between countries. But even the data recorded by Estonian doctors is not always collected or written up in the information system in a similar way."

Jaak Vilo, Sulev Reisberg and Raivo Kolde are working hard in the medical informatics workgroup in Estonia to make sure localised data is comparable to health data from the Netherlands, Denmark or any other European country. Researchers from other countries are conducting similar work by developing shared data models and tools in order to analyse their data.

"Estonia is not only working on a solution for itself here," Vilo emphasises. "Every country has to work together in order to develop shared standards and tools. With the help of big data, we are able to gather a lot of essential information regarding our diseases, medicinal products and treatment processes."

Data protection is of utmost importance

When it comes to big data, especially collected health care data, the most important issue is data protection – sensitive personal data cannot leak at any processing stage. We

have an e-Health environment, digital prescription system and Estonian Health Insurance Fund medical bills Vilo believes that this is a good combination. Using only secure connections for data and sharing that data in the future – that is how we can create better services. The data is of course entirely anonymous during data analysis. Vilo's research team has contributed to creating more secure solutions in order to protect data from leaking and from the data researchers themselves. Professor Vilo knows what he's talking about. He returned to Estonia in 2002 in order to start up an Estonian gene bank, launched the necessary bioinformatics path and developed health information solutions as the first necessary step.

"You get the biggest benefits from science when you compile all essential data and allow for other countries to add to it," he says and adds that naturally one of the primary aspects of processing health data is the secure management of said data. Raw data and personal data are not transferred between countries. Nevertheless, those same analytical methods can be used to compare and contrast results. It is also possible to develop artificial intelligence in one country and then apply it in another country. The human genome cannot be hidden forever, but DNA information must not leak anywhere, especially along with personal information as DNA between relatives is similar. When dealing with the RNA segment of the virus that attacked us, then there is no cause for concern – the professor confirms that it is sufficiently anonymous.

For clarification purposes, it must be mentioned that research which uses health and genome data will only be conducted on the basis of statements of research intent and authorisations provided to them by ethics committees. They also look at the basic principles of data management and data protection. The Data Protection Inspectorate and the General Data Protection Regulation are especially significant for broader research, but they do not prohibit conducting research, rather they encourage it. Naturally, there are

"You get the biggest benefits from science when you compile all essential data and allow for other countries to add to it.

no names or personal identification numbers attached to data. They are removed before data is released to the research team.

Translating an artificial intelligence decision into human language

The development of artificial intelligence as well as machine learning has steadily increased in recent times. They have become particularly popular in image analysis. The microscope has been a tool used by doctors for over a hundred years. It is used to analyse cancer tissue samples or count certain types of cells during an experiment. It has always been a labour-intensive process. While programs that are able to automatically count cells have been created before, the real leap in the field was made when the ability to analyse photos grew exponentially. Artificial intelligence is able to use photos to detect a cat, a motorcyclist or even Bill Clinton. This indicates that machine learning has enough quality for it to be used in medicine. One of Jaak Vilo's research teams, led by Leopold Parts and Dmytro Fishman, works with image analysis.

Teaching computers how to recognise cat photos has been easier than viewing a cell, because artificial intelligence can be trained using a wide range of cat photos. People love taking photos of cats and putting them online, writing the word "cat" alongside them. Pictures of cells are an entirely different story. "You are going to need a lot of sample data in order to teach the machine," Vilo confirms. You can mark the relevant areas manually or use previously developed slower programmes in order to get enough training data to rap-

ONE LOCATION FOR DATA AND TOOLS BY EUROPEAN RESEARCHERS

Europe's shared network for biological data ELIXIR develops and manages critically important infrastructure for sharing a large amount of data. Estonia is a founding member and an active user. ELIXIR creates and manages large research databases that all researchers and companies from different parts of the world can use in their own work. Tools that are needed in data analysis workflows are also developed and interfaced, e.g currently for analysing the RNA sequence of the virus. Established under an international agreement, ELIXIR is a long-term collaboration that will continue for decades to come. A researcher can access previous data online and upload their own data for others to use and compare. With the support of public research funding, all data is accessible and usable for free in the best possible way. The most important aspect of this is that data can be compared, results validated and ideas further developed. Additionally, shared standards, formats and interfaces between tools are created and training is also provided for users from every company and research institution. European researchers are working towards the same goals, advancing health care, pharmaceutical companies and various agricultural and bioeconomic companies.

idly teach artificial intelligence. Artificial intelligence will henceforth accomplish tasks that usually require a lot of time by either a pathologist or a biologist. The computer is a tireless machine and provides the same, repeatable and comparable answers every single time.

Now image analysis can be combined with health data and text analysis and the result will be getting one step closer to new high-quality solutions.

There is still another significant problem that often arises with using artificial intelligence. This is the so-called 'black box effect', where the computer, the artificial intelligence, tells the doctor its final decision and that's all the information it provides. How do you determine what is behind that decision? One of the tasks that Jaak Vilo's research team has is to explain data analysis to people, namely answer questions such as why artificial intelligence has reached a certain result or how definite a decision is. "This is extremely important," explains Vilo. "There is a big difference between a decision that is 100% certain or just 50%. Associate Professor Meelis Kull's research team deals with decision calibrations." He adds that research in this area is moving quite slowly. In the field of artificial intelligence and deep neural networks there is also a lot of collaboration with Raul Vicente Zafra's research team and in the field of business processes there is a lot of collaboration with Marlon Dumas' research team.

Data analysis in every field

Jaak Vilo indicates that several methods developed for bioinformatics can also be used in other fields, from analysing media texts, analysis that is necessary in the business world and even self-driving cars. Kristo Käärmann, who is conquering the world with Wise, is an alumnus of Vilo's research team and has said that he uses the analytical skills and knowledge he learned from the research in his own business dealings, where there is a lot of emphasis on data-based decision making. This is a clear example of a cross-sectoral discipline. The data researchers trained mainly at Tartu University can bring change anywhere data is collected.

In order for the data to be usable and beneficial, it is necessary that the FAIR-principle is adhered to: data should be findable, accessible, interoperable and reusable.

WHAT DOES THE FUTURE HOLD FOR THIS FATHER AND HIS DAUGHTER?

Toomas (30) and his daughter Emma (5)

Personal medicine is going to become even more detailed. Doctors will receive alert notifications about the health of Toomas and Emma before they start prescribing medicine that won't actually be effective. Under Professor Vilo's leadership, Tartu University is building public infrastructure which should store genetic data and make it accessible to doctors. Data researchers have become the most important people in companies, countries and organisations – Emma might become one of those important people. All important statistical information will be dynamically updated in the electronic health records of both Toomas and Emma. Both people and artificial intelligence will be able to read the electronic health record more easily.

DNA has become the most significant aspect of selective implementation of health examinations and test methods. The data is seamlessly intertwined and Toomas, Emma and their doctors will receive those early warning signals. All essential data from accidents and ambulances will be transferred immediately into hospitals. Ethics and technology will move in tandem, seeking the best approaches to advance evidence-based medicine. Estonian data researchers will start new companies that provide trustworthy services to health care systems in other countries.

The father and daughter can be reassured that the ultra-fast and dynamic creation of vaccines will better prevent future global pandemics. The RNA sequence of each new virus and all of its new variant will be found using bioinformatics techniques, which will be synthesised in a production workshop and packaged in a similar "shell" to the current Pfizer coronavirus vaccine. They will develop new vaccines that activate the immune system against the most common types of cancer in collaboration with Tartu University researchers. It is important for Thomas that Emma will live a healthy life of at least 80 years.

Yannic Le Moullec

Combines electronics and health applications

Yannick Le Moullec from the Tallinn University of Technology (TalTech) along with his team are applying various aspects of electronics to the health applications, as well as a few others. The results could spark a great deal of change in the health and environmental applications.

An ageing population and the preservation of the environment are two major phenomena influencing our societies today, and presumably for the next few decades.

Globally in 2020, there were more people aged 60 and over than there were children under the age of 5, and by 2050, people over 60 may account for up to 22% of the population. This creates major challenges for health and social care systems, which could potentially result in advanced monitoring and assistive devices becoming a necessity, not only for the elderly, but also for their caregivers.

Le Moullec suggests that "We can get an idea of the trends by considering various growth forecasts. The medical sensors market is expected to grow 7.8% from 2020 to 2030, and thee environmental sensors market is expected to rise by more than 9.25% between 2021 and 2026 alone, reaching 2.7 billion US dollars by that time."

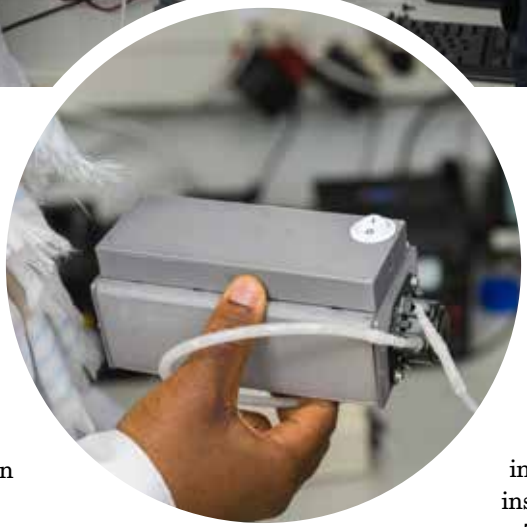
The French-born Le Moullec has worked in TalTech since 2013, ini-

> *The idea is to measure properties of the human body using algorithms and electronics by applying a particular electrical signal to the individual that we want to examine.*

tially as a senior researcher and from 2017 as a professor in the Thomas Johann Seebeck Department of Electronics. Under the EXCITE umbrella, he is liaising on two big projects in the field of electronics that are applicable to health. "They are related to health, but the core work and innovation is in electronics," he describes.

He says that, as it pertains to measurement electronics-related topics, activities have focused on the development of methods, algorithms, cognitive electronics, and impedance sensors for intelligent and quality pick-up of the electrical bio-impedance (EBI) signals, preferably via a non-contact approach, or magnetic induction to be exact. One challenge they face is acquiring cardiovascular data from noisy environments and estimating various hemodynamic parameters, such as the central aortic pressure (CAP) from the measured EBI of the radial artery located in our forearm. Patients and doctors around the world would see that change immediately.

"The idea is to measure properties of the human body using algorithms and electronics by applying a particular electrical signal to the individual that we want to examine. Typically, there are two locations – on top of the leg and on top the a hand. Electrical signals go through different layers of tissue and change the properties of a signal from which we are able to extract meaningful information about what is happening inside the body," explains Le Moullec.



> *The measurement electronics group is developing a prototype that measures central aortic pressure from just the forearm, utilising what is esentially a wristband, which is much more convenient than the standard measurement technique used today.*

The measurement electronics group is developing a prototype that measures central aortic pressure from just the forearm, utilising what is essentially a wristband, which is much more convenient than the standard measurement technique used today. Key researchers in the group include Professor Olev Märtens and Professor Emeritus Mart Min. Under their leadership, scientists are analysing signals and developing algorithms to acquire more meaningful signals.

So, using a non-invasive method like the wristband is proving to be much more convenient than the current one - the Holter monitor. The latter is not as easy to wear as the patches move around, creating electrical noise and interference. There is real interest from both hospitals

and doctors for this new method, as the procedure itself is faster and simpler: “One of the prototypes is quite advanced, though they are currently still in the lab,” says Le Moullec.

This kind of innovation could be patented, and his team has been at this stage before, they also plan to commercialise this invention as well. Although they are not the only ones working in the field, their uniqueness stands out in the realm of electrical bio-impedance.

Their method can be used in other devices as well; Professor Le Moullec reveals that the group is working on other applications, which are also based on impedance (for example, the measurement of metals) or bio-impedance. “They are not as advanced as the cardiovascular one, but the group continues to work on them. The device will be different, but impedance is the focus,” he adds.

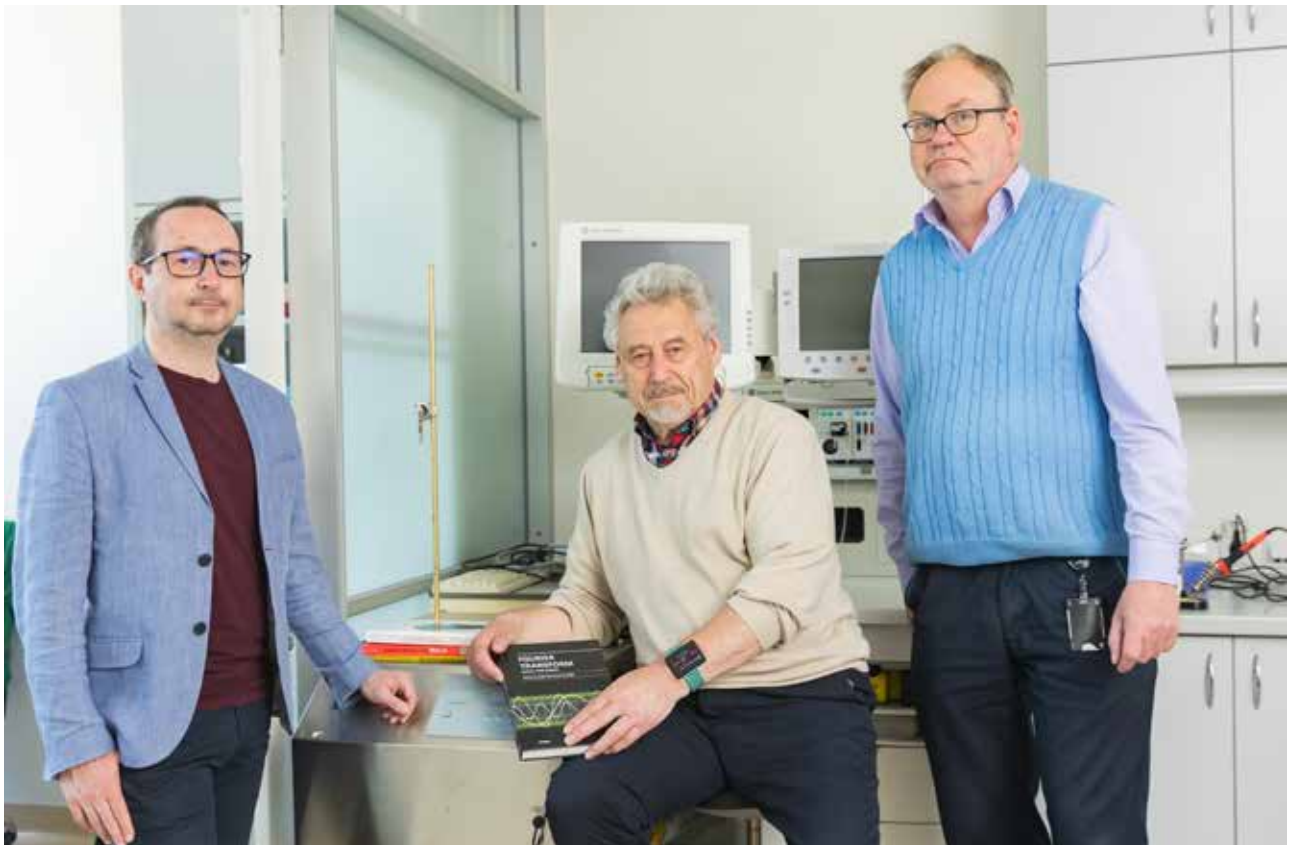
A little smart device changes a lot

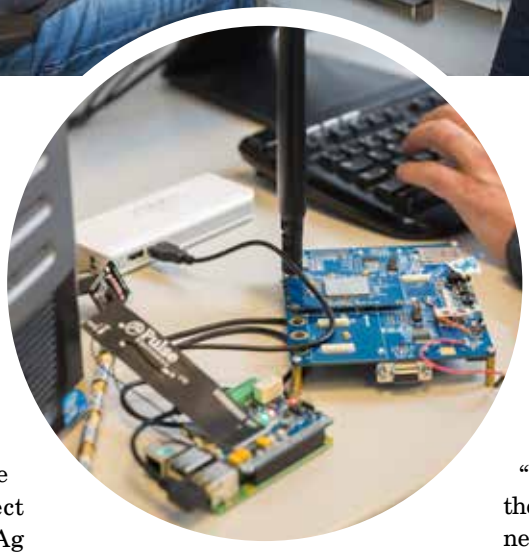
The other group liaised by Yannick Le Moullec, known as the ‘Lab-on-a-Chip’ workgroup, is working on a ground-breaking device that could revolutionise the medical sector.

> *We went in with a great level of detail to get the best out of this technology.*

The goal here is to create user-friendly and automated bioanalyzers that perform traditional laboratory analyses in a compact and portable format (Lab-on-a-Chip) which can be used to analyse various cells, e.g. bacteria for antibiotic susceptibility, differentiating cancer cells from healthy cells, etc.

Le Moullec says that more recently, their work has focused on imple-





menting a proof-of-concept for a low-cost, fully portable flow cytometer based on droplet microfluidics to enable field analysis of bacteria.

"Furthermore, through cognitive electronics, this system will be easy to use and fully automated from sample input through to result output. These activities were initiated in the framework of the EXCITE project and are now pursued in the ETAg PRG620 project (where key persons are Professor Emeritus Toomas Rang and Senior Researcher Tamas Pardy), in collaboration with TalTech's Department of Chemistry and Biotechnology," Le Moullec details.

Key results straight from site

They are working on a portable device that can analyse cell characteristics, such as their number, morphology, and differentiation. Currently, these are obtained from people to analyse in laboratories, using large and expensive devices, a process that could take hours or days before the results arrive. Lab-on-a-Chip, on the other hand, would be able to process the results from where they are taken, whether at the site of an accident or from the patient's home.

"We want to have a proof of concept, a prototype for this portable flow cytometer. The collected samples are mixed with certain fluidics and the liquid is flows through a small microchip that we are developing. There are micro-pipes in which the fluid circulates before it is then exposed to fluorescent light. This will be used to generate some sort of reaction. In addition, we will use a camera to take pictures and these images need to be processed," says Le Moullec.

He adds that they are using advanced algorithms and methods to analyse the signals and images. The end product must be small and portable, so the microchips therefore have to be sufficiently powerful. The current machines have significant computing capabilities, but they are large and very expensive.

"What we are trying to do is lower the price of the device. That means we need to have smarter algorithms. We need to be a bit more economical."

A much cheaper solution

The price of the device is a key aspect as it pertains to regions and countries that have limited budgets. You don't need to buy expensive lab equipment in large quantities for it to be a solution there.

Le Moullec says that there is still a lot of work to be done. Major innovations need to be patented before they are going to publish articles about them.

At the moment, they have started to develop different pieces and are focusing on the design of the microfluidic chip in the experimental phase.

"It is quite good already," says Le Moullec. However, research is only at the beginning when we consider camera sensor technology, implementation of algorithms and everything else that is responsible for analysing the images and detecting bacteria. "We started a bit over one year ago," he tells.

Very deep into standards

Yannick Le Moullec also talks about a third project, this time outside of the medicinal field - a wireless, green internet of sorts. A key issue here is energy efficient techniques; which algorithms, hardware and methods can be used? With the world adapting to 5G and further implementation of the Internet, there are going to be more and more sensors. Their energy consumption can't be unbearable and overwhelming. Devices need to be very efficient whilst simultaneously capable of working for long periods of time.

"Standards say that some devices such as NB-IoT modules have to be able to work for up to 10 years without changing the battery. We have a collaboration with some Estonian Telecom operators, along with potential interest from other network operators, but also from other sectors. It can be used for smart grid monitoring, water distribution systems and so on," says Le Moullec, adding that they are quite advanced and have worked for about four years on the project already. "We went very deep into the standards. Other groups around the world just use the technology, but we went in with a great level of detail to get the best out of this technology," explains Le Moullec.

All of Yannick Le Moullec's research revolves around our future, be it in healthcare or energy consumption, both of which are among the most important fields of research around the world.

WHAT DOES THE FUTURE HOLD FOR THIS FATHER AND HIS DAUGHTER?

Toomas (30) and his daughter Emma (5) have to be aware that for accurate health monitoring, research and development will consider both, non-invasive sensors (bio-stamps, tattoo-like sensors), and invasive, implantable sensors. These will be combined with novel low energy wireless communication technologies to enable remote analytics and diagnostics. "By 2050, it is expected that whole body monitoring, early detection and prevention, as well as personalised medicine will be truly become commonplace," says Yannick Le Moullec to our father and daughter duo.

"When it comes to the environment, we must address the climate and biodiversity crises. Worldwide initiatives and programs will drive the developments for reaching carbon-neutrality and a sustainable economy, such as the European Commission's European Green Deal, for instance. As part of this move, we must develop environmentally friendly electronics systems across the whole supply chain - resource extraction, new materials and compounds, resource optimisation and eco-design, a carbon-neutral supply-chain, sustainable processes, circular economy, and more," Le Moullec says.

He recommends a business idea to the pair to create a new wave of electronic components, including flexible electronics, organic electronics, degradable and biodegradable electronics, 3D-printed electronics from biodegradable polymers or biodegradable polymers, energy harvesters, etc. Toomas may be ready to jump on the bandwagon, because today, early prototypes of bio-degradable electronics that are more environmentally friendly already exist.

"For both phenomena, there are many opportunities and needs for conducting further research in that direction, as well as to develop applications that can be implemented using new technologies. Entrepreneurs will not only have to understand those new technological developments, but also to seize opportunities and contribute to new paradigms building upon the circular economy, inclusive business models and so on," Le Moullec tells.

Le Moullec says that assuming humans will not have disappeared, Emma could witness the realisation of transhumanism, at least from the technological perspective. This would result in the improvement and enhancement of the human condition. Technology would help us live longer, improve our mood, and provide us with unprecedented cognitive capabilities. The list of technologies that would support and enable such a realisation is considerable and particularly include the so-called NBIC, which stands for nanotechnology, biotechnology, information technology and cognitive science. In addition, other technologies will contribute to realising transhumanism, for example artificial intelligence, 3D bioprinting, cryonics, etc. Emma's life could be very different than her father's - both healthier and longer.

"In parallel or perhaps in total opposition to the above, the focus might shift towards the so-called 'bright green environmentalism', i.e. developing technologies that are clean and safe combined with social innovation to attain sustainable development. For example, nanotechnology and biotechnology could be used to reverse the damage done to the environment," Le Moullec concludes. So Emma might see a greener earth after all.

Raul Vicente Zafra

Wants us to understand Artificial Intelligence

Raul Vicente Zafra is a physicist and neuroscientist from Spain. He wants us to understand Artificial Intelligence, because it is one thing to have AI in our lives, but it is something else entirely to truly understand it, how AI makes certain decisions and why. Decisions that could ultimately affect our lives.

Zafra came to the University of Tartu of Tartu in 2013, initially in the bioinformatics department, and then later on became a senior researcher in computational neuroscience. Since 2013, he has headed the computational neuroscience research group under the Institute of Computer Sciences.

He says that his field lies in the intersection between neuroscience and artificial intelligence, with the aim to transfer ideas from brain research to AI and vice-versa in order to solve important problems.

"As we study the human brain, it is not easy to understand how neurons are working together to produce everything that we think and do, but when we look at machine-learning and algorithms, then we can find clues as to what goes on inside a human brain," he describes. Those AI algorithms can work at a very high level in some cases, but they do not solve all the problems. "We can make a comparison between how humans and machines solve these problems, what the similarities and differences are, and there is still more of that research ahead of us," he says.

Zafra admits that even ten years ago, although he himself was not into AI yet, a revolution had begun regarding machine learning and has made a massive difference since then. Computer vision, i.e, detecting objects with a camera, have fueled the likes of self-driving cars. He says it is an incredible journey from then until where we have reached at this point. Technology today makes far fewer errors than only a few years ago.

"These solutions can be used in practical devices, such as mobile phones and cars, not to mention chatbots and the possibility to read and extract information from incredible amounts of documents. The answers that these algorithms produce to everyday questions are already similar to how humans answer and write in a few paragraphs," he says. The algorithms that read and extract information will also be very useful to top scientists, because they know only a fraction of the articles and theses that have been written in their field. There are tens of thousands of articles per year concentrating on Alzheimer's disease alone, it is unfeasible for any one person to pick up this amount data and knowledge.

"AI algorithms can read the relevant documents and extract the knowledge to design models based on the information they have collected. It is then converted for practical use, and this type of technology can transform the way many do science in the future." Better technology begets superior technology, and that's where this fast pace is coming from, it is something that no one imagined happen so quickly.

He emphasises that we have reached a point where AI is not just a competitive edge for companies, AI-based solutions are an absolute necessity. It is very important to those who want to use data more efficiently and offer more personalised services. If we want to use our resources better, then eliminating unnecessary work and concentrating on smart tasks instead is a much more efficient usage of time and resources.

"For modern companies, AI is not just an advantage anymore. It is clear for all to see – if you don't embrace it, you are out of the race and eventually you will lose. A lot of this technology detects patterns to forecast something, it has a wide-spanning use across all business sectors," he explains.

AI and DNA

Raul Vicente Zafra then talks about an EXCITE collaboration project, in which they tried to predict if there is viral DNA in collected samples – human tissue, organs or soil, be it from forests or under water. Scientists want to learn everything about DNA and which organisms live there. Of course, viral DNA is something that piques their interest the most.

"We started to use AI two years ago to find patterns in DNA that can be used by AI algorithms to predict if there is a virus in a given sample.

> *We have reached a point where AI is not just a competitive edge for companies, AI-based solutions are an absolute necessity.*

We collaborated with the Karolinska Institute from Stockholm. They provided us with data taken from patients and we added the AI part. We have finalised that project, and want to move on to RNA next," he says.

In EXCITE, Zafra's own former student, PhD Ardi Tampuu, headed the research from the Tartu site.

Usually, scientists have identified different sequences collected from human samples and compared them to a huge database with all the sequences known to man. They tried to understand whether one sample was similar to a sequence that had been classified as a virus.

"The key issue here is that there are unknown viruses, and they are dissimilar to those that are known. We tried to predict by finding patterns that would indicate a virus using AI and machine learning to detect viruses that are not in the aforementioned database," he says.

Hopes are high on the RNA

Zafra says that now their attention will turn to RNA, but it's a little too soon to go into detail, as the research is only in its opening stages. However, they predict that RNA results will be more accurate than from DNA. The latter provides information, but RNA is better in showing which proteins a certain virus is producing.

> *We need to have a collaboration with AI, develop trust via understanding, rather than treating it as an oracle.*

"Our hope is that RNA will give us a straight forward link to the presence of a virus in these samples. RNA in a sense, is a better data source. Our partner here is once again the Karolisnka Institute," he says.

Big companies are leading the way in AI

As was mentioned before, deep learning started to grow rapidly about ten years ago. There are a lot of scientists around the world working on the same problems, contributing thousands and thousands of pages written on the subject every year, and Zafra says he finds it difficult to say where we are at the moment. "It's not easy to keep track, many scientists are working on many problems and applications, and the pace is vigorous," he says. "And if scientists such as us were not involved at all, only big companies like Google would have the knowledge and the technological readiness."

Big players are involved heavily and possess the type of computational and human resources needed, in addition to their enormous data banks. Only Google, Facebook and a few other major companies have these capabilities to train massive algorithms, they have the power to test and measure at large scale. It is from these aspects that algorithms learn from huge amounts of data.

AI can't be an oracle

Zafra also tells us about another project named Trust AI. It is a grant that was given to them last September and lasts for four years in total. It is a collaboration with scientists from Portugal, universities from France and the Netherlands, as well as three companies. One company deals with energy solutions, in particular forecasting. Another focus is a hospital researching a medical case about an unusual tumor. The third is a big retail company, and they want to optimise their logistics and deliveries.

"The key aspect here is that we don't only wish for AI solutions, but we also want to understand them. They need to explain decisions to us, tell us why the AI thinks that way," Zafra explains.

Artificial Intelligence is only becoming more and more apparent in our lives and businesses, therefore we need to have a collaboration with AI, develop trust via understanding, rather than treating it as an oracle," he says.

It is one of the most important topics in the field. Humans are seekers of causal explanations, which is no more evident than in children. They constantly ask "why?" It is indicative that, as a species, we like to understand things and decide whether an explanation is satisfactory to us or not. Understanding what the decision was based on builds that trust.

Zafra says that another important reason is a matter of transparency - AI is prone to biases. Their decisions might be based on something undesirable. You must be able detect that and make corrections. "There are also legal reasons for the AI decisions to have an explanation. People have a right to know, for instance, if an AI-driven system doesn't give you a loan, you would like to know why explicitly. An algorithm might decide to decline only because of your race or gender or another aspect that correlate with those. AI finds the easiest way possible and may suggest decision based on unfair aspects," explains Zafra.

> *We are going to experiment, develop a computer program to produce human-like explanations, and let humans rate the system to improve it further.*

A look at how humans explain

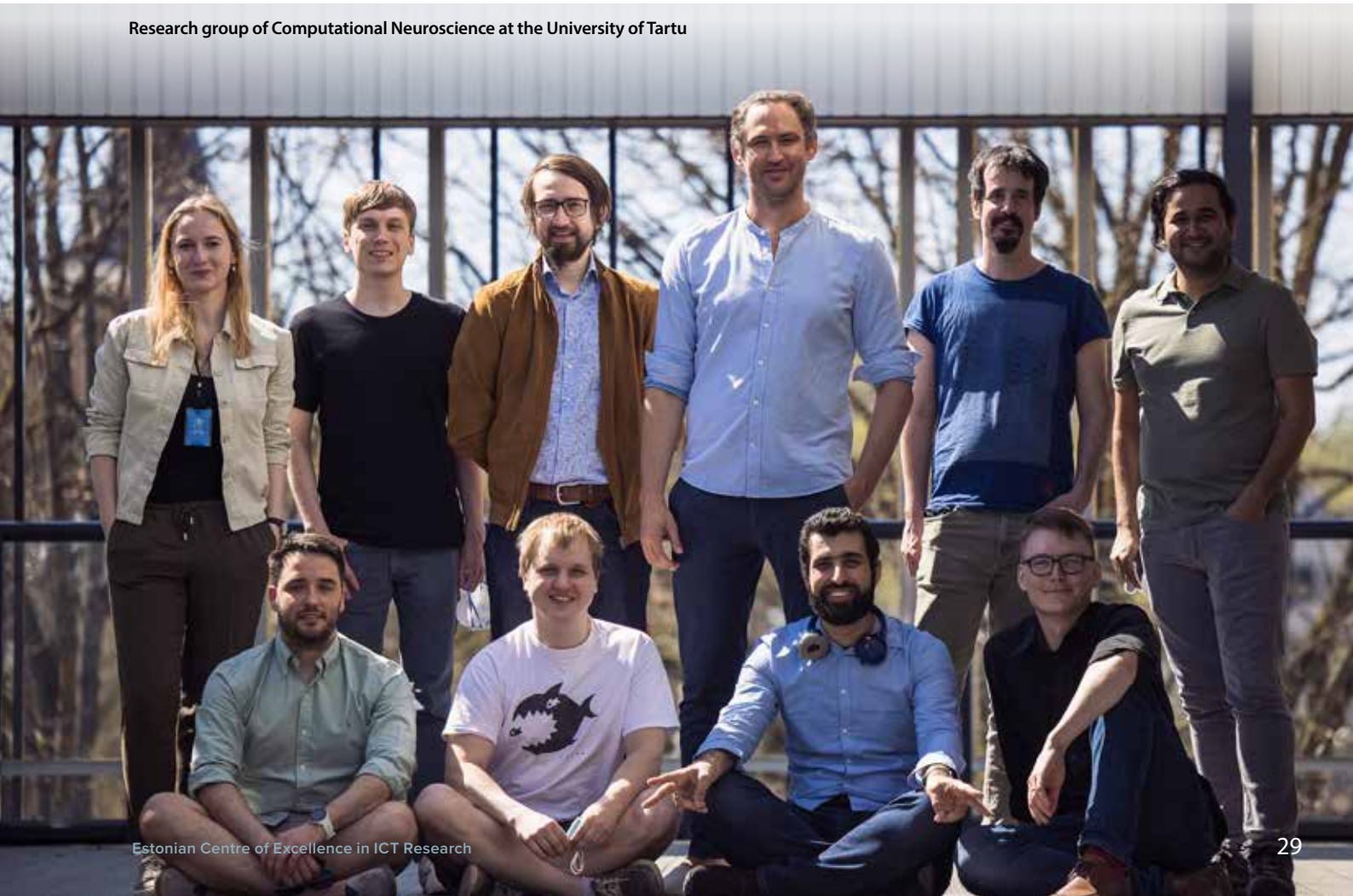
Progresses made in the field of deep learning mean that AI learns successfully, but it still has trouble expressing itself. There could be billions of parameters in a deep learning model and explaining all that can be very difficult. One solution might be genetic algorithms, where explicit formulas can be read and interpreted.

A human brain is very complex and somehow, but we are capable of explaining ourselves to others in a way that others find it useful or predictable.

"The cherry on top is that our group in Tartu has a unique role given our mixed background in neuroscience and AI. We get inspiration from how humans give explanations and how they like these to be given. Psychologists have documented this for decades, and we can use and build on that knowledge. We want to use these elements to select formulas in genetic programming that are more satisfactory to humans, formulas that are more efficient, shorter and simplified," he describes.

Humans tend to simplify what they think and know by way of short summaries. First, you need to know what the other person knows already. You wouldn't want to bore those who are already aware and possess knowledge

Research group of Computational Neuroscience at the University of Tartu



about a certain issue. ”How to produce an explanation that takes into account what the other person knows and emphasises what he does not?” he says. There will be five to six people working on that project, mostly from the Institute of Computer Science of University of Tartu.

”We are going to experiment, develop a computer program to produce human-like explanations, and let humans rate the system to improve it further. A human being, after all, is the end consumer of this information.“

A unique method

One thing that is certain is Zafra’s research focus is of particular interest to everyone, and there is a lot of effort around the world to find solutions to the problems relating to AI. They are trying a number of unique methods, however. Zafra says that if it were all that easy, then a solution would be already apparent, but like anything that revolutionises its industry, it’s a process that takes time. ”There are also those who say that it can’t be achieved, that you just can’t explain AI’s decisions to humans. That we just have to fold and say that an AI is an oracle, but if AI functionality improves and we use it everywhere, then we want to collaborate with it. If they cannot explain to us why they decided something, then there’s not going to be a collaboration,“ Zafra thinks.

AI that can justify its own decisions would also mean that people would welcome AI into their lives more easily. In healthcare, your doctor will probably always have the final word, but the doctor must also trust the AI when it makes a decision based on its suggestion.

Zafra and his team are doing just that – trying to make sure we progress towards explaining AI outputs in more human terms.

WHAT DOES THE FUTURE HOLD FOR THIS FATHER AND HIS DAUGHTER?

Father Toomas (30) and daughter Emma (5)

Raul Vicente Zafra first tells our father and daughter duo that, as we make predictions for the future, we tend to make them linear – we look at the road we are walking on and predict where it might bring us to. We are just extending the road. “But there are curves, there is the unexpected and there are revolutions,” he explains.

He says to Toomas and Emma that AI is here to stay, and its role in our society can only grow. “People say that robotics is the next big thing. Their role in industry is huge but I think we can say that robotics is here for everyone when there is a 1000-euro robot in every household doing general tasks. Not only vacuuming or cooking, but doing different tasks,” he predicts.

A phenomenon called the feedback loop will enable some sectors to grow much faster, once they have truly adapted to AI and robots. The ones who stay behind will get eliminated from the competition, warns Professor Zafra.

He has a warning for Toomas and Emma too: the same phenomenon, the feedback loop, is also present in social media. “It worries me the most. Algorithms can also be used to polarise, to create echo-chambers. You are given information that you like by people you share the same interests with, and it takes us into bubbles along with those people. You only understand and respect the ones in your bubble, anyone outside of it is vilified and rejected. It’s like you are a different species when you interact with people from another camp, it could be damaging to our development and cooperation as a society.” Zafra believes.

He turns to Emma and predicts that a hundred years from now, when we have personalised healthcare, Alzheimer’s and other mental illnesses will hopefully be a thing from the past. AI could also make us smarter and hopefully more empathetic if it used for the good.

”It can all either go very well or very badly. But one thing is certain – with more and more information we can make better decisions.“

Estonian e-state builder **Peeter Laud:** Vaccinations could have been organised much more efficiently

Peeter Laud, a senior researcher at Cybernetica AS, can be considered one of the founders of cryptology and cryptographic protocol analysis in Estonia. He obtained his doctorate from Saarland University in Germany in 2002 when he was just 25 years old.

His research is aimed at preventing security incidents in complex software systems. This is done using static analysis of the program code of the systems, which enables the correctness and security of the programs to be verified without starting the program itself.

It is no wonder then that his research team also has an important role to play in controlling and improving the security of Estonia's e-state. Even now they are analysing a number of proposals, such as those related to e-elections.

"We also act as consultants to the Information System Authority," Laud explained. "If something needs to be analysed, we can do it: we can guarantee that attacks belonging to certain classes will not be successful. We've also performed security analyses of larger systems and calculated the cost of attacks." This latter means that Laud and his team seek to determine how easy or difficult and how cheap or expensive it is to carry out a specific attack. How likely is it that a PIN code will be guessed? What is the probability that the attacker will be caught? "For example, in the case of a PIN code, the cost can be zero and the probability one in 10,000," he said.

Estonian Centre of Excellence in ICT Research

E-state security provider

The issue of security is and always will be a key issue for IT systems. Laud believes that the scientific community will keep proposing improved methods of analysis, and that with their help they will be able to fully analyse increasingly larger and more powerful systems.

"In order to reach very large systems, you have to be able to compile the results of analyses in such a way that the security features identified for the different subsystems are compatible and imply the security features of the whole system," he explained. "This work is helped by the system itself being designed so that the tasks of each of its components and the resources used to perform them are clearly defined. A negative example we can cite here is the first key in the ID card, which is used for both authentication and decryption. This has a negative impact, because if a weakness is found at one side, it is passed on to the other. There ought to be a third key."

And this is where we come to Estonia's pride and joy: e-elections and the e-state as a whole. Laud and Cybernetica have been behind the security of Estonia's e-state since its inception. Lately the most talked-about solution among these is the system of e-elections and their security. "The science behind it comes from us," Laud says, adding that this is mainly thanks to his colleague Jan Willemson. Laud feels that Estonia is doing relatively well in this area. Difficulties are related to circumstances wherein it is hard to identify a person in the first place. In some countries, for example, a person's identity emerges as a collection of many less well-distinguished events and documents, such as utility bills.

Laud says that the requirements of e-elections are contradictory: both data integrity and privacy are sought at the same time. If we discuss changes, then societal expectations of e-elections have evolved over time, so Cybernetica has had to think up a variety of additions. As society began to pay more attention to the verifiability of votes, mobile screen capture was added to check who people gave their vote to. "Privacy measures have also been added and privacy has become more complex," he said. "The decryption functionality is distributed between a number of servers."

> *The research team also has an important role to play in controlling and improving the security of Estonia's e-state.*

While the previous government was in power, some politicians expressed a desire to bring biometrics into play. The Information System Authority commissioned Cybernetica researchers (Laud's team) to carry out a study in this regard. "We need to determine whether that would be a sensible thing to do," he explained. "How expensive would it be? At present, it seems as though the solution would mitigate certain problems but produce new ones as well. Specifically, it's the question of false negatives that needs to be addressed." Laud adds that they are also examining whether the introduction of secure hardware would help in the case of e-elections. "Hardware that would be cheap," he said. "Something like Raspberry Pi. It wouldn't cost very much, but the question again is whether it adds significant value and what the risks are. No conclusions have been reached yet."

Guaranteeing data privacy

E-elections are currently mainly the purview of Cybernetica's product development departments, although innovations and improvements that need to be made still also reach the research cell led by Laud. This is especially true of foreign projects where, among other things, the above-mentioned issues of identification must be resolved if a person does not have a personal identification code as such.

Laud says that the working group led by him is an old one. "We've been defending Estonia's e-state since the end of the last century," he said. Diving deeper into Laud's field of research, the central topic is the issue of privacy-friendly calculations. Put simply, when someone collects data in order to create added value, several parties immediately emerge. There are people whose data are used and those who can view them, including the data collector themselves. The data may only be viewed by these

people and to the extent specified. There are protocols in place to ensure that the data are always protected, including during the calculations performed on the data.

There is a good example from a few years back. Laud's working group looked at graduating IT students: how their income is affected by them taking up work before graduating compared to graduating first and then starting to work.

"We collected data on participants in study programmes and data from the Tax Board on income tax paid," he explained. "We put together statistics based on those data. No one was allowed to see specific names, personal identification codes or other data in the process. That's one example of how we put what we were doing into practice. We're now looking for more such applications." Laud gives another example: checking the so-called border blacklist. "You want to obtain interesting information based on data, but at the same time it's important that you don't come up with too much interesting information," he said.

Laud says that during the process, 'noise' must be added in a controlled manner to obscure important information and guarantee that the input data do not come out to those who should not view them. However, the noise must be such that the data can still be used and viewed by those who are allowed to do so. An example would be a doctor who has to make a decision about a specific patient based on the data.

> *Societal expectations of e-elections have evolved over time, so Cybernetica has had to think up a variety of additions.*

At EXCITE, Laud's research group collaborates with Marlon Dumas and

Group photo from left: Andre Ostrak, Kristjan Krips, Jan Willemson, Dan Bogdanov, Alisa Pankova, Peeter Laud and Jaak Randmets.
On screen from left (up) Nikita Snetkov and Hiroki Kaminaga, (down from left) Liina Kamm and Armin Kisand.

Dominique Unruh, with whom they have also supervised doctoral students. The research group has also worked with Tarmo Uustalu. One of the doctoral students Laud supervises also performs parallel calculations for secure collaborative computing within EXCITE, while another is researching privacy-maintaining machine learning and a third is focussing on e-elections.

Vaccination data management could have been organised differently

Laud is of the opinion that the use of data related to COVID-19 vaccinations in Estonia could and should have been organised differently from the very beginning. Here, too, data had to be gathered from several places. However, combining them securely could have been arranged much more simply than it was.

"Vaccination data are scattered all over the place at the moment," he remarked. "My wife is a medical professional and got vaccinated, but her GP still called her again to go and get vaccinated. Information just wasn't moving. If we had infrastructure that preserved the privacy of data in different agencies, we could simplify so much." At present, the reconciliation of information requires the consent of the Data Protection Inspectorate, which is not easy to obtain. The inspectorate is also aware of the modern solutions Laud is talking about. "Theoretically, it's been devised how we could combine the processing of privacy-maintaining data with the X-Road," he said.

WHAT DOES THE FUTURE HOLD FOR THIS FATHER AND HIS DAUGHTER?

Toomas (30) and his daughter Emma (5)

To reassure this father and daughter, Laud says that one thing is for sure: we are learning how to better make secure systems all the time. All kinds of systems analysis methods as well as certification methods and the right business and other processes – their development and, to a lesser extent, their implementation – bring us closer to big problems caused by a lack of information security no longer existing or being significantly lessened.

"These methods include secure hardware whose implementation CPU manufacturers have taken to heart," Laud explained. "Certification methods and processes are evolving around them, so there'll be no panic-like events around the ID card akin to the one we saw back in autumn 2017. Problems might still come up from time to time, but they'll be sorted out much more calmly."

As such, we have good methods with which to achieve certain security features: identification and authenticity. Laud also says that authenticity needs to be rethought. Video and 3D images and audio can already be synthesised with any content, and in the case of 3D printing, also any object. "A new concept of digital ownership is needed," Laud remarked.

Now, however, comes a warning. Whereas the situation with security may be much better in the future than it is now, this may not be the case with privacy. Laud says that in words at least we value privacy; even the GDPR exists. "But though the GDPR's teeth are sharp, they're not paired with means of extricating yourself from them," he noted. "I don't see any significant pressure being brought to bear to process data privately. Certainly not in the public sector. For them, it's easier to add an exception to the law that allows the desired calculations to be made without adequate protection than to introduce privacy technology. I don't see any motivation in the private sector either. They have organisational alternatives as well that for some reason are considered good enough. So I certainly wouldn't rule out the advent of Chinese-type social credit."

To young Emma, Laud would say that complexity theory will be completed. We will be able to assess the resources needed to solve tasks, and to give lower bounds on the necessary resources, and this knowledge is good enough to practically structure system security around these solutions. We will also estimate how many resources will be needed when one or another algorithm is attacked if the algorithm itself also uses a certain amount of resources. "Thanks to that, we would know exactly how long one or another key would need to be," Laud added. "This would also give us certainty about the security of encryption algorithms."

Vitaly Skachek

Helped to build foundations for the Internet of things

Vitaly Skachek's field of research is relatively well-established on a global scale, but currently his research group is the only one of its kind in Estonia.

Skachek, who came to the University of Tartu at the end of 2012 and works at the Institute of Computer Science at the University, says that the initial works in his field were published in 1948. Shortly thereafter during the 50s, coding theory really took off. He believes that in the not-so-distant future, communication will become faster, data will move much more intensively, and therefore communications must become more reliable as well. That is where Skachek and his research group come in.

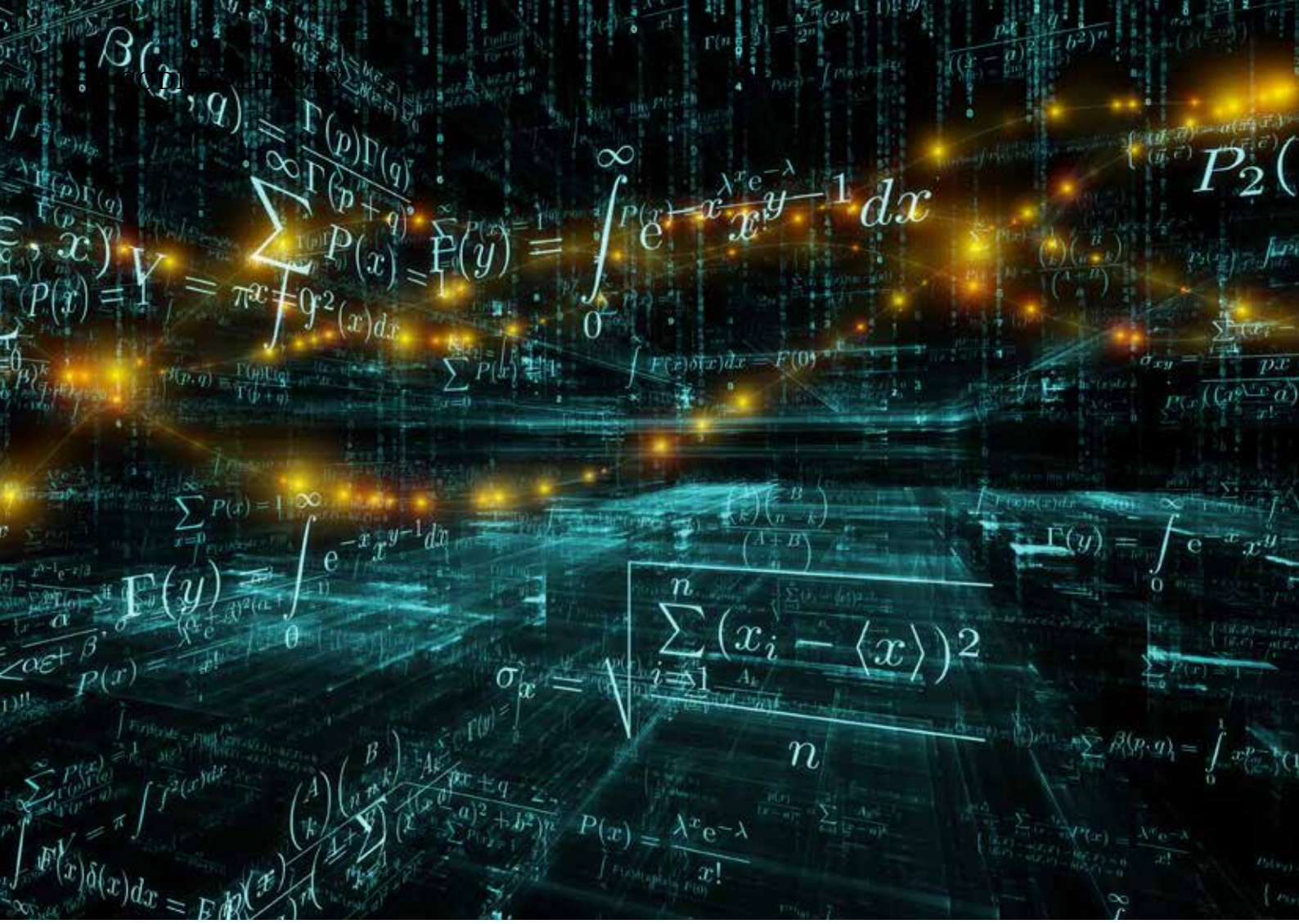
"The fundamental problems will not be solved entirely," he warns, adding that there is a lot of hype around certain technologies like robotics and machine learning. "But we are very far from independent artificial intelligence, like in the books of Isaac Asimov," he laughs.

He thinks expectations should be realistic. A very small percentage of research becomes something practical, and it could take decades before any finding becomes especially relevant. He likes to make a reference to his students about the French mathematician Évariste Galois. Galois only lived a short life in the early 19th century, but his works laid the foundations for both field theory and group theory. What he discovered was first thought of as a mathematical exercise, yet a two century later it has emerged to become an integral part of the cryptography and security domain. At first appearing to be an unnecessary theoretical issue at the time of its inception, it has since made a huge impact. "If Galois was working in a university today, he might be fired for not doing practical studies and not getting grants," Skachek laughs. The researchers of today may share this same fate – their discoveries acquire their true meaning years later.

> *"We are very far from independent artificial intelligence, like in the books of Isaac Asimov.*

Working with EXCITE colleagues

Skachek's group is the only one in Estonia that works in the field of codes for error correction and topics related therewith. To put it simply, we are discussing coding theory. He describes this research area as lying in the intersections between the fields of theoretical computer science, mathematics and electrical engineering.



"As part of EXCITE activities, together with my colleagues Ago-Erik Riet (Institute of Mathematics and Statistics in Tartu), Eldho Thomas and Ülo Reimaa, as well as the research group of Helger Lipmaa in Tartu, we worked on the properties of access schemes for load balancing in distributed systems and for private information retrieval," says Skachek.

He speaks highly of EXCITE, because it brings together top scientists and gives them an opportunity to collaborate. "I have met people I wouldn't have met otherwise. Taltech's Jaan Raik is doing work related to ours, and it has been an interesting connection. Being a member of EXCITE definitely has its benefits," Skachek suggests.

Professor Skachek talks about different modes of communication, whether it is wireless, optical, or wired – the end goal is for it to be fast and reliable possible, and time has shown that we have moved on from 3G to 4G and then to 5G quite quickly. "In theory, we can do better but we must find the correct way. Time moves quickly; twenty, or even ten years ago, we were talking about computer-to-computer and mobile-to-mobile communication, now it is much more complex. We are talking about distributed systems, such as the cloud," Skachek says.

Foundations to IoT

Error correction coding deals with reliable communication and data storage problems. Whenever you have a data storage device like a flash memory, a hard disc or something similar, or you have communicating devices like a mobile phone or a computer – you will always experience errors. Whether it is physical noise or any other kind of disturbance to our communication. "This field operates on the fundamental level of how we deal with these errors. How do we make communication more reliable," he remarks.

His field is heavily mathematical – scientists here use a lot of sophisticated mathematical tools, but predominantly algebra, combinatorics, and graph theory.

The main question here is - how can you transmit and store information reliably? What can and cannot be done? The considerable growth of distributed systems has made a lot of changes to the field but it is also right at the epicenter of what the future holds.

Of course, when we are talking about Skachek's field, we have to discuss the impact of the Internet of things. Many say that in the not-so-distant future, we will be surrounded by devices that communicate with us, and not just with us, but most of all with each other.

"Actually, we built the foundation of the Internet of things," he says casually. "Communication became better and more reliable for it to occur," he adds.

Two key problems, similar solutions

In 2004, a group of researchers in a crypto community discovered that you can use algebraic, mathematical tools to improve the efficiency of access to the databases. "We picked it up in 2012. Our work is theoretical, and

we have yet to work on real servers, but you can certainly boost the performance with these algorithms," he says.

Skachek's group is working with two problems coming from two different scientific communities. One is load balancing - think about Google, Amazon or any other big names, that has to deal with massive amounts of data, they all have servers around the globe.

"I'll give you an example. Donald Trump had a lot of Twitter followers, and each time he tweets something there is a lot of interest, although Twitter has many servers, the one where Trump tweets receives a high amount of traffic. In this case, data needs to be distributed more evenly using a process called load balancing," explains Skachek.

Professor Skachek says that they are working on a new model of load balancing, a better model compared to the ones that are used today. "It still requires more research," he admits.

Another issue is private information retrieval. You have many servers to store one database. Users are interested in a particular piece of data, but you don't want any outsiders to know what kind of data it is.

"A practical example: sensitive medical data can be accessed by the patient and the doctor – everyone else shouldn't be able to know what information is accessed, nor should the company that maintains the servers. Load balancing and private information retrieval are different problems, but it turns out similar techniques provide a good solution to both," Skachek shares.

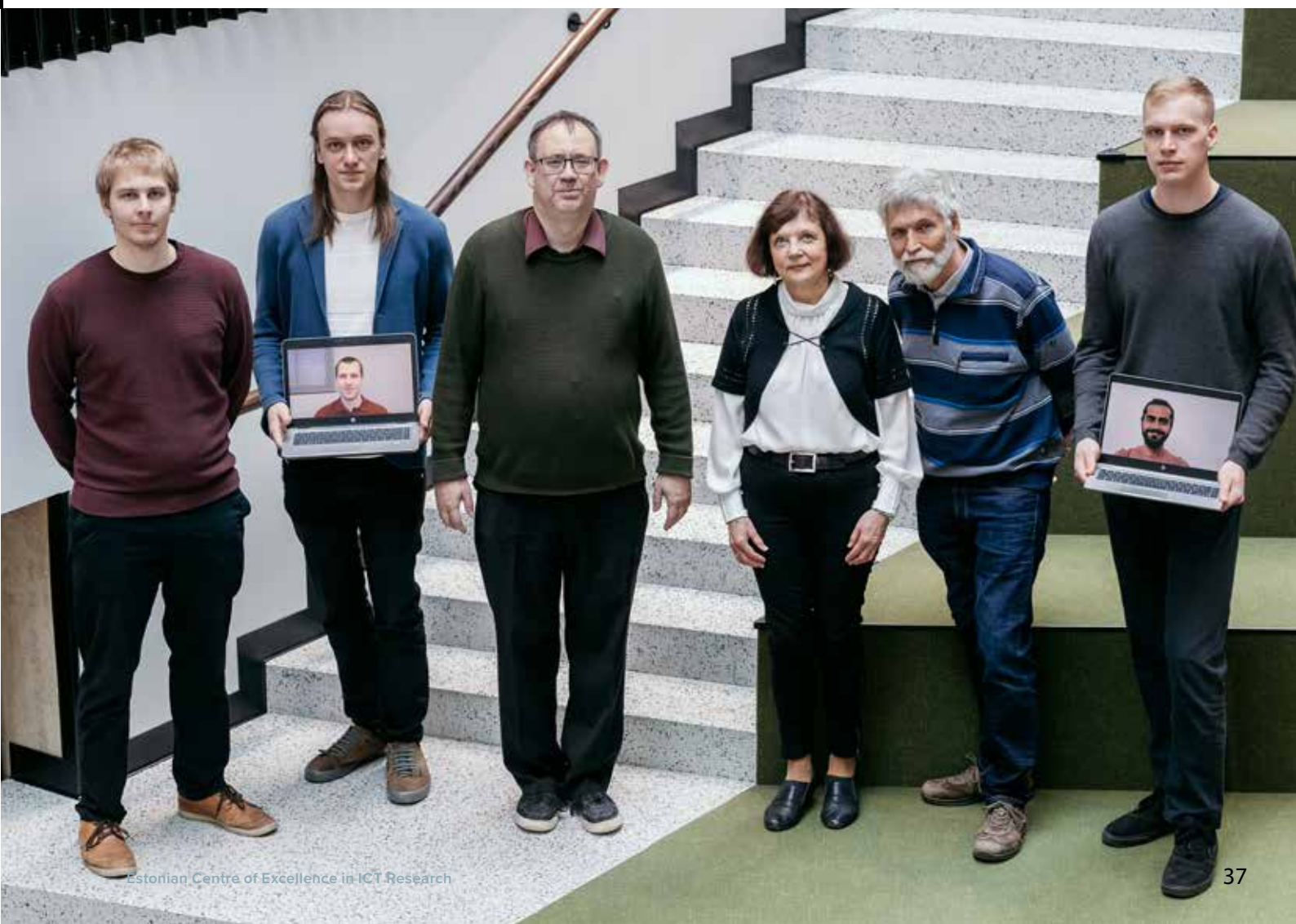
> *Maybe it is time to get to know each- other, because smarter solutions can be of use to any company that deals with data.*

Another problem for big companies

The big guns in the technology sector also face a problem related to the synchronisation of data in distributed systems, which Skachek and Ivo Kubjas are attempting to find a solution to. Skachek says that such an issue is important in the distributed data storage systems, such as those employed by Dropbox, Google Drive, and similar applications.

"We proposed an improvement to the known schemes which leads us to more reliable synchronisation protocols. The proposed method works in some cases, where the previously-known schemes were unable to," describing their success.

To put it simply, here is an example. Let's say you have a file opened in Google Drive and you have shared it with others. You make a change, and you'd like others to see it as quickly as possible. The key issue here is to make the piece of information you



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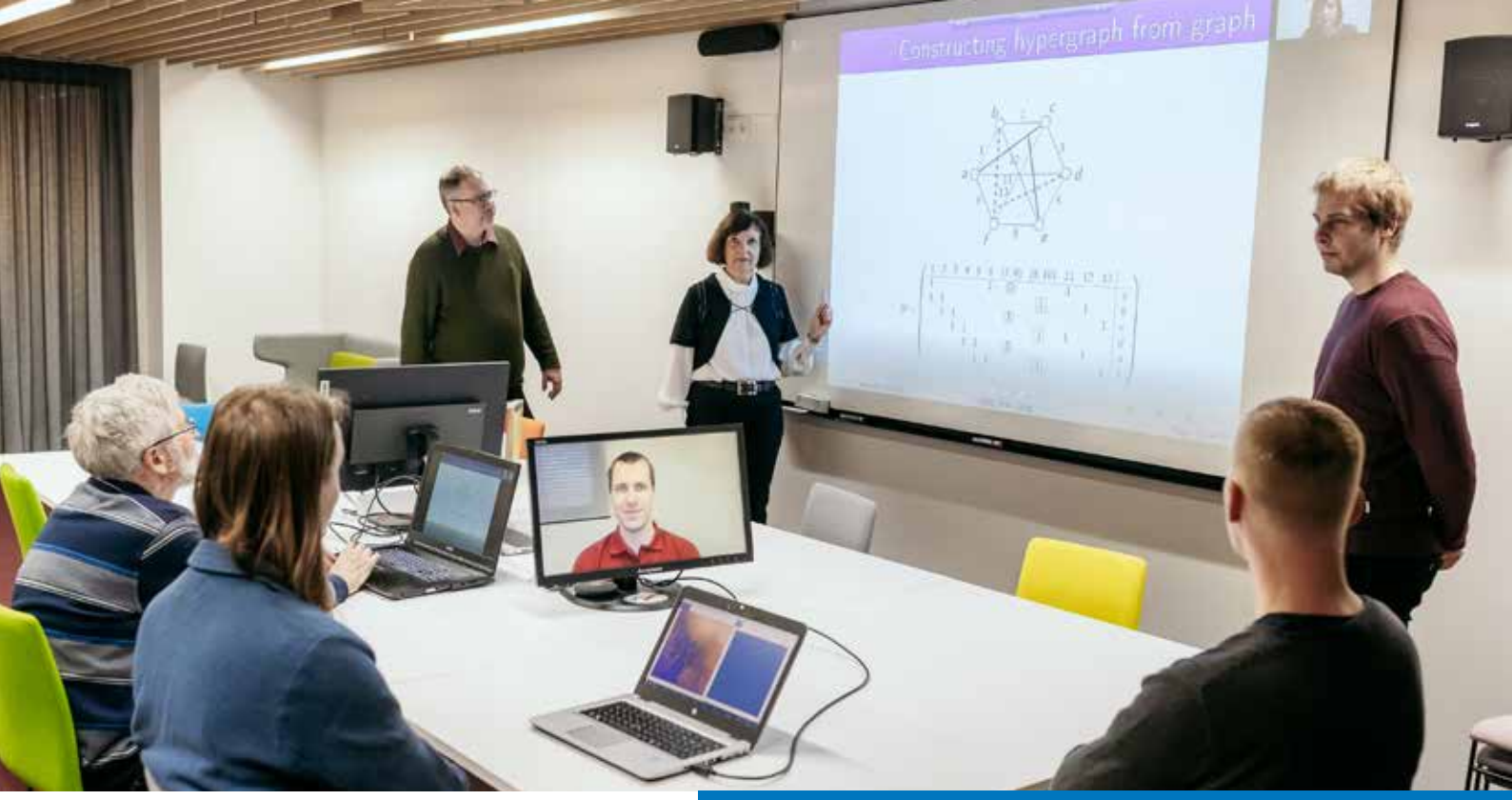


transmit to the others as small as possible, otherwise it could take a lot of time to synchronise. Your friends wait for ages. It is an algorithmic problem. Different devices need to understand instantly what the change you made was.

"There are many ways to solve that, but one of them is to use some data structure – you hash the data, make signatures of it. A signature is very small, and with the help of smart algorithms, other devices now know what the change was. This is very difficult to achieve," Skachek says. And they found a smart way to do the synchronisation more reliably.

Interest from companies

How does it all benefit companies and people? Is there an interest among enterprises? Skachek says it is a tricky question, suggesting Estonian companies are usually quite small and mostly app-oriented. Big companies like Amazon and Google are more diversified. To them, even a little step forward in how their technology works results in millions of dollars in profit. "The amount of data there is astonishing. Traffic is huge. Usually, this type of research is interesting to them. These companies are based mostly in the big technological hubs in the USA, Europe and China," Skachek acknowledges. However, when it comes to security and privacy, it's not just the big corporations that are interested - the smaller companies may be interested as well.

"We don't necessarily know the needs of smaller startups. They might not be aware of their problems and that we may have potential solutions. Maybe it is time for universities and companies to get to know each-other, because smarter solutions can be of use to any company that deals with data", says Skachek.

WHAT DOES THE FUTURE HOLD FOR THIS FATHER AND HIS DAUGHTER?

Father Toomas (30) and daughter Emma (5)

Skachek says that there are many unresolved problems in the field of information theory, which were not solved by the scientific community in the last 70 years, and therefore he expects that some of them will remain unresolved by the year 2050 as well.

"At the same time, there was a lot of progress in error correction, which led to the development of much faster and more reliable communications systems. For an ordinary observer that progress manifests itself in faster mobile communications (2G, 3G, 4G, and now 5G), in faster internet connections via fiber optics, in higher capacity of hard disks and portable memory devices, and in more accessible and efficient cloud storage," he says to Toomas and Emma.

In the last few years, the techniques from the field of error-correcting codes have found new applications in distributed systems, in network communications, and in privacy and security.

"I predict that in 2050 the error-correcting coding will be employed to a higher degree in decentralised systems, such as cloud storage and cloud computing. There will be more synergy between coding theory and other fields, such as machine learning and privacy and security."

Dominique Unruh:

Security of communication will have to be proven by computers

Dominique Unruh studied cryptography in Karlsruhe, Germany, at a University known today as The Karlsruhe Institute of Technology, before coming to Tartu ten years ago to continue his research. Unruh was one of the first in his field who started thinking and talking about quantum cryptography, a field he says must find critical solutions to the problems that quantum computers create.

When he was studying, quantum cryptography was still a niche area. "When I talked to other cryptographers back then, they said they didn't care about that. One highly-rated professor walked away when I started to talk about it. That was 15 years ago, now it has changed," Unruh says.

Cryptography is a method of protecting information and online communication through the use of encrypted codes, so that only those for whom the information is intended can read and process it. Unruh says that the systems of today will be unsafe from the moment quantum computers arrive, something he knew years ago, but is now something that a lot of scientists are hurriedly working on.

"Thinking about solutions to this

has become popular during the last three years, the field has exploded into life."

Negative scenario is good

No one knows the exact time when quantum computers will be ready for mass usage and it is quite the headache for those who must resolve the security issues. Unruh says that he is not an engineer and therefore not the right man to accurately predict when that will be, but what he is more sure about is that engineers will have very little say in it either.

"Looking at it as an expert in cryptography, we tend to take the pessimistic view, that they will come sooner rather than later. Quantum computers are beneficial of course, but at the moment we see them as something negative," Unruh explains with a little grin on his face. "We are not on red alert, but in a "let's not waste any more time" state of mind," he adds.

It all began several years ago, when The National Institute of Standard and Technology in the USA made a public call to develop post-quantum secure encryption schemes. "Then people started to take it seriously," he remembers.

The race has begun, and finally the same institution will decide - which standards in encryption and signatures will be in place. "If that is done, it will take years before they are installed in our devices," Unruh explains that it mainly concerns hardware, suggesting that it could be an expensive process. "In Estonia's case, our concern currently is what we do as scientists might not be useful to a smart card like your ID card. On computers and mobile phones, the new security solutions will work for sure, however smartcards might be just too small," he warns, but acknowledges scientists are working on these solutions as well.

Expensive in this case doesn't refer to money, but rather the speed of the processes. Most of today's devices should be compatible for the big change, but if not, a new device will be needed.

"Private users shouldn't worry too much, because an update will be made by service providers and I hope users will get these updates automatically." But it would be wise to still ask if the device you are buying can be suitably upgraded. They might also be too expensive for some devices.

> *A whiteboard is one of the most important communication tools a mathematician has, you can't discuss formulas in a chat.*

Missing the blackboard

As Unruh's main research field is quantum and post-quantum cryptography, his days are full to the brim with mathematics. Practically, it means he is standing in front of a blackboard writing formulas, and Unruh employs this perspective when trying to see the mathematical problems behind cryptographic systems. The other part of his work is writing articles, his predominant method of communication with the cryptography community.

He says that blackboards in his field of research are an integral part of the work, and he misses face to face interactions with fellow researchers.

"A whiteboard is one of the most important communication tools a mathematician has, you can't discuss formulas in a chat. If I tell you a formula, you wouldn't remember

anything at the end, a formula is a lot like a picture in this way. Online whiteboards are not the same either, so the pandemic has been challenging in that sense as well."

Teaching the computer

The other matter that interests Unruh and his colleagues is formal verification. No matter what kind of cryptography we are discussing, scientists need to make sure that it is resolutely secure. It needs to have a mathematical proof. It says rather simply, in this system, the communication cannot be hacked.

"The problem is people make mistakes and proofs are very complicated. Whether it's the person who writes the proof or the one that reads it and verifies it, neither one might not notice a flaw. It's like finding a needle in a haystack, but that one mistake might change everything and make a system flawed," Unruh explains.

He adds that in research papers there are constantly errors. In many cases, they can be corrected and they don't mean that much, but they can have a very serious and detrimental impact as well. Verification loses its meaning when we just hope that these complicated calculations are correct. Even when you really are focused, you still might make a mistake. "One solution is to have a computer do the proof, but first you need to somehow explain the proof to a computer. One thing computers are – they are very careful. You can't explain a proof to a computer when you have made a mistake. It is very complicated, but essentially when a computer understands you, you have succeeded," Unruh describes.

A tragic experience

Unruh shares a painful experience from his own not so distant past. He wrote an article about 70 pages in length and put it up online, not yet published in any magazine.

"Someone wrote to me, that on page 50 there's a formula that he doesn't understand how it works. I checked and realised that I had made a little mistake. But it was still a tragic one, three months of hard work straight down the drain. I was lucky it was discovered, he was the only one who wrote to me. If no one had noticed the mistake, everyone would have believed the article. But it was a very important proof for quantum cryptography," he recalls. It tried to prove that one hash function that is commonly used works in a post-quantum setting. "We still don't know that. It doesn't mean it is not safe, but we can't be certain," he says. It is why computers should come to the rescue.

You have to invent a language

How do you explain quantum cryptography to a computer, so it can ensure the proof is correct? Like most computer-related solutions, you have to write a program. For that, Unruh's team has developed its own language. You must teach the computer what a secure system is, so what are the logical set of rules when making a security proof?

The translation for a computer is ten times longer than it would be for a human and all of it written in an artificial language. Unruh's work is to make the language easier and easier. It may never be as compact as the human version, but Unruh hopes they are getting closer and closer. "I don't want my research team to be the only one able to make security-proofs like that, because there is a lot of crypto around us. My job is to make the tools, the infrastructure that others can use as well."

Unruh's team has already found a method and performed a non-trivial security proof, which was a considerable effort. While it worked, it would be challenging to convince others to use it, they must find a better way.

> *You can't explain a proof to a computer when you have made a mistake. It is very complicated, but essentially when a computer understands you, you have succeeded.*

He says that there are some aspects that computers are better at then we are. An easy example - you want to prove that one big number multiplied

by another is a third, larger number. It is something every person who has attended school could prove. However, we are not better at that than computers. If something is certain, but you need to check that several times, then a computer can do it better. "We can automate these aspects, computers can and will answer these questions automatically, so that people can focus on where our brain is needed most."

A mistake can be costly

To understand the importance of this field of research, let's take the competition The National Institute of Standard and Technology established. Scientists are developing post-quantum cryptography solutions and one of them will be chosen as a winner. Scientists around the world have to confirm that this solution is safe and impregnable, then governments and companies around the world start to adapt it. A lot of money is spent because we have a foundation that is as solid as possible.

"And then someone comes forward and says it is attackable. That would be a horror scenario, and we want to avoid this as much as possible," Unruh says. Microchip manufacturers use formal verification, airplane manufacturers do as well. If something is unsafe, then a company could lose a considerable amount money, but it would also consequently be a very real threat to our lives.

WHAT DOES THE FUTURE HOLD FOR THIS FATHER AND HIS DAUGHTER?

Father Toomas (30) and daughter Emma (5)

Dominique Unruh hopes that both Toomas and Emma will live in a world with secure devices. That there would be no more attacks on our systems because they are unassailable. They can use their data with peace of mind, knowing that they and their data are safe even when online.

"I hope that we can use private data, but others will not be able to see it. Today, we are giving it away every day ourselves. Companies use it for their own benefit. I would like data to be used only for the good of mankind, not to feed the profits of companies," says Unruh to our father and daughter. "I would like big data to improve our lives, instead of knowing which product to buy next."

There will be very secure systems, but Unruh says that he wouldn't believe they are a hundred percent trustworthy until they are computer-verified.

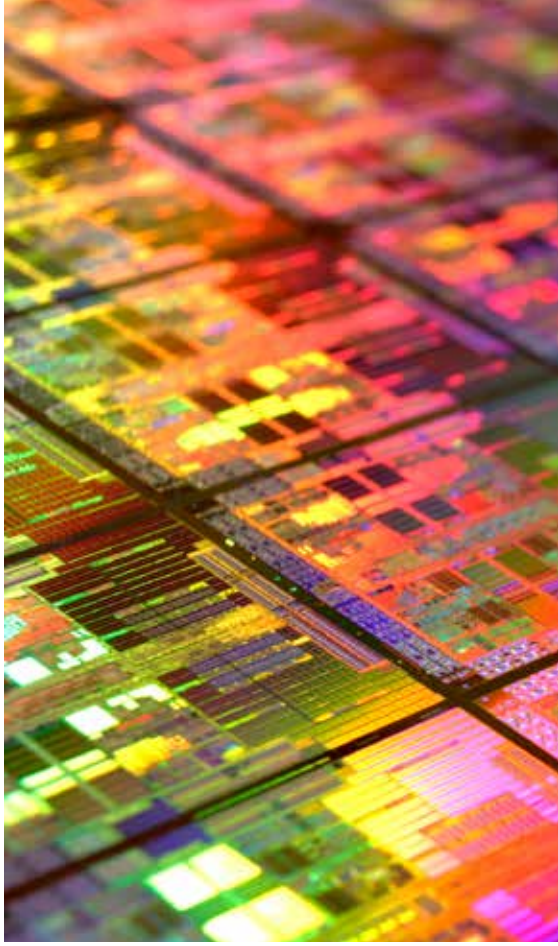
Jaan Raik:

Computers must undergo a revolution in order to continue their rapid development.

Professor Jaan Raik has been the leader of the Centre for Dependable Computing Systems at TalTech and has held an interest in computers for decades. He works in the computer chip science field, where it is necessary to rack your brain in order to design faster, more complex and more sustainable chips. The research team led by Jaan Raik is one of the larger research teams taking part in EXCITE and has been highly successful in coordinating pan-European research projects.

His opinion is that, in the near future, a major shift must be made in this field, perhaps even a revolution, because computers, processors, servers and everything related to it will have a rate of energy consumption which we cannot sustain.

"Computers themselves only have one small step left before they reach the level of the human brain," says Raik when discussing the power and



complexity of computing and decision-making. "We are not that far off from the brain," he notes. Therefore, it is only a matter of time until computers reach the capabilities of the human brain.

"The key aspect in which we are greatly lagging behind is energy consumption. Our brains consume between 12 and 25 watts of energy, which is around one-fifth of a person's energy demand. "That is absolutely nothing when compared with a supercomputer. The latter requires an entire power plant," says Raik.

Therefore, the efficacy of the computers is insufficient and the amount of resources they use sets limits of its own. The clock rate of computers has not risen in the last decade. Why? Power consumption would simply be too significant. "The chip inside there would just burn out. It would exceed the sun's temperature or the temperature of a nuclear reaction. The chip would become too hot and there would be no way to cool it," clarifies Raik.

> *When discussing power and complexity of computing and decisionmaking, it is only a matter of time until computers reach the capabilities of the human brain.*

As a single processor cannot be made more powerful, they have started using multi-core processors. Raik believes that this is a problem with several aspects.

"The first is that our planet will suffer. We are generating a vast amount of carbon dioxide while computing. *Bitcoin* mining is a great example. It requires vast amounts of energy, but the activity itself does not provide essential added value. Another bad aspect is that all necessary processes take up a vast amount of energy. It goes without saying that mankind does not wish to abandon technology" notes Raik. Rather, new is better and it must always be more powerful. Energy itself is not infinite; therefore, something needs to change.

"The solution is most likely going to be a fundamentally new paradigm for computers. I cannot exactly state what that is going to look like. Perhaps they will attempt to imitate nature as nature has done a great job with economic computing. Times are certainly going to change," says Raik convincingly.

Quantum computing and new technology on the way

Jaan Raik speaks about chips that are based on silicon technology and the architecture of Von Neumann, which originates from the 1940s. Those inventions will soon celebrate their 100th birthday and Raik believes that this knowledge will soon reach its limits. He is hoping that a revolution will occur in this field within 10-20 years at the latest.

Raik believes that quantum computers will not exist before 2050. They will be a major breakthrough when they arrive, of course, and many processes that require a lot of time on current computers will be resolved extremely quickly. His cited examples are path planning, search assignments and certain types of optimisations, which these types of computers could solve in an instance. He admits, however, that this is not an absolute magic wand because a quantum computer cannot solve every task.

"However, the direction is likely moving towards the emergence of several computer technologies, each with different knowledge, such as neural networks, processors, separate graphics processors, etc. Niche solutions will certainly emerge that will be able to perform certain tasks extremely well," the professor anticipates.

Still, the energy consumption problem remains. One answer may be found in electrochemistry, where chemistry, the movement of substances and certain reactions are at work. "Just as we have certain substances in our brain that neurons can send or secrete. One option is to see how the brain is constructed and then imitate that."

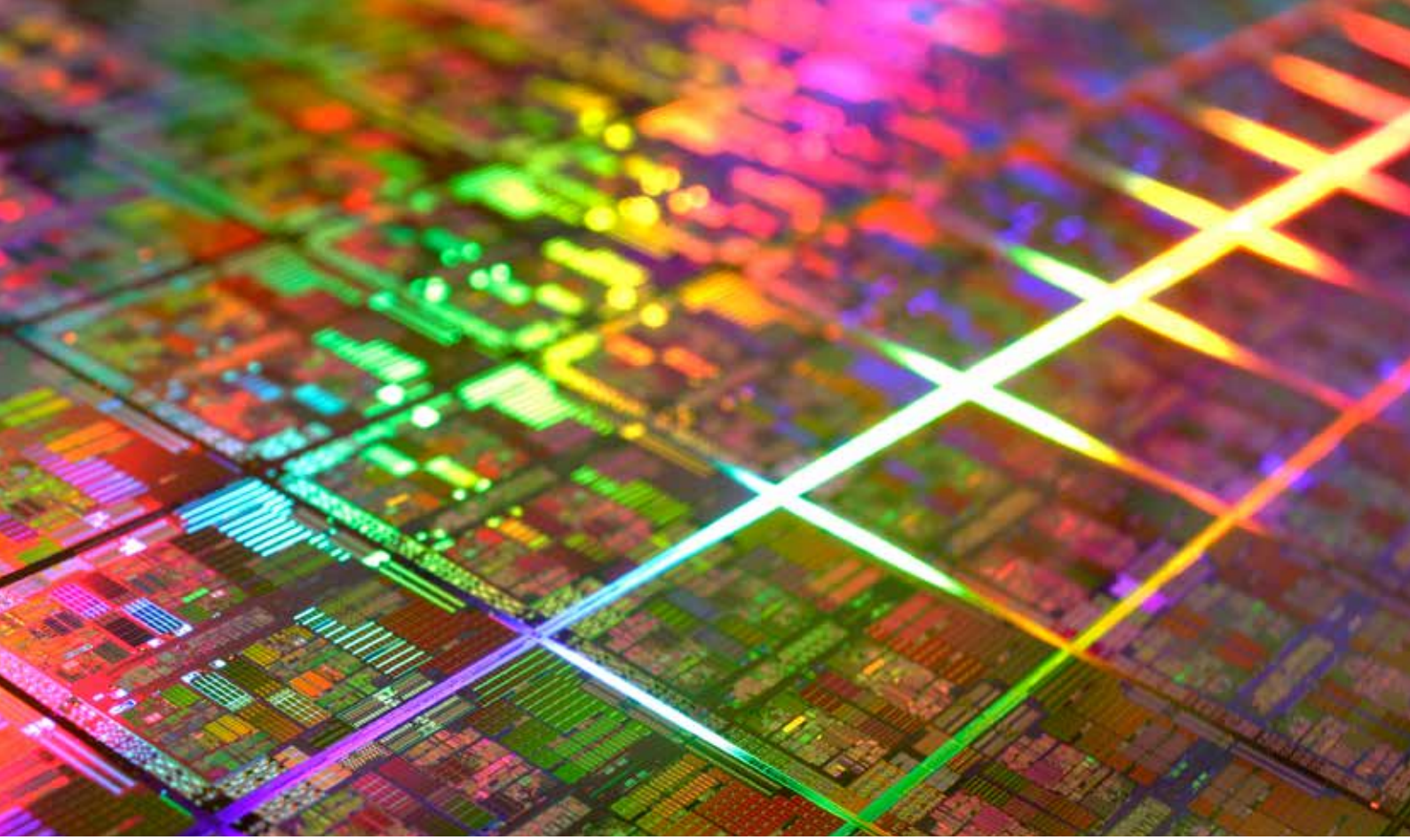
Autonomous robot

Jaan Raik's research teams are working on several significant projects. EXCITE projects are extremely interesting and quite 'outside-the-box' according to Raik. Let's begin with machine vision, where the emphasis is not on the machine vision itself but rather on the autonomous system that controls it. It is essentially a robot that is not externally controlled. It acts on what it sees and makes decisions accordingly.

"It has of course been programmed with some type of overall mission that it needs to accomplish, but while it is working or in some sort of environment, it starts to draw its own conclusions, take action and see how the situation develops. It attempts to get closer to its objective independently," says Raik.

He adds that this is an extremely exciting application made even more interesting by the fact that Alvo Aabloo (also from EXCITE) has a team where his people are able to create artificial muscles as well as miniature soft robots. "We provide the capacity and infrastructure when building chips," Raik says on the collaboration.

Aabloo's postdoctoral fellow Saoni



Banerji defined a task with a camera robot where the robot looks at and observes the situation inside a person's ear. That robot's job is to diagnose inflammation. The camera image moves on to a neural network where it is processed. The robot itself controls the camera and processes the image. This was Banerji's original idea and a project proposal has been written for this. Raik states that this solution's application may have a broader use – it can be used on various robots that work independently and with whom contact cannot be established. "The robot has a brain that understands what it sees and processes the image it sees. The robot classifies what it sees. It recognises objects, localises them and can react to them. When it sees something, it moves accordingly," explains Raik.

One-size-fits-all solution

Raik works alongside Maksim Jenihhin, a professor who is a member of his research team, adjunct Professor Masoud Daneshtalabi and students in order to develop a chip that is 40 nanometres across, i.e. extremely small; it can be said that this is miniature technology. A rather complex system can fit on one square millimetre. A nanocamera, which they do not need to develop themselves, will be attached to it. It will be purchased. There is a neural network inside the chip that detects objects. There is also a designed controller on top of the chip, which in turn may be programmed with different algorithms. That controller receives information straight from the neural network. The neural network can be considered the brain of the miniature system as it processes the image from the camera and also controls the robot.

> *Our objective is to make a one-size-fits-all chip so that we can offer it to other research teams and/or companies that can use the same machine vision-led approach for other applications.*

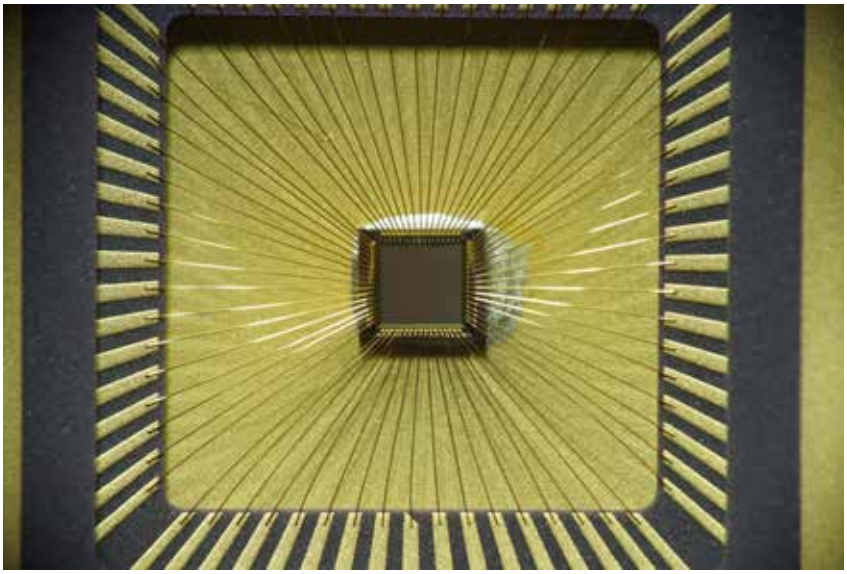
The researchers have held discussions with various companies on possible interests and applications. The medical sector has had the most concrete interest, but the real application possibilities cannot yet be imagined.

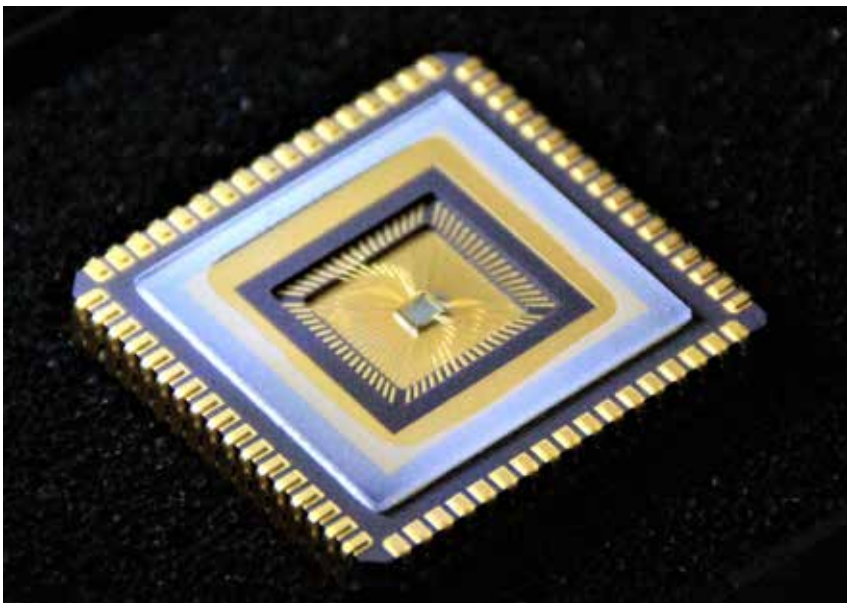
"Our objective is to make a one-size-fits-all chip so that we can offer it to other research teams and/or companies that can use the same machine vision-led approach for other applications," says Jaan Raik.

An operational prototype must be created

The work that the chip can do is limited by the camera resolution, the size of the neural network as well as the complexity of the controller. "However, this still has a great deal of potential. We do not yet know where its limits are," tells Raik. He elaborates that when considering resolution, it will have 300 x 300 pixels, two realised convolutions in analogue electronics as well as two unifying layers and a three-layer neural network where each layer has around 400 neutrons. It also has a simple processor and a limited number of control signals. "Those are its parameters, but even with these, we are able to accomplish great things."

Raik states when discussing the soft robot that the plan is to make something that looks like an insect. The robot uses artificial muscles in order to move around – the muscles contract with the help of an electrical impulse and afterwards they will extend





again. This insect is really small, light and consumes a negligible amount of energy. Raik believes that being an intelligence insect could very easily be one of its applications. Nevertheless, this is a miniature robot that has the capacity to climb somewhere where there is very little room and where it cannot be contacted.

The first objective is to create an operational prototype which shows that this miniature self-seeing and self-managing robot, which requires very little energy, is actually realistic.

We cannot say that what Raik is doing in association with Aabloo is an entirely new approach. The uniqueness of the work done by Estonian researchers is embodied in programmability. The second innovative aspect is that the neural network they are building is mainly something that has not been done before. “On the analogue electronics side there are tricks, which we can use to make the neural network more compact and simpler; however, we lose the linear activation function as a result. However, a nonlinear system is great in some ways. Inaccuracy can even be a positive. It makes learning more efficient. This is an exciting novelty,” explains Raik. There are also smaller unique aspects that our researchers provide to the wider scientific community in the form of articles.

Putting theory into practice

Raik’s second collaboration is with Professor Maarja Kruusmaa regarding underwater sensor networks. Raik has been involved in breakdowns and testing from an early age. He has involved himself with this subject for 28 years, but mainly theoretically. Studying underwater sensor networks provided an opportunity to apply this knowledge in real life. This is an environment in which there are a lot of breakdowns and where reliability is a major concern, according to him.

You can read more about this project on pages 48–52; however, Jaan Raik explains that underwater breakdowns may be extremely severe and it is very difficult to receive a clear signal and a concrete result from there.

In collaboration with the Centre for

Biorobotics, Raik's research team was to manage breakdowns – how to make intelligent conclusions from all of the data. In addition, they we able to create a good system that worked on various levels – on the sensor level, the sensor group level as well as the aggregated data level. He was able to make a diagnosis on the basis of those things – how healthy is the sensor network, which sensors are permanently broken, which of them have an electrical issue and which have a physical defect? They were also able to compute the flow rate, taking the corresponding defect into consideration.

"It was positive for us that we received a full article in the European Dependable Computing Conference – it was a great accomplishment. This collaboration fortified my theoretical side," says Raik. Raik and academic Maarja Kruusmaa are both supervising Lauri Vihman, a PhD student on this topic.

Self-testing satellites and smart biomedical engineering

Raik's research team contributed to a wide range of topics in the EXCITE centre. First, in the space sector, where research team member Dr Vineeth Govind worked out a fail-safe buffer for TalTech's satellite project, which expedited the transmission of satellite image data. A research project on the topic of self-testing satellites was conducted in collaboration with Professor Jüri Vain, who is on the research team of academic Tarmo Uustalu as well as a jointly supervised PhD student. This collaboration provided three scientific articles. Unfortunately, something happened here that is often the case in research projects – the PhD student decided to stop their studies.

Raik and Gert Jervan, a professor on his research team, worked together in the biomedical engineering field alongside Professors Ivo Fridolin and Maie Bachmann from the Department of Health Technologies at TalTech – they supervised PhD students in collaboration with each other. Laura Orgo is a PhD student who successfully defended her dissertation in March 2021; the topic of her dissertation was using EEG signals to analyse and detect depression.

In addition, a senior researcher of the research team, Dr Tara Ghasempouri, developed human language processing algorithms for automatic classification of cybersecurity reports in collaboration with the Department of Software Science and Dr Mairo Leier collaborated with the Centre for Biorobotics in the sensor networks field.

Top-level research is no longer a priority in Estonia

"EXCITE is a lovely exception, but the odds of receiving funding for research in this country is basically close to zero. Even for those individuals who are widely known and respected in their respective fields," says Jaan Raik.

He reminisces about the mid-1990s where there wasn't too much money in research and people departed. After that, however, funding opportunities increased dramatically. Estonia became a considerable research site in Europe. Funding for research has steadily decreased over the last decade.

"When we look at the current situation, it becomes clear that Estonian research will inevitably dwindle. At a certain point, funding will turn into a waste of money. Should we reach a critical threshold, we will fund research in conditions where the apex has left and the research that is funded is no longer research," illustrates Raik. If top-level research can no longer break into the best conferences and magazines, it is no longer research.

Raik continues, saying that we are approaching this critical threshold, which is sad because Estonian research and Estonian IT research have both been a considerable force on the world stage. We are unusual in Eastern Europe. e-Estonia is widely known, but our researchers and research teams are also well known.

"We will lose a critical amount of research in the upcoming years. EXCITE is a speck of hope, but that alone will not save our research," he notes.

WHAT DOES THE FUTURE HOLD FOR THIS FATHER AND HIS DAUGHTER?

Toomas (30) and his daughter Emma (5)

What should 30-year old Toomas and his five-year old daughter Emma know about the future of this field? First, Jaan Raik tells them that this is a rather complicated question in computer science because this field is continuously changing. Research which is even a few years old is nowadays morally obsolete. It is certain that in the future the possibilities offered by computers will be vastly better than they are currently.

In the upcoming decades, Toomas and Emma may both see a revolution, where new paradigms of how computers will function are going to be created. By 2050, the first quantum computer will hopefully be developed. This will in turn help father and daughter solve various search tasks and planning assignments.

Developing machine learning and machine vision will bring along tiny smart robots that will be of help in medicine and other fields where it is required to work in narrow and complex circumstances.

Whether future Emma will be able to work as a top-level researcher in Estonia is yet to be determined.

Underwater robotics is full of opportunities

Estonia has one of Europe's top 15 research teams

Professor Maarja Kruusmaa and her team's research is one of the most expensive in the field. Among artificial intelligence, there is no niche that is more volatile than underwater robotics.

Drones that fly in the air have become commonplace and even children can have fun with them, but the underwater world is much more complicated, so it's no surprise that we can't just buy a robot or a drone to explore the seabed with from a shop yet. Professor Kruusmaa and her research team are working hard to make this a real possibility.

The approximate quantity of water on Earth is 1.34 billion cubic kilometres. 97% of this is seawater locat-

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ed in our oceans. Estonia has approximately 25,000 square kilometres of territorial sea and plenty of inland water bodies. We can dive and snorkel, but very few of us can explore the deep sea. Humans meet the limits of their physical capabilities at a certain depth. In order to explore the sea, protect it and reap its benefits, we need solutions that can do it all autonomously, without the need for a human body or even a brain. Why is the latter important? Because no means of communication works deep underwater. It is impossible to give regular control commands.

First, Kruusmaa explains that in order to test the underwater robot, they develop new algorithms with mathematicians to see whether the robots become more mobile and fault tolerant. The robot that moves autonomously as programmed will be the practical result of their work. Achieving this is time-consuming and expensive. “Reliability in this context means that there needs to be as low of a chance as possible that the software will not operate,” she explains. “This is rather difficult to achieve underwater.”

With conventional ITsystems and electronic solutions that are used for conventional robots, a lot of trial-and-error experimentation can be done, but we can’t do that underwater. It is both expensive and time-consuming. Kruusmaa compares this process to that of building a house, where in a similar way you cannot just start putting materials together without ensuring beforehand whether the building is going to collapse or not.

“In underwater robotics, we have to do field tests. The fault tolerance must be perfectly considered beforehand. We operate at a centre of excellence, where we conduct basic research. For example mathematical algorithms. We simulate everything in order to make sure that the robot works as it is supposed to in all possible scenarios,” says the leader of the research team.

Kruusmaa brought this topic to Estonia

There aren't many research teams in the world that could have reached such high capability, because underwater robotics is a field that requires a lot of financing. Kruusmaa says that this cannot be achieved overnight. This kind of capability is not created based on a couple of individuals. It requires infrastructure and several scientists who can do technical engineering work. Maarja Kruusmaa states there are 15 such research teams in Europe who are also up to the required standard at the international level. "We communicate a lot with each other."

How did it happen that one of these centres of knowledge and development in this field is situated in Estonia? Kruusmaa herself is one of the reasons, she made this field relevant. In addition, Estonia is a maritime nation. "Our coastal sea has different conditions when compared to deep oceans," she explains. "Several technical problems arise here as well. There are shallow waters, low visibility, low-temperature climate, sediments – shallow water is an unstable environment. Waves and currents. Underwater robots have different challenges over here."

If the robot vanishes, then it's gone for good

Why is developing underwater robotics more expensive than terrestrial artificial intelligence? The robot has to be water proof, but it's also important that the robots can be used in locations where they can't be reached. If something should happen, then it might stay at the bottom of the water – somewhere it can never be reached. As Kruusmaa says, once the robot is let loose, they have to hope it comes back. As there is no Wi-Fi or any other smart solution underwater that can be used to communicate with the robot, there is no way to monitor it. "If the robot does not return, then you lose all the data," says Kruusmaa.

> *While people won't feel the benefits of underwater robots in their own wallets, the world would indirectly become a better and safer place.*

The water-resistance needed is not comparable to how a drone flying in the air must be able to endure rain. There is pressure underwater, and if at all possible, the water will leak in. Kruusmaa says there's no need for witchcraft, but the solutions are going to cost money. There is another difficult aspect – electromagnetic waves cannot travel through water very well. Whether that's Wi-Fi, radio waves or GPS. If you want to communicate with the robot, you can only do so with a cable. However, that means the robot cannot go too far.

"If you remove the cable, then the robot is 100% autonomous," says Kruusmaa. "You must build a robot that can be completely autonomous. It must be able to move from one place to another without GPS coordinates and maps."

Even operating a cable-connected robot is not that easy. The user interface needs to be good. You might not even see the drone once you place it underwater. Operating this is not intuitive and it takes a long time to get used to.

Collaboration with two top scientists

Kruusmaa's research team works closely together with two of EXCITE's principal investigator. They're working alongside Ülle Kotta on the topic of fault tolerant control algorithms. Kruusmaa states that Kotta brings the base knowledge as a mathematician, while Kruusmaa's research team brings the applicational element. "We have the robots and the know-how regarding building and testing. Ülle has the knowledge in describing them mathematically and proving that they work as discussed," she explains.

The second project is a collaboration with Jaan Raik, who is a professor of fault tolerant systems. Together, they rack their brains on the topic of underwater sensors and sensor networks that have to collect data underwater. This collaboration must result in a software system that understands when a sensor is not functioning properly. It has to detect errors. "We need to simulate it so that the data received using sensor networks is credible. Additionally, we need to understand when the sensor network is so poor that it no longer functions," Kruusmaa illustrates.

Underwater robots will drastically change things

We now get into the practical uses of these types of robots. On the one hand, any type of underwater work requiring manpower is often both expensive and dangerous. Underwater welders make a lot of money, as do divers who dive in dangerous locations. The hazardous nature of this type of work is a factor.

But there are places even a professional and experienced diver would

never go. For example, the dangerous and unknown interiors of shipwrecks or locations residing under port structures. If there is a significant threat to human life, they will not go. The same issue occurs with jobs that need someone to traverse long distances or go extremely deep underwater. An underwater robot can traverse from the West Coast of Scotland to Newfoundland, all the while collecting data. A human is not able to accomplish that. "They never will be," says Kruusmaa. "There is no use in making a person do such work." Therefore, underwater robots could be used for a lot of work already being done underwater, while adding even more possibilities.

For example, these robots could be used for environmental monitoring. They could continuously monitor our coastal waters – the quantity of microplastics, the proliferation of cyanobacteria, fish spawning grounds and pollution.

We could even talk about using them to look out for criminal activity. The underwater robot could successfully scope out all the ships coming into a port to ensure that drug dealers have not attached any packages to the underwater sections of them. It would be time-consuming and expensive for a diver to perform such a task. The robot would be able to perform this on every ship that arrives at the port.

> *We are reaching a stage where underwater robots can be bought by middle class mothers as a Christmas present for their child. You will soon be able to buy them from supermarkets.*

"Therefore, it can be said that while people won't feel the benefits of underwater robots in their own wallets, the world would indirectly become a better and safer place," believes Kruusmaa.

Underwater drones in shops

A regular person can still see one of the developments that underwater robotics is striving towards. As robots become faster and can traverse longer distances, the components and robots themselves are becoming smaller. They need to be managed in a different way, and we need to think about how they can remain stable underwater so that currents and waves do not wash them away. These types of breakthroughs make it so that current large and expensive underwater robots become smaller and less expensive. If the price of the components decreases, they will become accessible to regular people.

"10–15 years ago, flying drones were extremely expensive and only available to the military. Even a couple of years ago, it was not feasible that the owner of an expensive yacht could purchase a robot, throw it in the water and then use it to see what is happening under the keel. We are reaching a stage where underwater robots can be bought by middle class mothers as a Christmas present for their child," Kruusmaa points out. She notes that they will not reach the price point of flying drones, but there is still a trend towards significantly lower prices. "You will soon be able to buy them from supermarkets" she believes.

This also means that interest regarding the production of underwater robots is growing. However, the private consumer market in this field will most likely be unstable, as it is with all sorts of gadgets – they are trendy at one point and then they go out of style. On the professional market, it is more sensible to operate as both a manufacturer and a seller. Companies will not

conduct themselves irrationally, because their success relies on increasing effectiveness and mitigating risks.

Collaboration with companies

The professor doesn't feel that there's a problem in top research not being directly funded by companies. Why should they take on that risk? Her research team in the field of underwater robotics is funded primarily by taxpayers in the European Union. Estonia's contribution is extremely small.

Kruusmaa explains that their research team still works on basic research, which means that it will take several years before the robots become available to use – years of research, tests, errors and learning from those errors.

"The interest from companies comes along at a later stage," she says. "It is true that we are testing sensor networks in the port of Sillamäe. There are a lot of interested parties there. There are a lot of interested manufacturers as well. Robotics is more challenging. I do not know of anyone in Estonia who is building smaller robots right now."

Their installation has existed in the port of Sillamäe for many years. During this time, the system has malfunctioned once, but Kruusmaa finds a positive in every situation – the purpose of testing is that when something breaks, it must be rebuilt.

In the end, the robots will be built by engineers, who will have received the necessary knowledge from researchers. Kruusmaa states that there are two ways in which her research team's discoveries reach the rest of the world. The first of those are scientific publications, which can be read by anyone and applied to building better robots. The second is when knowledge leaves with a departing member of the research team. "From a laboratory to a company. Several brilliant minds have left us just like that," she says.

> *The main thing that makes the Estonian underwater robotics research team unique is that the Centre for Biorobotics researches biology-inspired robots.*

The main thing that makes the Estonian underwater robotics research team unique is that the Centre for Biorobotics researches biology-inspired robots. Different types of technologies are applied. There are also shallow water applications that are often even more complex than the deep water ones.

It is clear that working in a complex and expensive environment can greatly change the way we get knowledge regarding our seas and lakes. Additionally, thanks to Kruusmaa and her research team, at some point we will find beautiful photos and videos from the deepest waters on social media instead of cat photos – the underwater world is still mysterious and unknown to many of us right now.

WHAT DOES THE FUTURE HOLD FOR THIS FATHER AND HIS DAUGHTER?

Toomas (30) and his daughter Emma (5)

Professor Maarja Kruusmaa believes that robots are going to be more autonomous in the decades to come and will be able to function by themselves. Secondly, they will be able to work autonomously for longer periods of time – you can send your robot out and have it return in two weeks with the results. Where will it get the required energy? Underwater battery charging installations already exist today. Third, there are new fields developing that we have not been able to work on yet, because people don't want to or can't perform this work.

Additionally, anything related to the environmental protection of water. Immediate knowledge of pollution, contamination, cyanobacteria, etc. In the future, we will be constantly analysing and monitoring water bodies.

Alvo Aabloo:

Soft robots may save lives someday in the future

Robotics is professor Alvo Aabloo's passion. Soft robots in particular may soon bring major changes in quite a few areas – particularly in medicine.

The University of Tartu has around 40 people working with robots, approximately 10 are working in the soft robotics field. In the beginning, Aabloo worked in the underwater robots field alongside fellow EXCITE top researcher Maarja Kruusmaa. However, Aabloo states that the soft robots field is moving increasingly towards medicine and nature. This work involves materials, management, control and also construction of robots.

Aabloo says they are among the best in their field. The global experts in this field all know each other and attentively observe each other's work and activities. "We are not unique, there are quite a lot of people experimenting with this," he explains. "We combine various materials and we have few unique materials that we are attempting to combine with existing conductive polymers."

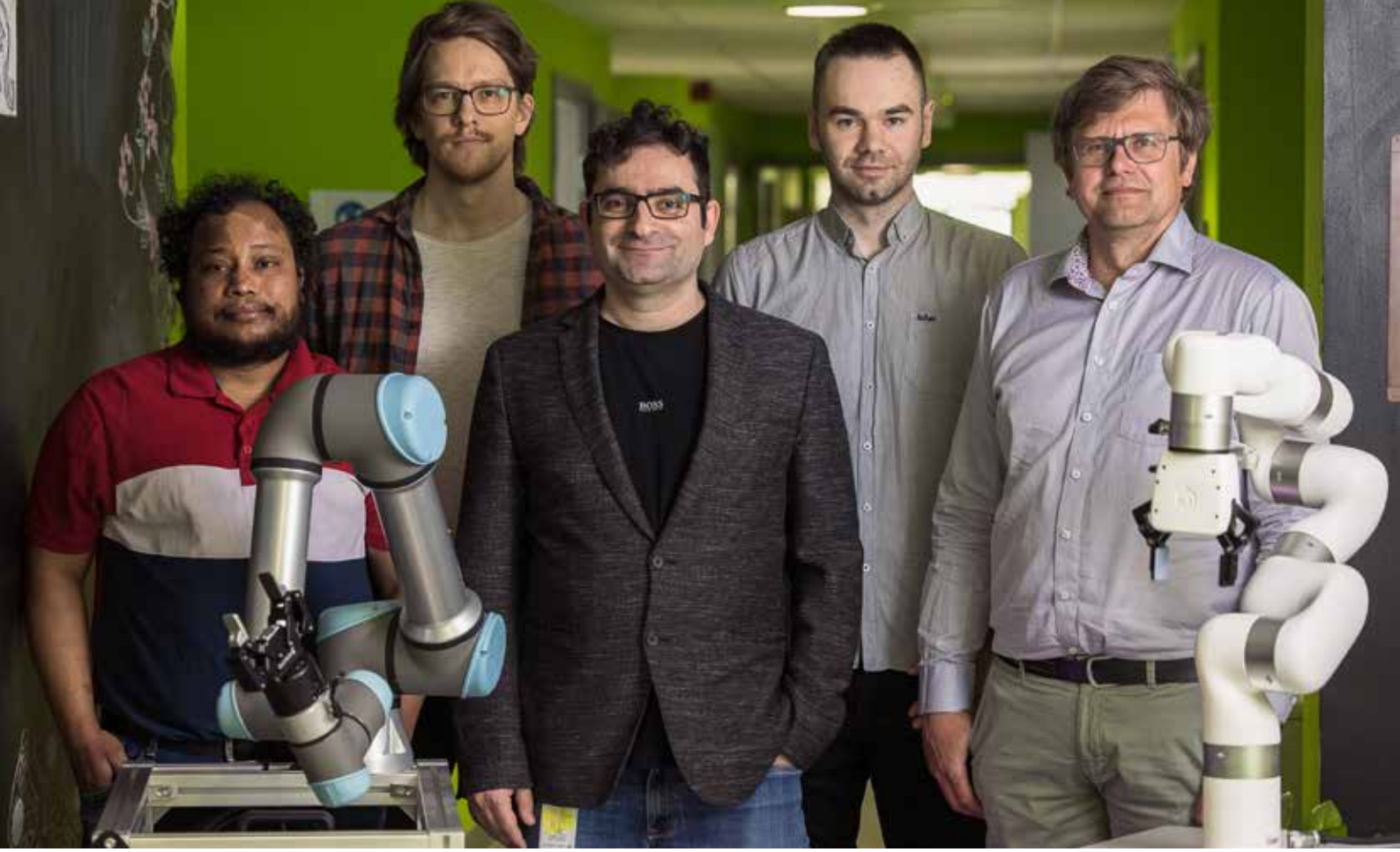
He highlights that the developments in the field nowadays are primarily based on materials – the materials are not as good as researchers would like them to be. However, a lot of effort is put into attempting to develop them so they can keep up with the field of so-called real robots. Aabloo states that the latter are even faster and more effective now.

"However, we have special applications into which we are unable to send these iron men," he says. "I mean both nature and medicine. We prioritise non-invasive surgery and our creations can be well implemented in that area." As a consequence, they need to consider issues like biocompatibility as well. If the robots are created by researchers to go inside a person and stay there, the materials they're made of cannot be toxic. Normally, they tend to be.

Aabloo's path to this field

Alvo Aabloo used to work in the field of polymer batteries, until he happened to read a story about people working in the exciting field of soft robots. He understood while reading that story that there were a lot of similarities between what he was doing and what he was reading about. In the case of batteries and supercapacitors, maximum energy efficiency is what people are looking for, but in the case of soft robots it is mobility. The materials are quite similar. The optimisation just has a different objective.

"The topic seemed both familiar and original, and it felt like something that could interest people," he said. "After all, it is a device inspired by biology. Another turning of the gear-



wheel does not attract people much anymore. It is extremely important in research that the public understands what you are doing or why you are doing it."

Within EXCITE, Aabloo often visits Professor Jaan Raik, working at TalTech in Tallinn. They are collectively working on microfabrication. The knowledge as well as the software exists in Tallinn. They make the designs together and then Aabloo's research team goes to France, where there are adequate laboratories to make the materials in. "We have an excellent working relationship with Jaan Raik," states the professor.

International team

Aabloo has an international research team. They do a lot of international collaboration too – there is an international consortium as well as a European project with Italians and the French. There have also been projects with nearly 20 international partners.

The professor says that there are about 50 top research teams in the world that are working on the same thing. Around 15 on those are working on the same materials as Aabloo's team. "There are exactly that many credible research teams."

The essence of soft robotics

Let's now explicitly state the concept of a soft robot. In principle, they are robots that are made of soft materials. If a human touches one of these robots, the robot will yield. The robots are made of polymeric materials which bend if external force is applied. The robots are also quite small. Therefore, they are safe to be both near and inside people. They won't injure you even if something goes amiss while operating it. Meanwhile, in the industrial robotics industry people are still working on making it safe for the robots to be in the same room with other people.

"It's great that we do not have to develop any type of particular software for that. We simply have materials that are flexible," explains Professor Aabloo.

He says that in the beginning, not much was said about various possibilities the robots could bring to the field of medicine. No one believed that they would develop so far that they could be placed inside people. Aabloo says that soft robots can be

used anywhere there is some other living organism in the proximity of the robot – whether that be a human, an animal or some fragile object.

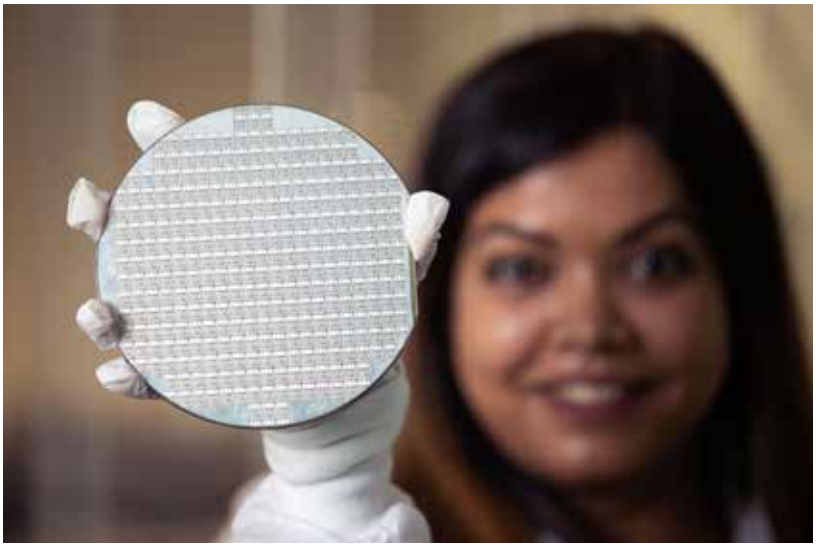
"Development is rather fast in medicine and there is serious demand for it," he says. "Rapid invasive surgery is used to treat a heart attack, a stroke or other serious conditions. A while ago we collaborated with Philips and they stated that it is necessary for a stroke to be treatable by doctors who are not that experienced yet." This provides an indication about the importance of this field. It's about health and saving lives.

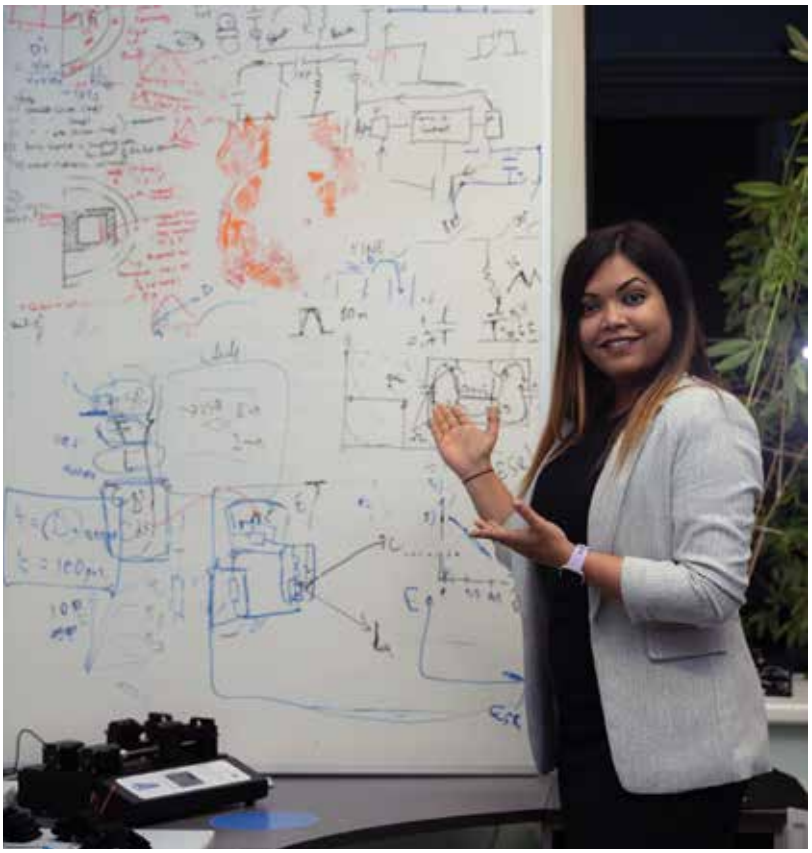
A robot's three key components

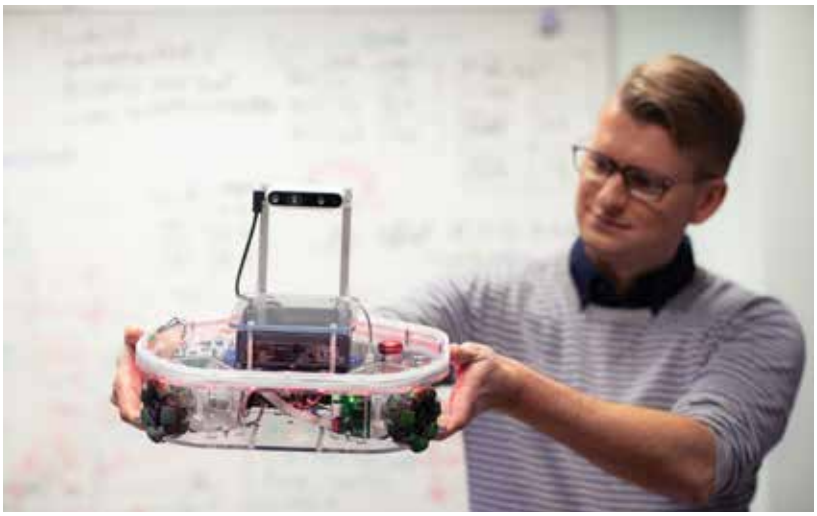
Anyone who has not had any experience in this field may not imagine what a soft robot even looks like. It has a power supply as well as a soft and a flexible part. It definitely has some smart electronics inside. They also attempt to make these electronics soft and flexible. We have the technology for that now.

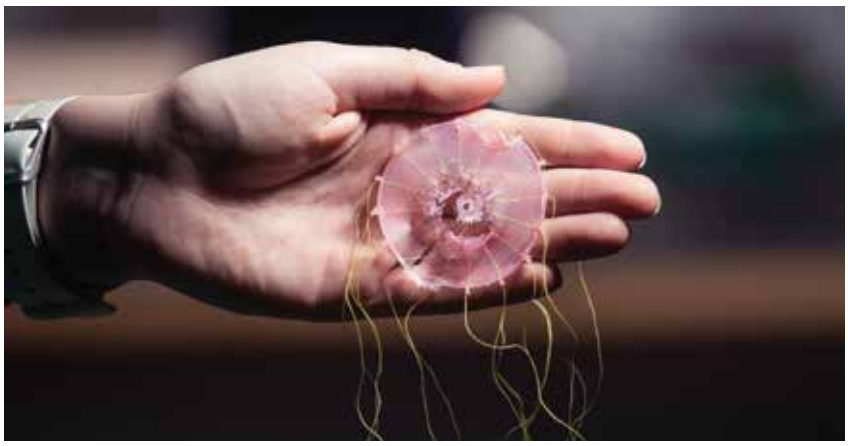
> *It is extremely important in research that the public understands what you are doing or why you are doing it.*

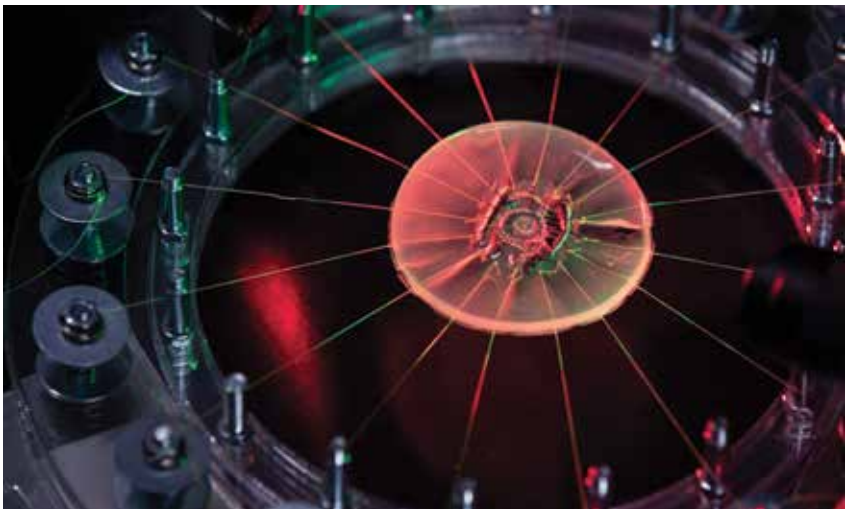
Aabloo provides an example of their current activities. If someone has an ear infection, the doctor uses a light to look inside the ear, but they cannot see deep into it. The research team is attempting to develop a soft probe that could be inserted in a person's ear so that the doctor can view it deeper. The camera will be placed inside the person's ear. The doctor can then redirect it into the middle ear and have a look around and in turn make better-informed decisions. If necessary, they can also take samples. This can also help them administer medication to the right spot – it can be accurately localised. That latter means that the medication can be stronger, because they start working immediately and they do not have to traverse other areas of the body.











"This is how we will progress," says Aabloo. "Perhaps at some point we can insert monitors or something to administer medication inside people during surgery. This localised application of medicine is a current topical issue, because the pharmaceutical industry can already make better medications, but more potent medication is also more hazardous." The localised solution only poisons a certain part of a person, so they can defeat the illness without jeopardising the rest of the body.

We are still a great distance away from developing muscles

Even though Aabloo's field uses the term "artificial muscles", it does not mean that we are close to adopting artificial muscles. Today, they cannot yet replace a dead muscle, because people's muscles are constantly regenerating, the cells are changing. Artificial muscles are unable to regenerate and they have a finite life expectancy. "When speaking about artificial muscles, we are talking about accessories and equipment that can be used elevate quality of life," Aabloo explains. "They are tools that doctors use so that they do not have to cut people open as often." Switching everything to laparoscopy is the long-term objective. This means that they will make a couple of small holes in a person's stomach, chest or someplace else. Smart catheters will be inserted into them, and their ends can be used to conduct an operation on the person.

> *"There are about 50 top research teams in the world that are working on the same field. Credible research teams, who are working with the same materials as we, are around 15.*

Aabloo provides an example from when they collaborated with Philips – that project focused on using a catheter tip to treat a stroke. The catheter would be inserted into a person's thigh and the final target would be the human head. "We are slowly progressing in that direction. We could be evolving faster, but the aforementioned materials science is something that needs to be further developed."

Ultimately, success will depend on luck

In addition, Alvo Aabloo talks about how their creations could find wider use and create cash flow for the researchers themselves. They have created patents, but as of now, nothing is being made into a product. It's going to take a while. However, there is a lot of interest in this niche – everyone is expecting someone to find the solutions. People have been working

on this topic for nearly 20 years. Now they are waiting to see what it can swap be and actually used for.

Let's bring the discussion back to materials, because they are the key issue of the entire field. For example, speakers are being created with similar materials that are also being used by Aabloo's research team. Aabloo elaborates that they are placed on a wall like tapestry, but there is actually a speaker inside. Unfortunately, they only last a couple of years. Conversely, artificial muscles have to be extremely small so that they can be placed inside people. Only this will make the product competitive.

"Many people around the world are working on smart tablets and catheters. Who succeeds with these creations will be mostly based on luck," says the professor.

Other applications besides medicine

Medicine is not the only field where soft robots can be useful. Aabloo states that energy harvesting was once fashionable, but it has lost its novelty. They believed that we could harvest energy and use it in a localised manner, because everything is moving and vibrating around us. So-called off-grid energy sources could potentially arise. Even though the momentum has waned, Aabloo's research team is still working on this topic. The main obstacle here is also the lack of appropriate materials. We need to develop them ourselves. "We are working on it," assures Aabloo.

He is working on a home-grown autonomous robotic bar named Yanu. This is where the interesting part comes in. Aabloo says that creating the bar robot would be very simple, but its appearance would resemble a factory. "And who wants to spend their evening in a bar that looks like an industrial plant," he says.

This brings forth a question – should the aesthetics and the artistic side of things be considered when it comes to robots? People want the environment around them to be attractive. Robotics has mainly been the playground of engineers up until now, but when talking about service robots, we are also talking about aesthetics and they should resemble a human. "It must at least seem like the robot is alive," explains Aabloo. Communicating with machines is not a characteristic in the Western World. In Asia however, e.g. in Japan, communicating with robots is commonplace. "Over here, we need to make machines more like humans. But if they are too similar, then they also have an alienating effect," he says. They have to evoke some sympathy as well as emotion, while at the same time also create an understanding that you are dealing with a machine, not a real human being. "We should not create too much confusion for people," believes Aabloo.

Soft robots and artificial muscles are extremely exciting fields. Researchers are currently attempting to mimic and comprehend how plants work, in order to build robots that use principles and rationales that are plant-specific. For example climbing. "Plants can really easily tether themselves to things. Researchers are examining all of this closely and attempting to emulate it in soft robots. The applications of this will still be mostly medical-focused."

WHAT DOES THE FUTURE HOLD FOR THIS FATHER AND HIS DAUGHTER?

Toomas (30) and his daughter Emma (5)

Alvo Aabloo foresees that in a hundred years from now, our everyday reality will be that of soft robots operating all around us. Particularly in both the care home sector as well as medicine. They will monitor both elderly people and children. He believes that service robots will take off in particular – ones that work with humans. "They need to be safe. Even if the person doesn't fully know how to operate them, they must not get hurt." Micro-robots have real applications in health care. Why is it taking so long? Aabloo says that humanity is currently focused on energy concerns and the green transition. Those topics remove a little bit of efficiency from other areas. "When Europe succeeds with the green transition, other topics will be focused on again," Aabloo is certain. However, the issues facing both elder care as well as medicine are clear and considerable. The number of nurses and in-home caregivers cannot infinitely grow. Therefore, technology has to resolve those issues. It is quite logical that hospitals will use robots as personnel in the future.

In addition, the future robot nurses and caregivers may look like humans, not just boxes, bins or heaps of metal. They will hold people's hands and provide them with support. Aabloo says that a lot of human faces have been created using artificial muscles, but at present time they are still rather expensive. The technology must become more affordable and it has to be optimised. "In the case of elderly people, the communication and support issue needs to be resolved," he explains. "They need assistance and a watchful eye or help remembering things. There needs to be a mixture of various technologies – machine learning and neural network learning so that the robot can adjust to each individual." He is certain that even a hundred years from now, elderly people will still require physical contact. We are going to have to wait and see how they will conduct difficult operations and treat serious illnesses in the future, but we can assume we are not far off from a time when soft robots will be extremely useful and help save lives.

Marlon Dumas:

Is it possible for an AI to run a business all by itself?

Professor Marlon Dumas and his team have set their hearts and minds to figuring out how artificial intelligence can make businesses work better, and the more he studies this question, the more he is convinced that businesses will always require a human element to understand and serve their customers.

Marlon Dumas came to Tartu University in 2007, and he knows that data are poised to become one of the most important ingredients of successful businesses and governmental services in the coming decade. “Since the 1980s, we have learnt a lot about how to collect, store and manage data. Companies nowadays record a lot of data about their customers and workers in their information systems. But the next step – getting answers from the data – is still an arduous and manual process. Extracting knowledge from data in the 2020s is just like transportation in the 19th century. It was slow and tedious then, as it is holding back a lot of progress now.”

Horses and carriages

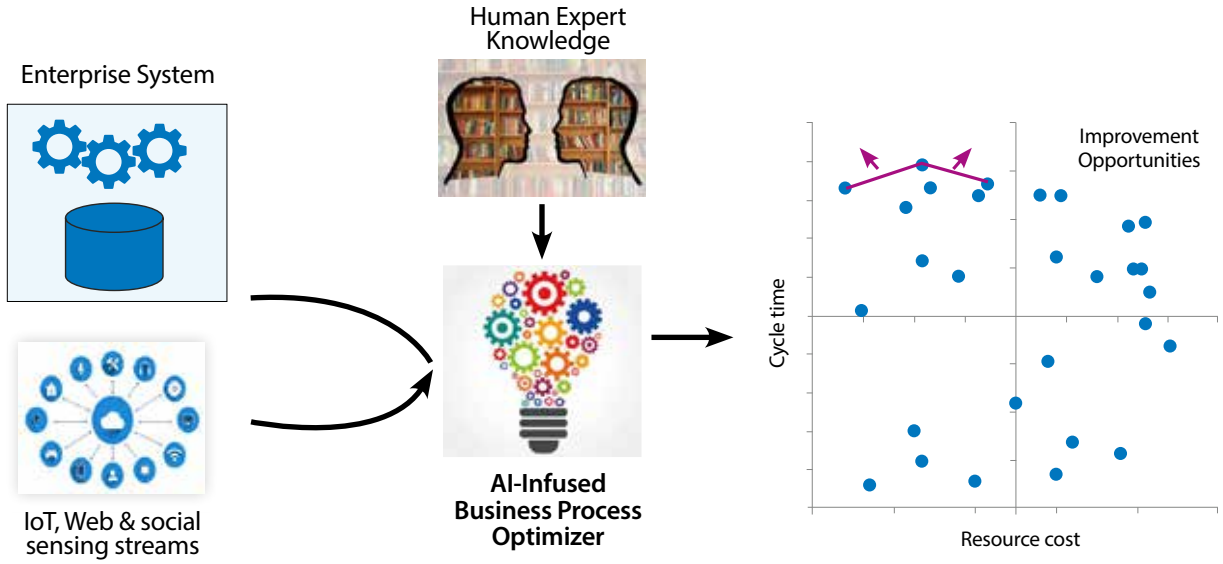
Let’s consider two examples. First, your company’s shipments are delayed from time to time. Second, your clients did not receive what they ordered. With current practices, it takes weeks or even months to figure out all the reasons why this is happening and to change the company’s processes to fix the issues. Oftentimes, entire teams of analysts and data scientists need to be mobilised to extract, clean and fix data errors before they can even begin to analyse these data. Then these teams need to produce and analyse different charts and graphs to answer questions.

“This is a very slow cycle, like traveling with horses and carriages in the 19th century. Back then, people understood that we needed the next generation of horses and carriages, right up until cars and planes came along and changed everything. What we need now are the cars and planes that will allow us to turn data into intelligent decisions fast,” says Dumas.

It could be frustrating for a manager to get constant complaints about late deliveries of particular kinds of orders, and he would want to know why that happens, but it could be any number of factors. Data scientists take a year’s worth of data and spend weeks or even months scouring through these data to figure out the patterns that lead to those complaints. Sure, they succeed most of the times, but then after a while, new issues arise, so the manager has to call in the data scientist once again. This cyclical process goes round and round seemingly without end.”

Artificial intelligence can help us to understand what info is needed to get the correct answer. Simply put, it identifies patterns, and the answers derived from these patterns can improve any business. It has the capability to analyse thousands of possibilities to discover why something has gone wrong. “This is the type of research we are doing in EXCITE. It is going to be a commercial product

Automated Process Improvement



Research group (from left to right): Awais Ali, Fredrik Milani, Orlenys Lopez-Pintado, Gamal Elkoumy, Marlon Dumas, Manuel Camargo, Katsiaryna Lashkevich, Anti Alman and Kateryna Kubrak

in as little as ten years. We strongly believe in the AI-driven business improvement."

Dumas believes Estonia is an excellent testing hub to develop the "cars and planes" that will allow businesses to extract the necessary knowledge and insights from data. Estonia is "fresh and dynamic," he says and adds that "Your country was reborn in the digital era. Your government and businesses have grown with it. It is a very good place to study and to test what we do," says Dumas.

Two main challenges

There are of course challenges in the way, one of which is privacy. In Europe, there's a solid framework called GDPR, that prohibits scientists from tracking the biometrics of truck drivers while they make a delivery without prior consent. They have to find clever ways to collect and analyse these data, while protecting the privacy of the individuals they are extracting data from. "That is much trickier than it seems at first. If I know three places that you have been, I can probably figure out that you are behind the data trail I am seeing in front of me. We need to anonymise, but to do so in a way that does not render the data useless," Dumas tells.

> *Estonia was reborn in the digital era. It is a very good place to study and to test what we do.*

The second challenge is in finding complex patterns in the data, and then to be able to explain them in a simple way, so that they can then be interpreted by business users. We have technology, called deep learning, to find very complex patterns in large amounts of data. But making sense of those patterns in order to inform decision makers is challenging. Deep learning can tell you that a delivery will be late, but it cannot tell you why in simple terms. It is frustrating. It is a so called 'black-box technology'. "We are working very hard so that we can translate it into terms businesses can understand. That is what they really need," says Professor Dumas of Tartu University.

Finding out routine work

Turning data into business improvement opportunities is challenging, but when solutions to this type of problems are found, they have very visible benefits. Take for example the problem of finding out routine work that can be automated instead of wasting the time of your workers. Everyone that works somewhere understands this – you constantly copy and paste something, do unnecessary and tedious work that you think can be avoided. Dumas knows that AI can improve this situation. It can detect routine work from data and automate it where possible, so that workers can focus on the work that requires their real skills and expertise.

"To discover routine work, we record it from your work laptop step-by-step. This means that we collect a lot of private information and we have to do it in a safe and secure manner, naturally. Then we need to understand what steps you are repeating often and which of these steps can be automated," describes Dumas. But that is not enough. We have to find repetitive routines we can automate, and then we have to specify to the users exactly what processes we

have identified and how we are going to automate them. If we automate a routine using a software bot, we need to explain how we will ensure that this bot will not make errors and that it will understand the difference between routine work and exceptions. "You wouldn't trust Excel to finish your job for you, if it just tells you that it's going to, you want proof."

> *The customer experience is going to improve dramatically in the next 10 years, customer experience will be the big winner of the 21st century.*

Making e-government better

Marlon Dumas's team is helping also a government agency to analyse usage of portals by citizens. These kinds of projects take three to six months to set up. At the end, you can answer a handful of questions predominantly concerning the most common journeys that users take, and which journeys are causing problems for users. Where do they struggle the most and what do they spend too much time on? "This is not sustainable. It is quite a lot of work and it requires a lot of data pre-processing and a lot of consideration for security. We expect that in future, with the help of AI, we can find a faster way," says Dumas, and adds that machine learning will be able to find what parts of a very complex web site, such as a government portal, are causing problems for users and how the site can be improved to make the life of its users simpler.

One example of the need for this type of AI are the recent challenges related to setting up a large-scale vaccination campaign. Elderly people needed to find relevant information. Therefore, government sites need to be updated, and any issues people are encountering when finding relevant information need to be resolved fast. It's a matter of public health.

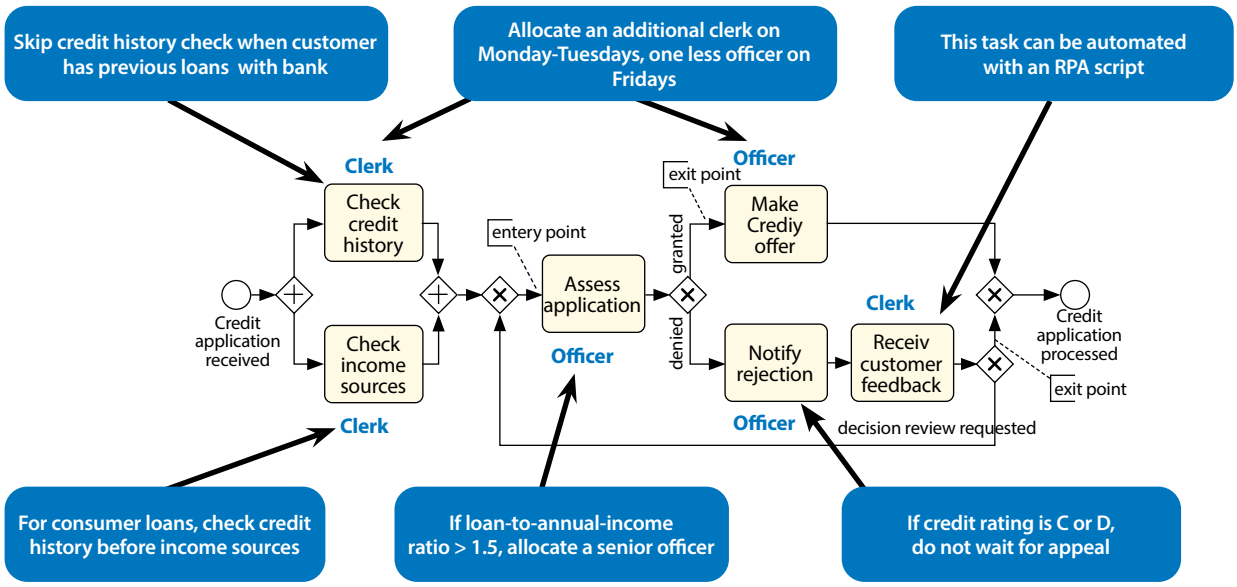
In the future, AI will be constantly identifying what challenges different groups of people are struggling with and whether they can get the information that they need. "If we continue analysing customer data as we are doing today, it will take weeks or months to find and fix problems that users are facing, and so we will not be able to adapt adequately enough to face future challenges," adds Dumas.

Not replacing data scientists

So, in ten years' time, hybrid business models will be possible. It means companies that are partially run by AI, and partially by human beings. Humans will still make the final interpretation and decisions – however, do we make this last line of work to be automated as well?

Dumas argues that AI is not replacing data scientists, but instead it is making their job more effective. Instead of spending a large amount of time in preparing, validating, and analysing data, data scientists will be able to spend more of their time in interpreting the patterns they find in the data. More broadly, Dumas emphasises that there is no reason to panic about whether AI will take our jobs. "The nature of jobs will change for sure, I am optimistic - the repetitive part will be removed. Data scientists like to interpret results and turn data into decisions, instead of wasting a great deal of time finding out how to turn the data around to find relevant

Example: Improvement Opportunities



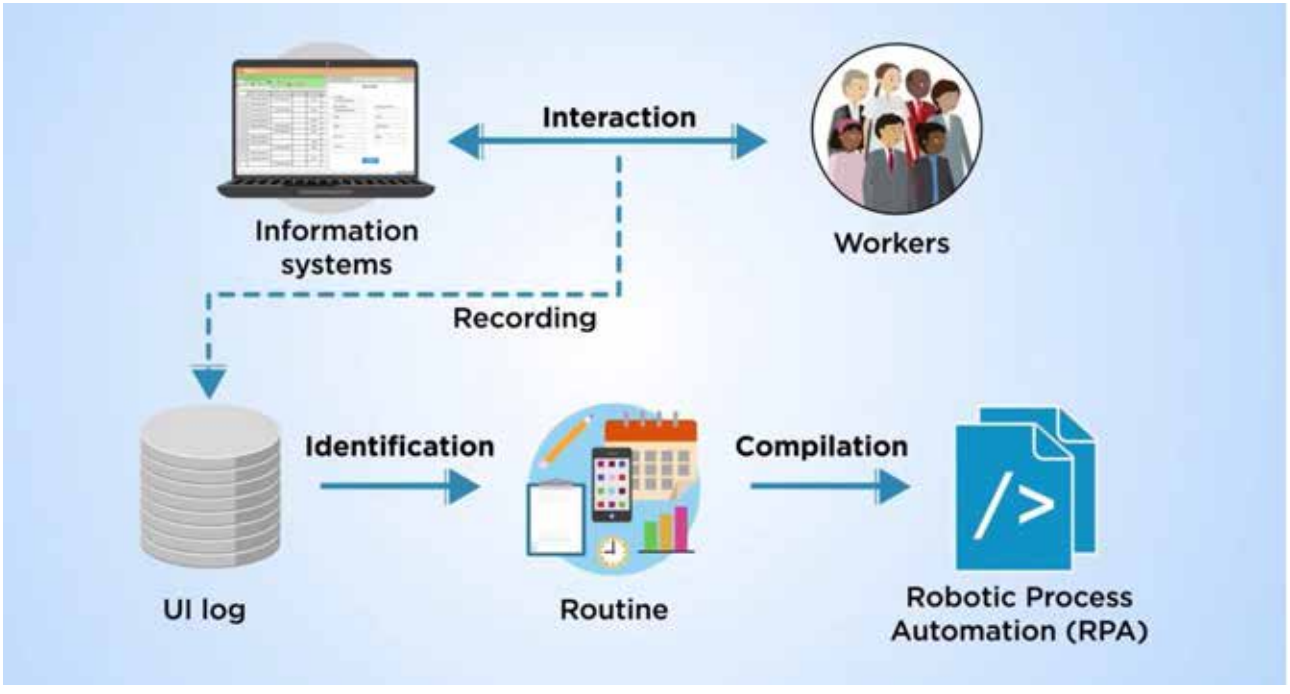
patterns," Dumas describes. He adds that every larger company has a customer excellence manager. Today, a lot of that person's work goes into finding out what exactly went wrong, instead of talking to the customer themselves. "It's a shame they are not doing that." In the future, AI will help customer excellence managers focus more on the customer. Ultimately, businesses create value by serving customers, and humans are the best placed to understand what the customer wants or needs.

And there are, for sure, gains for end-users as well. Everybody has been frustrated by an e-shop, whether it was the layout or the webpage itself, whose logic you just could not grasp. . Finally, after some stress, you leave without a purchase. AI-infused businesses can detect that you had problems and it takes days rather than months to address that.

"The customer experience is going to improve dramatically in the next 10 years," Dumas promises, "just like transportation improved dramatically in the 20th century, customer experience will be the big winner of the 21st century."

No big servers or supercomputers

The Dumas team is developing a little machine that has a component that finds data. It knows what kind of data can be found and how it can extract it. It is very difficult, because there are usually a tremendous amount of e-mails, documents, and other infor-



mation that it needs to sanitise and remove private information before it can be analysed. An analysis component is also being developed, that will turn numbers into something that can be effortlessly understood.

It will not happen tomorrow or next year, Dumas gives it at least ten years. What does that all mean for a business owner or a government official? Since all information today is ever-increasingly transferring to the cloud, there will be more and more cloud-based services offered in the future, and these cloud-based services will be AI-infused to help business owners and managers to efficiently convert their data into decisions.

"As a manager, you will buy AI-infused add-ons to your information systems, to help you improve your business processes. You will configure the add-on, it will gather the right data safely, and it will detect opportunities for automation, issues that your customers are facing when using your services, issues that are making customers unhappy. This list can go on," Dumas explains.

He acknowledges that his team are still at the beginning of their research. "We are building toys," he says, reminding us of the horses and carriages allegory. "We are in the second half of the 19th century, we are thinking of an engine and producing a prototype. But the cycle of development these days is much quicker - AI-infused business machines ready for commercial use might arrive as soon as 2030. We are heading towards a transition period," Dumas concludes.

His team is naturally not the only group of scientists working on the issue. There are big names like Microsoft, IBM, Amazon, and a lot of AI start-ups that are working on the same problems, some of them with offices in Estonia. However, Dumas believes that when we talk about global innovation, that you needn't walk alone. It is even a positive thing that there are a lot of competitors pursuing the same goals.

"Estonia is an excellent test bed with your e-government adding a great deal of value. There are many post start-up companies, like Bolt and Wise, as well as the universities that are involved. A lot of testing is needed in this area. 19 out of 20 ideas can go straight to the scrapheap. Estonia is small and has a great appreciation for innovation," Dumas praises.

WHAT DOES THE FUTURE HOLD FOR THIS FATHER AND HIS DAUGHTER?

Father Toomas (30) and daughter Emma (5)

Toomas and his daughter Emma would like to know whether it is possible for a company to run solely on AI. It could be as simple as just buying an AI box in the cloud, with eye-catching logos and everything it comes with, press a "start" button and just look at how your company's earnings grow bigger and bigger. And you wouldn't have to do a thing.

Dumas gives us an example. Let's take an e-commerce company that is selling electronic equipment. Now, I am offered a chance to let an AI run my business. It takes care of the website, orders products, sends advertisements to the media, it even makes the sales. The warehouse is also fully automated. So, are Toomas or Emma able to do that in the future?

Dumas doesn't give it much hope. "You will need people to handle exceptions, to make changes when needed, for instance when customers want something new or different. AI can be very good at replicating what it has already seen and learned, but it isn't quite able to adapt and react to something it hasn't seen before. This beautiful AI box is going to break down when exceptions happen, when customers want something new," Dumas says.

For example, one customer still hasn't received the product she ordered one month ago, and the AI can't understand why. The customer goes to court and wins. There can be hundreds of exceptions like this. That's where the human intelligence comes into action, there is an essential human component that is required – empathy, some situations are solved with the simplistic understanding between two human beings. Customers are humans, and you need to be able to adapt according to their worries and questions. "And I haven't even mentioned common sense. We should not change our delivery partner every day just because of a few errors. We still need to develop ways to solve problems ourselves, give adequate responses and make the most important of decisions," Dumas explains.

Even when our refrigerator is buying most of our groceries and our car orders new tyres when it understands that the current ones are on their last lap, there is always going to be a human element that an AI just can't handle, and that is most apparent when it comes to new situations. Emma should not be worried – her intelligence and creativity are very much needed in the future. Dumas recommends that Emma continues to develop her creativity, her communication skills, and her empathy to others, but also her analytical skills and her critical thinking skills, to understand how AI works and how to make the best out of it.

Ülle Kotta:

A researcher seeks the best solution, the industry a functional one

Ülle Kotta is a leading researcher who has been working in the field of automatic control for decades. She is concerned that the importance of control theory tends to be underestimated, but she does remain hopeful that this will change. New and highly complex systems greatly need the help of theorists.

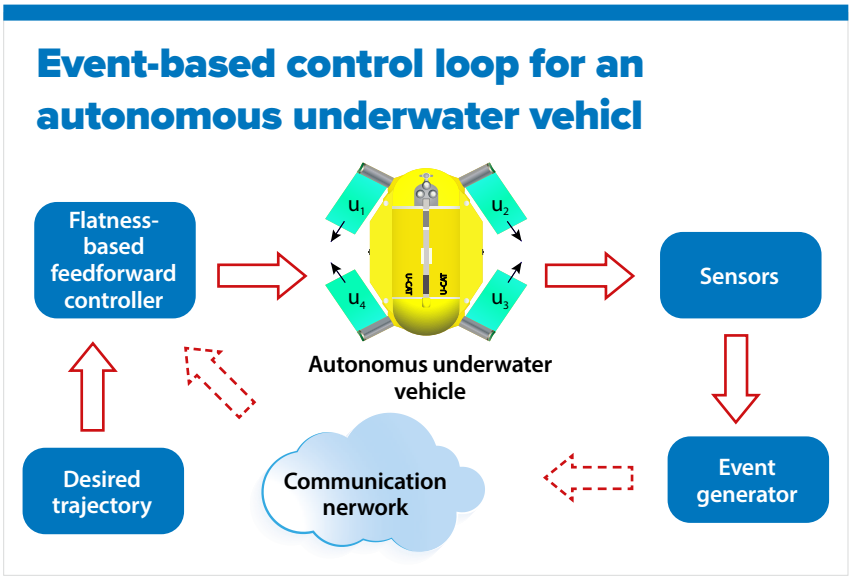
As Kotta says, the results of control theory, including control algorithms, are used in virtually every field, from economics to medicine. Increasingly, the reliability of the system depends on the condition of the controller. “Modern technology would not work without controllers,” she explains.

Control engineers do not make things, instead they improve existing technology and make it more efficient. However, the gradual improvement of processes in the form of control algorithms does not usually lead to dramatic changes.

Where do we see controllers? We have all come into contact with simple controllers - for example, a thermostat in a hot water boiler or a refrigerator, or motion sensors. There are also dozens of control systems in the human body that regulate blood circulation, body temperature, biochemical processes etc. Speaking of more complex control systems, we can bring the examples of autopilots and self-driving

cars, large electrical systems, transport systems, robots.

"It has long been known that processes and systems can be controlled more easily and with less energy consumption if control engineers are involved in the development of technological processes or tools," Kotta explains the importance of the discipline. "They are able to tell where to place the actuators and sensors, how many of them are needed, how the system would have to be reconfigured if any element malfunctions or an element stops working, how to construct objects with good controllability properties and thus significantly save on resources."



The field of control is not visible

A control module or a controller should therefore be a natural part of any system that is operated. Systems engineers have a deep understanding of dynamics - how something changes, spreads, moves over time. "The situation is complicated by the fact that most people do not notice the existence of a controller. It is hidden. The field of control is thus not visible. The controller becomes visible only when it stops working," says Kotta, describing the situation in her field. Her research group deals with fundamental control problems, theory. They have no direct contact with industry, although ideally there could be. Here, however, the small size of Estonia and our industrial sector is highlighted. Kotta remembers a time when research and development teams could be found in larger companies here as well, which in turn were able to communicate with external researchers in their common language.

"The problem is that all the attention is focused on the final step in the transfer of knowledge to technology," she says. "Researchers are expected to create a working prototype. Earlier stages of development are not of interest to financiers. This approach has long-term effects." She says that it is difficult for industry and academia to work together because their interests and goals are different. "The researcher seeks the best solution, the industry just wants one that works more or less. I have had postdoctoral researchers who have gone to work in industry and then come back from there. If they wanted to improve something in the industry, they were told not to waste time on it, what we already have is good enough. A scientist is not satisfied with something that only works more or less."


In the back row from the left Arvo Kaldmäe, Yuri Belikov and Vadim Kaparin. Ülle Kotta and Christian Meurer in the front (keep the robot fish).

Working with robotics group

As part of EXCITE, Ülle Kotta and her young colleagues Arvo Kaldmäe, Vadim Kaparin and postdoctoral researcher Ashutosh Simha have collaborated with two groups. The field of control is one wherein you must find opportunities for cooperation with others.

Together with Maarja Kruusmaa's biorobotics group the work will focus on the mobility task of biology-inspired underwater robots. Such robotic fish are safer and potentially less harmful to the environment. However, these advantages are accompanied by a more complex control logic, which is what they were working on. The role of asymmetric motion was investigated in order to improve the maneuverability of such robots. This project has reached the stage wherein orientation control of that artificial fish has been tested in a real lake.

The principle of asymmetry was also used in the novel simple design of the flapped paddle-fin for underwater robot, which results in greater efficiency in force generation.

The third project carried out together with robotics researchers will investigate the use of event-based control in low-cost small underwater vehicles, which will enable a reduction in communication between the sensors, the control module and the ac-

tuators. This would eliminate any unnecessary communication. Information exchange will only take place when something important changes in the system. As communication decreases, the load on the communication channels is reduced and it is also possible to save on the energy consumed by the system, which is important if the robot is running on battery power, for example. Event-based control uses the flatness property of underwater robots. This wonderful property allows us to describe the behaviour of the system through a single variable, flat output.

The Kotta group has also worked with Alvo Aabloo's group. The topic under investigation has a complex name ionic electroactive polymer actuators. Kotta explains that the actuator is a device through which control is performed. The first review article in the field on the control methods of such actuators was also published.

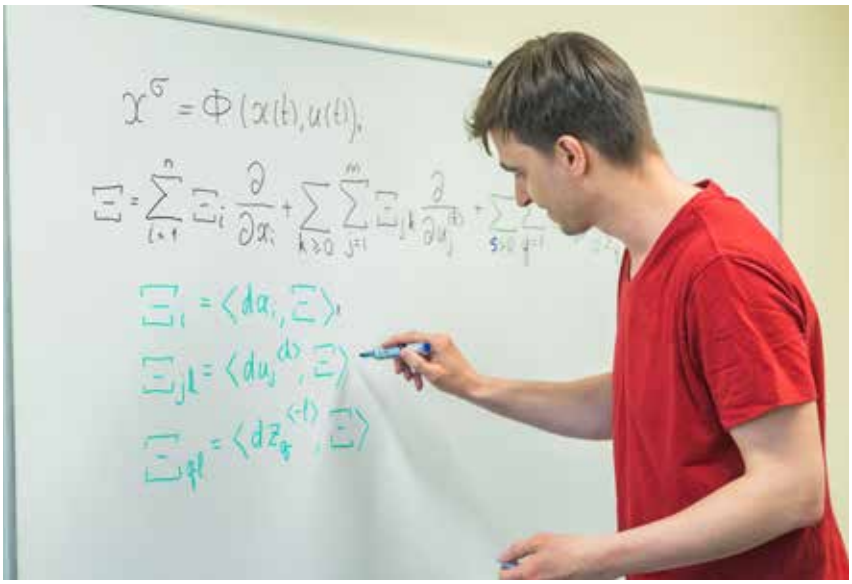
Materials that pose a great challenge

Ionic electroactive polymer actuators are made of interesting and modern materials. There are many novel difficulties. If we are to use a piece of iron, then its properties are known to us. Smart ionic polymers behave differently however.

"When coffee makers come off the production line, they are all the same," Kotta explains. "However, the studied actuators have a dynamic variability. Each specimen is somewhat different." She adds that in the case of tiny actuators, sensors cannot be used in real-life applications. This means that the measurements are not instantly available. "These are however akin to oxygen for control. Feedback is the basic mechanism of control that compares a predicted trajectory, state, level, or position to an actual one. If the sensor cannot be attached, it is not possible to measure the states of the system. This leads to inaccurate control." Complex models can also not be used in real time, because then the controller becomes complicated. According to her, this is a huge knot of control problems the field is faced with. There are currently no solutions to these problems. If periodic movement, repetitive action is desired, simple controllers can be used. However, if a fixed position or energy level is to be maintained, a simple controller is not enough.

"From a control point of view, the field is exciting, but it's still in an embryonic state," she says.

> *Processes and systems can be controlled more easily and with less energy consumption if control engineers are involved in the development of technological processes or tools.*



Impact of renewable energy sources

Ülle Kotta also talks about a completely new topic that her research group is focused on which they are working on in cooperation with a top university in Israel. This is an extremely novel topic, led by tenure Professor Juri Belikov. Kotta first explains that electricity networks today operate on outdated principles. These principles have been established almost a hundred years ago. At the same time, renewable energy sources are increasingly being used. This poses significant challenges.

"Renewable energy sources produce energy with great variability – sometimes there is wind, sometimes there is sun, sometimes there is not," Kotta says. "There is a lot of uncertainty. The first problem, however, is how many renewable energy sources can be integrated into the current grids so that they work and do not start to fail or have interruptions." You can't just keep adding energy to the grid and hope nothing happens. The next step could be to develop new infrastructure that takes into account the high proportion of renewable energy. Storage technologies must also be included. The latter comes into play when the load is higher and renewable energy cannot currently be produced at a sufficient rate.

The third fact is that the price of energy changes over time. Through the latter, the load can be levelled. Use energy in some places when it is cheaper.

"There is a lot of uncertainty in the new paradigm that should be taken into account," Kotta explains. "I will now cite a colleague - power engineers are a very inert bunch of people. They are not very open to new things." Energetics is still so-called old industry that does not simply adopt new things. Another issue here is money, because new solutions require a lot of resources.

Here again is highlighted the fact that the usefulness of control theory is not understood. Engineers don't understand it either. After all, the systems and devices somehow work, they don't seem to need to be modernised. Everyone is happy with what we have, although it could be much better.

Working group seminar.

Mutual understanding and funding

In-house research teams disappeared just as companies began to optimise costs. It was hoped that knowledge could be bought cheaper from universities.

"Large companies should have research centres that act as an intermediary between universities and industry. Without them, business and science will remain distant and incomprehensible to each other. This is not just a problem in Estonia. The same concerns exist in Spain, Italy, France and other countries larger than us."

Ülle Kotta adds that there is currently no European funding for general research, but this research is very important. Especially considering that Europe is focusing on important new directions, such as the green revolution, energy, medicine and transport systems. According to her, working for one specific company does not do much for the benefit of society, but extensive research would do.

"50 years ago, scientists contributed more to the interests of the society as a whole. Currently, the application of science is enterprise-centric. Why so? Scientists back then did not have to constantly struggle to get funding. Salary was guaranteed by the university. This is not always the case anymore. Researchers need to get funding and aren't able to think about general issues such as the green revolution, climate neutrality and transport systems," she points out. In fact, these issues should be addressed by large groups across Europe.

Climate neutrality has also been set as one of the goals of the Tallinn University of Technology. Kotta discusses that maybe the money will start coming to basic research through the university itself. According to her, the other extreme is France, where researcher's position is guaranteed in universities. You have to do something very bad to be fired. You also do not have to publish a large amount of research. "Theory is at a very good level there, however. In a sense, also in Italy. Basic science in our field then. However, good applied science can be found in Germany, the Netherlands and Sweden. Finland has many control applications in the wood and chemical industries. There are no such large industries in Estonia," says Kotta.

Changes in the field of control variable itself

Ülle Kotta also talks about changes in the field itself. From the beginning until recently, the models of objects to be controlled were largely known and studied. There were accurate models. When a control algorithm was developed, it was accurate, reliable and reasonable. There were no surprises. Now, however, the number of fields of applications has grown exponentially. There are no models for most of them. The object to be controlled is almost unknown. Heuristic methods are used. They have begun to be addressed through big data.

> *A scientist is not satisfied with something that only works more or less.*

"This has its own problems. If the data changes, so must the controller. If we develop a controller, implement it and the circumstances change, it will not work. There is no proven and safe result."

Kotta explains that a distinction is made between three types of models. The so-called white box means we know that if we do "x", "y" will happen. Then there is the black box model, where the control variable goes in, the controlled variable comes out the other side - but we do not know anything about what happens in between. Finally, there are also grey box models, where you know some things about what is going on inside the box.

"Today, big data based control is still often used heuristically," Kotta says. "There is no structural approach. It has not been thoroughly studied so that the result would remain reliable. Modern systems are becoming increasingly complex. There are many hierarchies. It is possible to construct controllers and control algorithms at different levels, but in many cases these are not connected. Data does not move to the level of abstract formulas and from there to the level of programs. It would be nice if the different levels of control could be integrated. We are relatively far from that right now."

Bringing control knowledge into policy

Ülle Kotta says that politicians should know the basics of control of complex systems. Society is still a complex system. There is a lot of inherent uncertainty in such systems that data collection does not alleviate. However, a complex system is also vulnerable. According to control theory, the worst thing to do is to optimise for one goal. This means that if the situation changes, the system or a part of it will no longer work. Developing diversity instead of making the system components uniform could save the situation. The diversity of the system makes the system more robust, i.e. it helps it adapt better to changes in the environment. Each element has its own weakness and less diversity means more vulnerability. However, robustness is achieved at the expense of system efficiency.

"From a theorist's point of view, making the system effective is disastrous," Kotta explains. "Another aspect is that there are two types of feedback in control - positive and negative. The latter is good because it reduces the error between the desired and the actual. Positive feedback amplifies the error. There are many positive feedback processes in society today. There is not enough knowledge on how to break the chains of positive feedback. I am talking about economic bubbles and stock rallies, for example."

Driving and self-driving vehicles

There is more and more talk of self-driving vehicles today. Ülle Kotta says that control theory is applied there at a lower level. The car moves along the required trajectory, an obstacle is met and the car passes it - this is a practical output of clasical control theory. Another place where the theory can come in handy is predicting the states of the system according to the measurement data. There is constant refinement going on. This is how the future can be predicted. "Where's the car in a few seconds?" says Kotta as an example and adds that the real problems in this area are linked to something else. She has attended seminars where people directly involved in self-driving vehicles have said that current vehicles cannot read road signs or see people in the rain. "They only work in nice weather," she says.

WHAT DOES THE FUTURE HOLD FOR THIS FATHER AND HIS DAUGHTER?

Toomas (30) and his daughter Emma (5)

Ülle Kotta says that if control engineers were involved already in the initial design and development phase of processes and tools, it would be possible to create systems with very good controllability properties that would also use very few resources. She hopes that Toomas will see this approach become prevalent by 2050.

Kotta also hopes that by 2050, mathematical control theory will be closely intertwined with data-driven machine learning methods. She also sees that today's technology needs a generally accepted formalism that integrates models or control algorithms at different hierarchical levels so that the different levels of control (the general and the detailed) communicate with each other and work together.

Fault-tolerant control has been important in the recent past, and still is. While this will continue to be important in the future, cyber security will be even more important in 2050. If industry 4.0 will automate the operation of most industrial processes, it will be necessary to ensure the security of the processes. Although fault-tolerant control is to some extent related to cyber security, it is not really intended for that. Fault-tolerant control does not prevent errors, but mitigates their consequences. At the same time, the goal of cyber security is to detect and prevent malicious attacks. "So when Toomas sits in a self-driving vehicle in 2050, he wants to be sure that the car's control module can detect and prevent situations where someone is trying to change or influence the operation of the control algorithm."

However, Emma should know that recent research of exotic energy sources suggests that in a hundred years' time the problem of cheap and clean energy will be finally solved – be it with renewable or some other type of energy (e.g. cold fusion). "If this assumption is correct, it will create a qualitatively new development cycle in many areas with completely new control problems," says Kotta.

She hopes that in a hundred years' time, there will be knowledge of how to deal with complex systems. Modelling, analysing, and control complex systems requires new types of models and intuition. Such systems cannot be studied in parts, but as a whole.

"Currently, there are no quantitative methods of analysis and synthesis or precise mathematical models for studying such systems. In traditional models, the important is distinguished from the insignificant, but in complex systems this is impossible," explains Kotta. Complex systems need so-called evolutionary models with dynamic structures.

Ülle Kotta makes things even more exciting for Emma. She mentions that in a hundred years' time there will be space travel, the colonisation of space will be ongoing and we'll have cyborgs moving around the world with us.

Software verifying software

Niccolò Veltri:

Theorem provers will also be used in schools

Niccolò Veltri, a researcher at the School of Information Technologies of the Tallinn University of Technology, is working on theorem provers as part of the project EXCITE. Specifically, Veltri is developing programs to help analyse, verify and improve existing ones. His work is in many ways still theoretical, although in part it has already found application in software development.

"Modern societies are relying heavily, and to an ever-increasing extent, on a variety of machines to perform many fundamental tasks," says Veltri, who studied mathematics at the University of Florence, in addition to postdoctoral research on the topic at the IT University of Copenhagen. "Since we have placed a lot of trust in these machines, we always assume that they function correctly. Occasional failures in these systems and machines can lead to both major financial losses and wider problems for society as a whole. For example, important security systems may be attacked, sensitive or personal information may be leaked, and vehicles with technical errors or incorrect programming may be exposed to the public."

The researcher adds that corresponding computer software has been developed to verify the correctness of most of these useful machines, ensuring their accurate and error-free operation.

"Consequently, the systematic formal certification of hardware and software delivered worldwide is extremely important," he says. "Certification ensures the reliable functioning of these systems, and an ever-increasing number of software developers are moving towards creating software aimed at the verification of software itself." He adds that Estonian IT companies have also seen the need for high-assurance software and started to make developments in this direction.

"This means increasing monetary investments in the departments and working groups that use formal methods to analyse, certify and control their own software products, including the software that is designed to analyse other programs being created," explains Veltri.

Developing software for program analysis

Veltri's research in the framework of the EXCITE project revolves around the development of methodologies for the formal verification of various computer systems, predominantly using various logical and mathematical techniques.

"My tools are interactive theorem provers," he explains. "These are highly expressive programming languages that can be used to encode many of the mathematical structures often used in computer science. With these, researchers in this field try to create specific mathematical models for computer systems, which in turn can be used to simulate and thereby predict the behaviour of these computer systems. As a result, we produce models that have been certified because their correctness and reliability have been proven by the machines themselves. This then gives the end user confidence that the system works correctly and is reliable."

Veltri adds that the idea of developing theorem provers and related languages that certify the correctness of programs is not new, but as our lives are becoming increasingly reliant on computers, the evident need for them has risen to a whole new level in recent times. The researcher adds that as computer systems are constantly becoming more complex and comprehensive, it is no longer possible for people to control all systems and lines of code themselves as it is also extremely expensive. However, machines can be employed as useful tools for attesting the correctness of these complex systems and programs.

> *Certification ensures the reliable functioning of systems, and an ever-increasing number of software developers are moving towards creating software aimed at the verification of software itself.*

Veltri adds that the development of software for formal verification began as early as in the late 1960s, which at the time was more of a task for academic research. The need for theorem provers saw a significant surge in the 1990s as computers became more powerful, their use expanded into all walks of life, and companies began to suffer financial losses due to being unable to anticipate potential problems. Problems, for example, with the operation of new computer programming languages on new computers should they become many times more powerful in a few years, or the inverse issue of the operation of software, where new programs require much more power from their processors.

"A key example is one of the world's largest computer chip manufacturers, Intel, which produced tens of thousands of new processors which were discovered later, after production, to have a major flaw. The error occurred because they were unable to anticipate all possible errors in chip production. The employment of theorem provers in this case would have been able to detect such an error prior to the chip commercialisation, and the company could have been able to correct the issue. It is possible that in the future, these provers will be so smart that they can find and solve similar problems themselves, but currently this would not be useful either,

> *It is computer program-based control of critical computer systems that are important to the state in the most fundamental aspects of modern life – online elections, banking, medicine – that restores the confidence in technology and science.*

in terms of money nor time, if the error can be corrected by a person after being found during the formal verification phase," explains Veltri.

Veltri's work has two directions: the first is the theoretical development of new theorem provers aimed at the formal verification of software, which should have enough expressivity to reason with a large variety of programming languages. One way of thinking about theorem provers is as extremely smart notebooks. Users can type in mathematical expressions and prove theorems, whose correctness is assessed by the prover. Users can also interactively ask the system to prove some results for them, and the prover is often successful in this task.

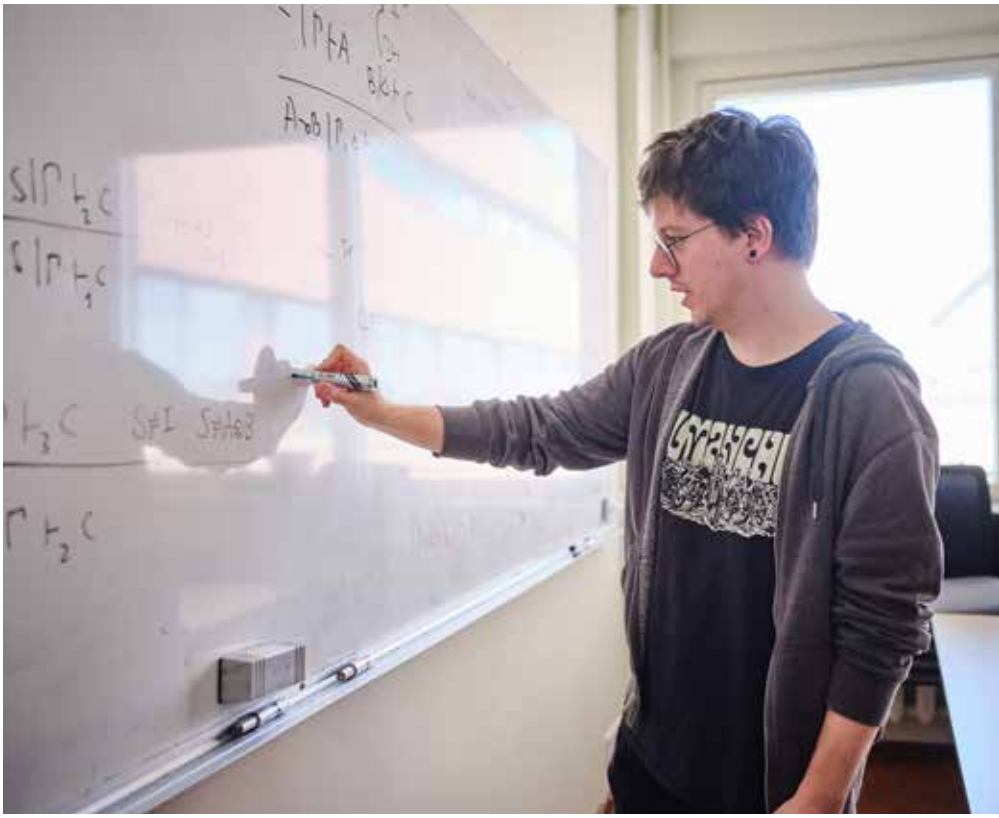
The other, more practical direction that the researcher is working on, is the use of these theorem provers for the purpose of formal verification of existing programming languages and the development of new languages. This task ensures the correctness of programs with respect to given specifications describing their intended behaviour. In turn, this allows for proactively improving and upgrading computer systems, guaranteeing their smooth functioning, which in today's digital climate is crucial for many essential activities of everyday life.

"It is difficult to explain, but the trend is in making software development simpler, more controllable and therefore ultimately, to improve it," says Veltri. "Today, we are still in the process of creating theoretical solutions, but we have also put a little of it into practice. Although at a very low level at the moment, the initial results are rather promising."

Which field would benefit the most?

In the long run, theorem provers could and should be used by all developers in the analysis of any program. At the moment, however, it can be seen that areas that require the most critical precision, as well as those where a lot of money is at stake, show the greatest interest in these formal methods. Veltri highlights self-driving cars and aviation, as well as insurance, banking and medicine as examples that would benefit with the use of theorem provers.

"Let's take a self-driving car. On the one hand, it requires an extremely large amount of information and on the other, a highly accurate, reliably faultless functioning system, from both its hardware and its software," explains Veltri. "The correctness of self-driving car's software can be assessed by testing the system millions of times, but it can only be truly assessed through for-



mal verification. Surely, the highest guarantees of correctness is the fundamental goal we have for critical systems that are responsible for human lives, such as self-driving vehicles. Theorem provers figuratively act as "notaries", certifying the correctness of the systems. They can also be used for finding bugs and subsequently improve the systems themselves."

When it comes to banking or medicine, where an incredible amount of secret, encrypted and restricted information travels, most of which also contains sensitive personal data, these systems must also operate in such a way that no handling errors occur. Most of the world's major information leaks have been related to poorly-built systems, rather than hacking or malice.

"It is interesting that many companies are increasingly creating units that deal with these issues. It is understandable that there is such a unit in Estonia, at companies such as Skype for instance, or Guardtime or Bolt, but banks and insurance agencies have also been affected by this development. Everyone is working so that these companies can be 100% certain that the software – or indeed, hardware – they develop or commission will function as it should. It is always a question of getting additional guarantees for both the organisation and their customers," adds Veltri.

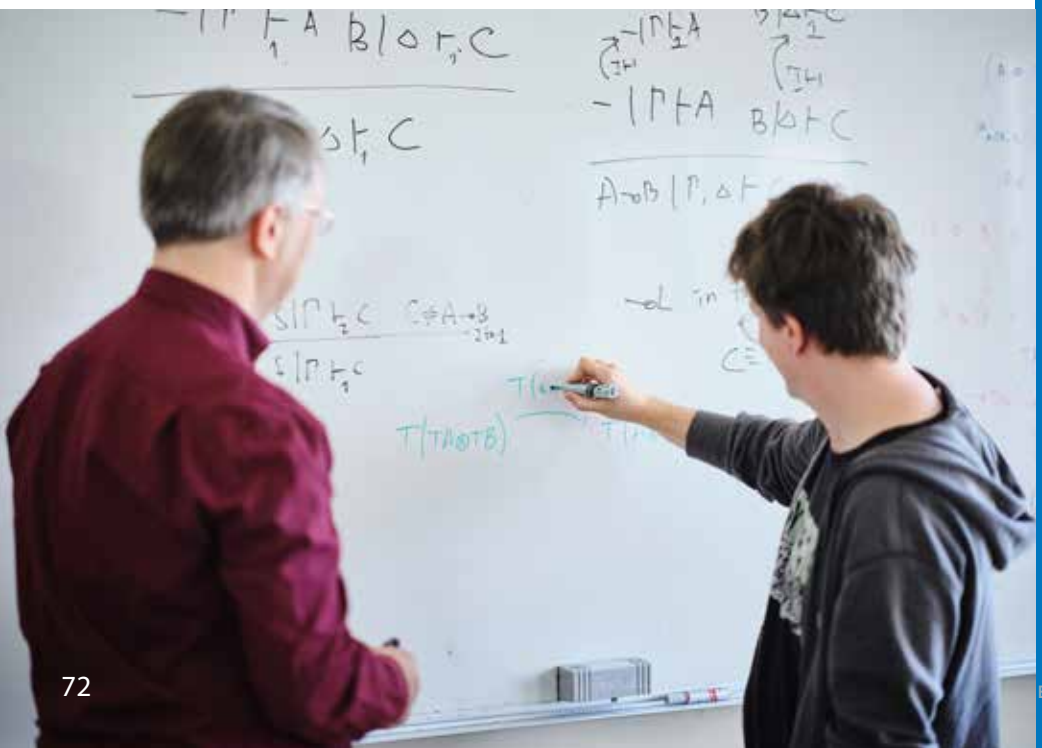
The result is a safer digital society

Veltri thinks that in 30 years, as a result of new high-assurance software and formal certification, our digital society will have reached a whole new level of security and reliability. But the question remains: what does the average person gain from all this?

"It is computer program-based control of critical computer systems that are important to the state in the most fundamental aspects of modern life – online elections, banking, medicine – that restores the confidence in technology and science. Confidence which is currently rather shaky and low. This trust, in turn, provides us with a higher quality of life in every area of life," he adds.

Veltri notes that state-of-the-art technologies for software analysis and control are already in use in many successful IT companies around the world and in Estonia. In the coming decades, this phenomenon is expected to grow and expand, and it is also expected that the formal certification of programs will become standard procedure, and a central focus for every software company and state agency that creates computer systems.

"As a result, the developers themselves, their customers and most importantly, the end users, will have the added reassurance that the programs that run our lives and use on a daily basis work correctly," explains Veltri.



WHAT DOES THE FUTURE HOLD FOR THIS FATHER AND HIS DAUGHTER?

Toomas (30) and his daughter Emma (5)

In a utopian world, all computer systems should be constantly analysed and be subject to constant formal certification. Veltri thinks that by then, much of the development, management and control of high-assurance software will be delegated to different machines.

"This, of course, requires a huge leap in the development of artificial intelligence and an enormous amount of computing power," he explains. "Computer power could be obtained from the more ubiquitous quantum computers. However, when it comes to interactive theorem provers, then by that time they will not be just standard tools for verifying and creating computer technology. It can be assumed that these theorem provers will also become one of the main tools in the emergence of new mathematical knowledge, and this is not only the case for the chairs of mathematics and computer science at the university, but these theorem provers will be used in education from the high school level." Maybe not by the time Emma reaches high school, but perhaps a little while after.

Tarmo Uustalu is creating a new computer language

Tarmo Uustalu is a leading researcher at TalTech and at Reykjavik University, and is developing and enhancing new programming languages and theorem provers with his research team as part of an EXCITE project. Uustalu considers himself a technology pessimist, and is attempting to create order in a world that is transforming faster than ever before in human history.

"In a way, information technology is in a peculiar situation," says Uustalu. "It is in a state that no other field would accept under any condition. Because it would not be acceptable for a television set or a car to completely shut itself off and require a restart two or three times a day. However, that tends to be the case with computer programs. There is also a cultural acceptance of the fact that computers just stop working. Nobody is surprised about this."

The professor adds that given how rapidly and how much the entire world is becoming more IT-dependent, the situation itself is becoming more critical. "If we take energetics, for example – power stations and distribution systems – or the chemical industry and medical institutions, all IT-related faults in these sectors are completely unacceptable. There

are already a lot of problems when X-Road, the electronic health record or the ID-card system don't work as intended."

Mistakes must be prevented

Uustalu provides a simple example to explain his thoughts. "I gave a digital signature a while back, and my screen displayed a red signal indicating that my signature is invalid as well as a green signal indicating that my signature is valid at the same time. If that type of situation were to arise while signing an important contract online with another party and a notary, there would be immediate disputes over whose signature is valid and legal and whose is not. Even though the signature may be valid, like it was in my case, there will still be a lot of confusion, and in an intense situation the transaction may fall through. My digital signature software was most likely out of date, but that doesn't justify the situation at all," says the professor and adds that it is absolutely normal and correct to ask questions about electronic voting. Software should always be audited.

> *We are creating brand new languages that use partially completely new basic principles compared to the current mainstream languages.*

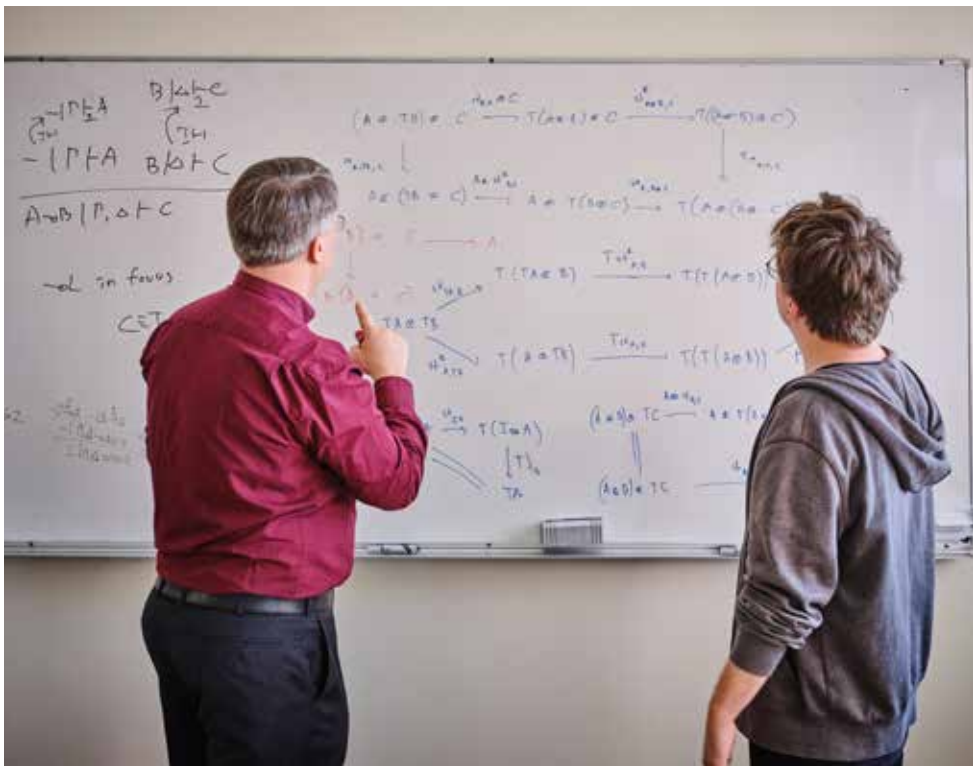
We are more dependent on the IT sector than ever before in 2021; in medicine, public administration, education as well as entertainment. We are already heavily reliant on IT systems and on them working correctly, quickly and without faults in most fields. Uustalu, along with his research team in the EXCITE project, is working to avoid defects in programs and coding. They want to avoid errors not through employees who manage the programs but by using newer programming tools such as programming languages and the tools related to them, including theorem provers.

Software can be written by "anyone"

"The IT field can be divided into two parts: hardware and software," explains Uustalu. "Large corporations manufacture most of the hardware. These companies hire several thousand of the world's smartest people to design the best computer chips in the world. These chips are generally trustworthy because they have gone through a high-level of quality assurance. However, software can be written by basically anyone. All you need is education and experience, which is rather impossible to adequately evaluate and manage."

Niccolò Veltri and Jaan Raik, who focuses mainly on the hardware, are working to make programmers' work easier, more standardised and more manageable. Already existing coding tools are used to analyse and evaluate them, while also essentially creating better languages to use to write these programs.

"We are creating brand new languages that use partially complete-



ly new basic principles compared to the current mainstream languages. These principles are mainly focused on noticing errors from the beginning while writing code. Just like in the military – rules exist, a procedural framework exists and there are protocols that mustn't be violated. All of this is written into the new language. On the one hand, it can be rather limiting, but on the other hand, it can be helpful for programmers as a whole," clarifies Uustalu.

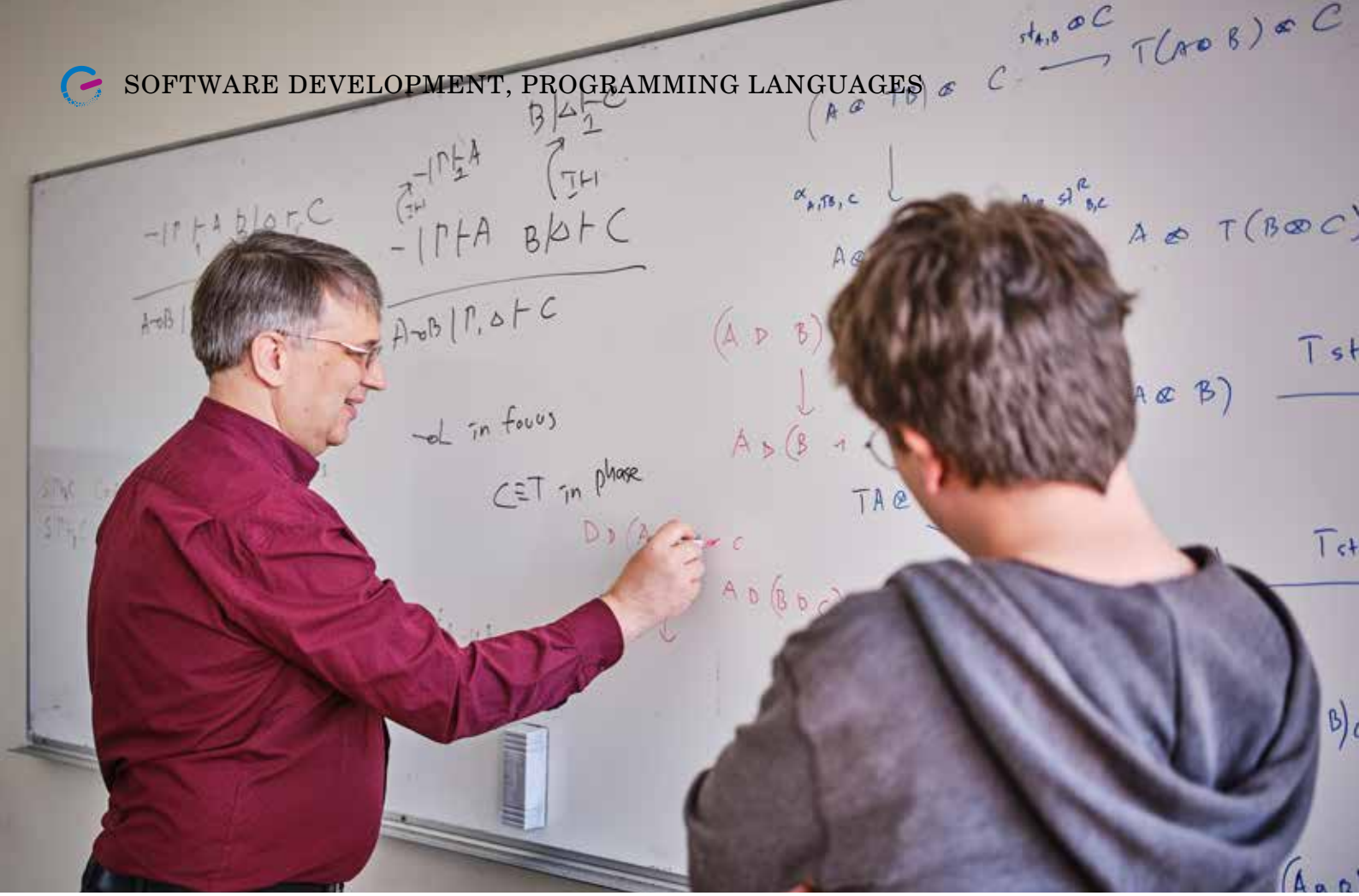
Completely new programming languages

In conclusion, these new programming languages can be summarised by the phrase "correct by construction", which means that the language itself examines the programs while they are being written. The important thing is that the written code complies with the rules and works as intended.

"The language has written rules which the code must follow or it cannot be activated," the professor explains. "We joke amongst ourselves that code can be written either in a way that does not do any harm or in a way that does some good. The absolute minimum we require from a program is that it does not do any harm or deteriorate. The main objective is for the code to work as intended and do good."

> *The languages we are working on are already essential in banks and insurance companies, especially in the departments that calculate schemes on how 'the house will always win'.*

Is there a certain degree of artificial intelligence in these new languages? "Automatic program repair systems exist – programs are analysed and fixed either before launching or while they are running. In the latter case, the idea is that when various problems and errors arise while the program is running, there is a 'mind' written into the code that recognises these errors and can 'reorient' on the go. Synthesis goes above and beyond that – the idea of synthesis is closer to machine learning and artificial intelligence. Program-



mers write code by learning from examples and adding their own wisdom to them. Synthesis is rarely used in Estonia, if at all. But we do use automatic repair. We have worked in this area ourselves," he says.

There are applications for the new languages in the whole IT field

The languages Uustalu's research team is working on are functional languages or languages that have very expressive type systems (rich types). "The languages we are working on are already essential in banks and insurance companies, especially in the departments that calculate schemes on how 'the house can always win'," says Uustalu. "Specialists working in these departments often have a doctorate in physics and are extremely proficient in math and understand how to code it. Functional languages enable a person to write exceptionally elegant code for these tricky simulations."

In everyday life from a normal person's perspective, the professor sees two paths where his developed languages could have a significant impact: systems related to security and to privacy. "Security incidents that arise in people's communications with the state as well as corporations are very serious and often do not come down to incorrect protocol. The errors occur when those protocols are carried out.

Helping the ID-card

Let's provide an example. Arnis Paršovs recently defended his doctoral thesis examining the Estonian ID-card at Tartu University. Paršovs has previously 'beaten' the ID-card several times and was rather brazen in his doctoral thesis, because after all the incidents that have occurred in the card's 20 year history, the authorities still do not understand the gravity of the problem. This is certainly an area where superior software technology can help," explains Uustalu.

The second example is closer to home, from Uustalu's own research team. "Denis Firsov is working part-time in TalTech and part-time in an Estonian unicorn company Guardtime, a timestamping company," he explains. "Unlike the others who work there – who mostly have a background in information security – Denis's background is in programming languages as well as theorem proving. He started working there and soon realised that the theorem prover that was widely used in this field, EasyCrypt – a program that examines timestamping protocols – is full of errors. Perhaps he saw these errors because he has a background in formal methods and was able to view things from a different angle; he knew where to detect them. However, the new language should eliminate such errors."

Firsov discovered another problem directly related to timestamping and the definition of one of its security features. Everyone has been using that definition for a couple of decades and a lot of conclusions have been derived from it. Those conclusions are correct, but the definition is worthless because of the error – if you read it thoroughly, it turns out that is does not guarantee safety as is actually intended. Therefore, all the security evidence that is built on the original is actually much weaker than previously thought.

"This specific example, in which

there is an error in the system, directly affecting all of us: just how protected are our data and activities on the Internet and in other programs, even if we are promised security while enabling cookies and allowing access. This makes all access and protection mechanisms an issue from the beginning. For example with Facebook, where there have been foolish infrastructure leaks, the main problem has been in access management systems with fundamental flaws that do not protect anyone in reality. Therefore, there is no need to hack into Facebook, because you can essentially just walk in the front door," says Uustalu.

> *Artificial intelligence is doing more work for us, e.g. in banking, where it analyses the entire personal history of an individual, all their previous behaviour and then makes a decision based on that. In this case, it is necessary for the system to be fair and honest.*

Everything is trending increasingly towards artificial intelligence

Uustalu believes that algorithms based on artificial intelligence or algorithms that decide things for us are becoming increasingly more common. But how can we guarantee that explainable artificial intelligence does what we want it to do without any errors or causing harm to humans?

"We are already seeing facial recognition used at various borders," he says. "We as a society keep making more decisions to use these systems, which means that they keep being developed and will likely become ever-present in various places in the near future. The question remains: how can we ensure that these systems work as intended, that they are useful, correct and flawless? Let's look at it even broader. Artificial intelligence is doing more work for us, e.g. in banking, where it analyses the entire personal history of an individual, all their previous behaviour and then makes a decision based on that. In this case, it is necessary for the system to be fair and honest."

The professor also says that the new language is not all-powerful, it still needs human calibration and 'training'. "In reality, we cannot create a language at any point that excludes a person completely from the equation. We can use the language to give the code various limits and parameters and then let it learn and solve problems itself. However, a person is still required. Still, there is a lot of friction between the rigidity of languages and their independence and flexibility. We have to be able to sufficiently analyse their independent thinking. We have to program artificial intelligence so that it is able to and obligated to account for itself," explains Uustalu and adds that even if we are able to completely develop an automatic language or write code that automatically works, it is not possible to get it to work like a human without a human's assistance.

"We reach a critical limit when we must give up all control," he says. "That is not sensible, even if automation is more profitable. Sadly, we cannot fully waive control and trust any system completely."

WHAT DOES THE FUTURE HOLD FOR THIS FATHER AND DAUGHTER?

Toomas (30) and his daughter Emma (5)

In essence, the theorem provers mentioned in the beginning and their capabilities to write a new programming language were already there in the 1980s. The breakthrough in these two directions arrived when computer hardware became powerful. The last 10–15 years have been an excellent time of development for both of these directions. Some sort of momentum has been reached, a common understanding of the need for them.

Uustalu is unable to say what will happen in his field 50 or even 100 years from now. "For me, it is terrifying to imagine what might happen 50 years from now, it's such a long time. In reality, I am a technology pessimist. The way the spread of the Internet and the widespread explosion of social media has changed our lives and our social situation has been fundamental. We don't even know if that change is good or not yet, not to mention how reality will look 50 years from now," he says.

Model of a smart apartment building developed by Estonian University of Life Sciences used to demonstrate ideas constituting a Smart City within the Tartu Smart City project.

Satish Narayana Srirama: Because of our work, future smart devices and solutions will be a lot cheaper

Satish Narayana Srirama worked in the University of Tartu for many years, but last summer moved back to his native India and joined University of Hyderabad. He is still a guest professor in Tartu, and still leads the lab that has been created there. Srirama's research group is working on issues that are essential to our much smarter future.

Our society has been dreaming of smart cities for many decades. Artificial intelligence and machine learning were already a topic of discussion in the 70s. Today, we have the knowledge, technologies, possibilities, and the infrastructure to make that dream a reality. It seems so close, yet we still have a long journey ahead of us. Nevertheless, it is not merely science-fiction anymore. "We will get there. The next generations will see it for sure, but there are many obstacles along the way. We are walking with baby steps at the moment," Professor Srirama begins.

Srirama speaks about how our world is becoming more digital and smarter every day. Compelling Internet of Things (IoT) applications are launching constantly in all domains. Srirama's group vision strives to provide IoT and cloud services at a minimal cost for every person, whilst keeping an eye on the quality of the user experience. They design differ-

ent architectures for smart applications, optimising the energy consumption and improving the performance of cloud servers and data centers.

"It will play a major role over a period of a few decades. We also see that our research on efficient data flow between fog and cloud will significantly impact the performance of the cloud and IoT-based applications, which can then further influence the quality of experience for everyday people," Srirama says.

A huge benefit for companies

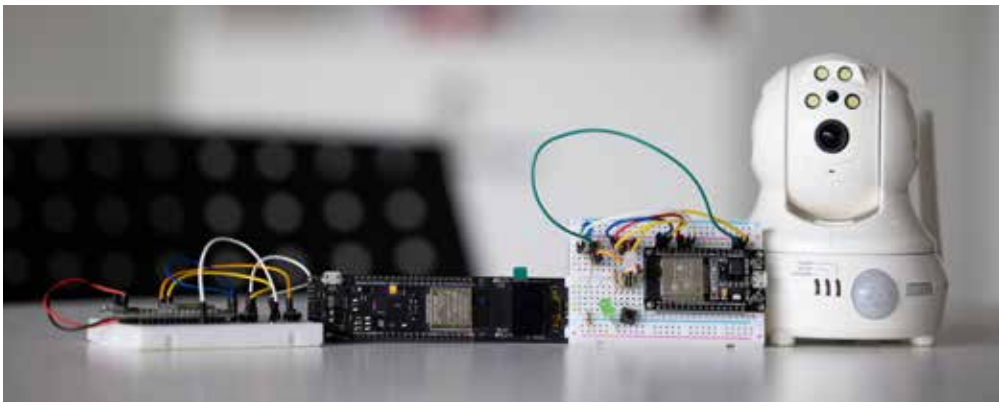
They believe that with the current progress of their research, they would be able to provide a significant contribution in terms of theoretical evaluation and experimental results for future state-of-the-art tools. One such contribution can be seen in the energy consumption of cloud data centers and fog servers.

"We will also continue this research on edge devices in the future, which would be highly beneficial for the businesses that use them in reducing the cost and increasing their revenue. Because of the significant cost reduction, businesses will see a huge surge in demand. The demand will not only be from the citizens in special economic zones, but also from every household. With the increase in demand, business would be able to further minimise the cost and increase their revenue. We also work with inclusive business models, where the smaller enterprises such as cafes can also have their share in this technology transfer to the public," Srirama adds.

AI to help out

Professor Srirama's research revolves around IoT and fog/cloud computing, stating the aim of his research group is to make our lives smarter by providing better IoT services.

"Within this, we are investigating and addressing several research challenges, such as reducing our carbon footprint by investigating the energy consumption of data centers and Android devices, higher quality of service (QoS) through personalised service delivery, and data pipelines.



> *We design different architectures for smart applications, optimising the energy consumption and improving the performance of cloud servers and data centers.*

In addition to that, we are also focusing on the coverage analysis of NB-IoT and SigFox," he describes.

So just focusing on cloud services and resource management has evolved into different aspects of the cloud and fog.

"We are not only solving the cloud-related mathematically complex issues by the traditional approaches, but we are also now investigating if artificial intelligence can be used as a potential approach," Srirama says.

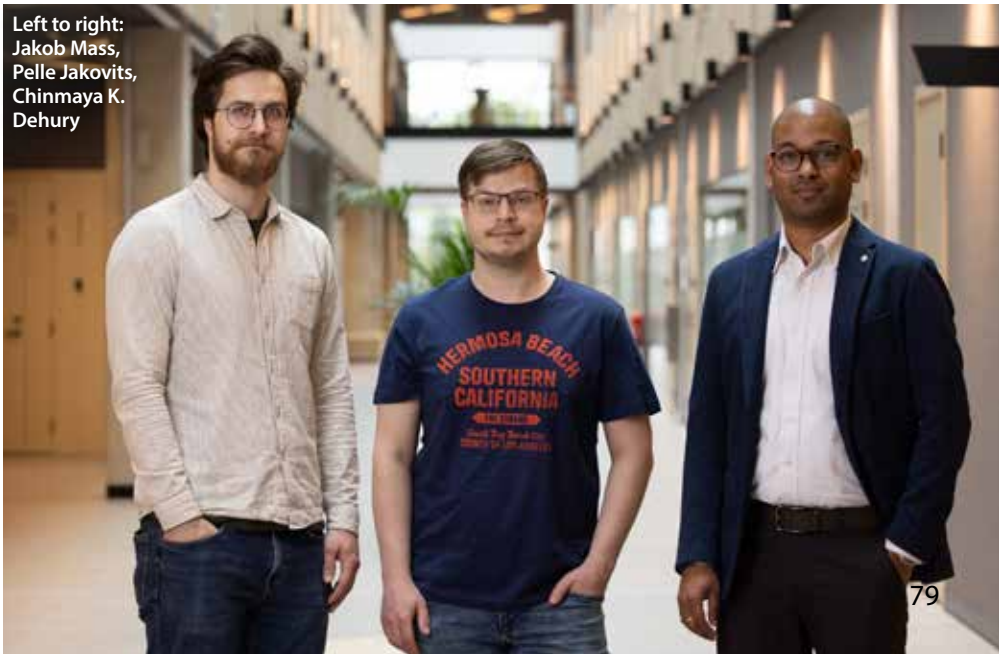
Cooperation in EXCITE

He praises EXCITE as a platform to carry out research work in a collaborative manner. Srirama has worked together with N. Poddar, S. Z. Khan, J. Mass and Yannick Le Moullec on analysing the coverage capability of two LPWAN technologies i.e. NB-IoT and Sigfox, for sending sensor data over long distances with limited energy requirements.

"We carried out the experiment at the University of Tartu and Tallinn University of Technology. With this analysis, we would be able to recommend the business and research with which technology they need to go in different situations. Moreover, in collaboration with Professor D. Pfahl, we have investigated the role of energy consumption in the development of Android software solutions," Srirama says.

Energy optimisation as a key issue

Currently, the world of science is a little bit behind, despite the fact IoT solutions are becoming smarter and



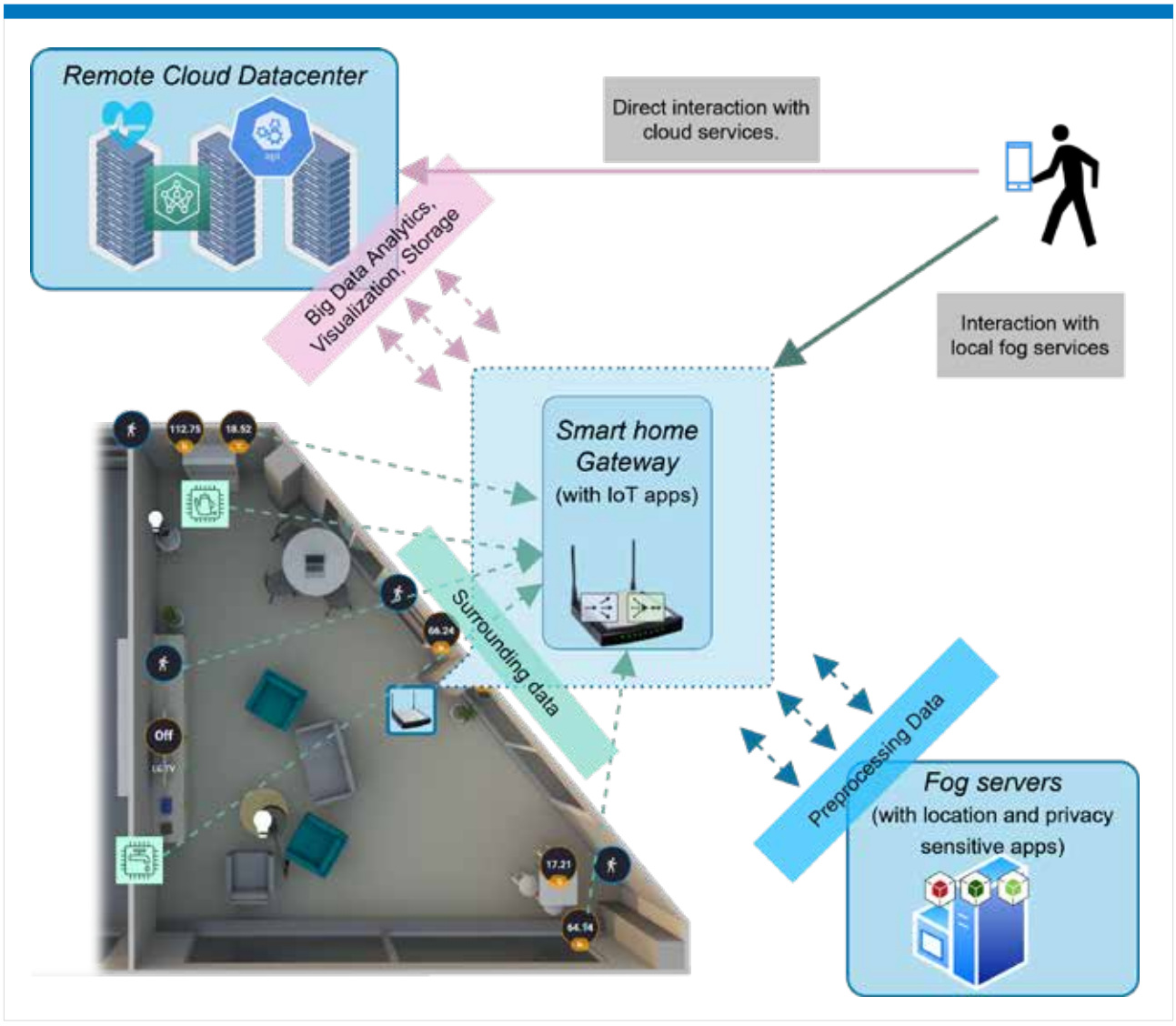
Left to right: Jakob Mass, Pelle Jakovits, Chinmaya K. Dehury

smarter, we are still using basic architectures and manually developing each and every system. Srirama says that we are basically manually joining dots together, and this has to change if we are to optimise our energy consumption.

"Long-term, we want to develop generic architectures, so that it would be easy to develop IoT solutions, but the biggest problem we face as we look toward the future is the energy consumption - batteries drain out too quickly."

It is not a problem for devices we have in our homes as we can just use a charger. But when we consider other environments, such as forests, water, and other places where access to a power source is not readily available, it becomes a problem.

Srirama says that as it pertains to energy optimisation, they want to develop different models. However, the main idea is to use AI to determine when it is necessary to communicate at all. Let's say you have a sensor somewhere in a deep forest,

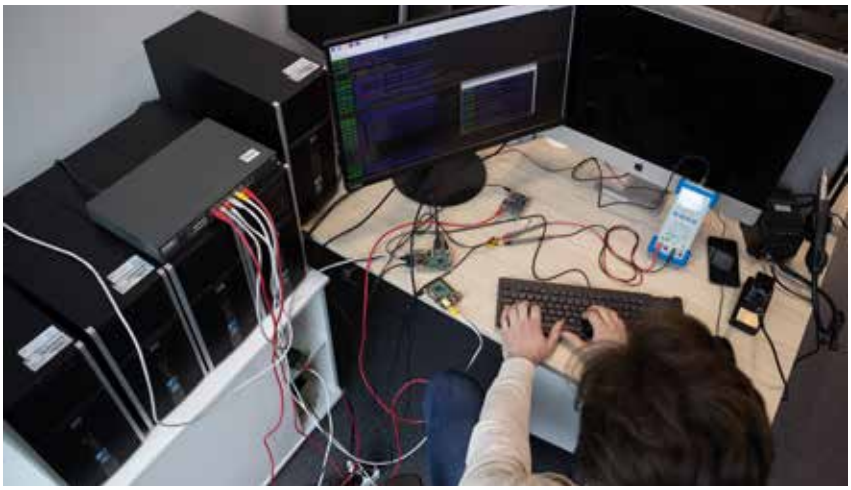


today you collect information from that sensor with every passing second - the battery will drain out in a day. If communication were to take place once every minute, and every other 59 seconds it does not, it saves a tremendous amount of energy. Conversely, we should be wary that the conservation of energy does not defeat the main purpose of the sensor.

Data centers have a big goal

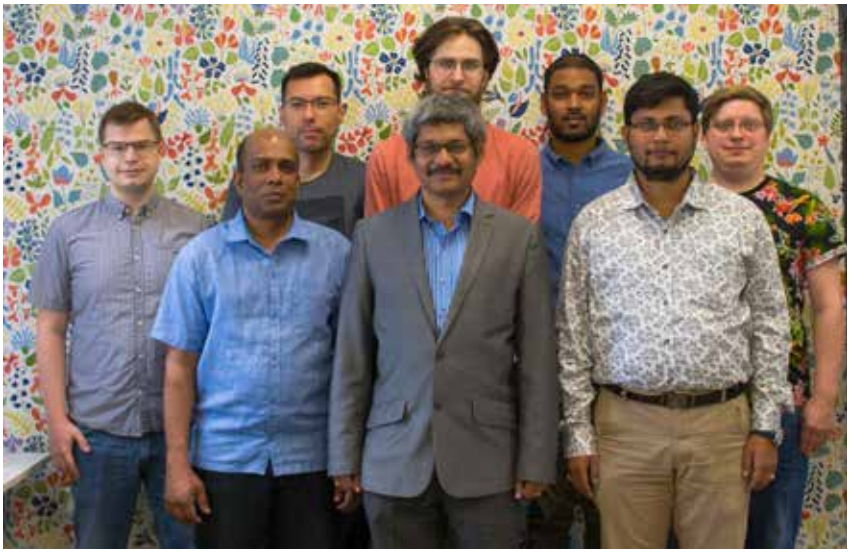
Around the world, the phrase 'eco-friendly' is being mentioned more frequently, which highlights an additional challenge cloud computing would face. If we were to take the global usage of energy and rank countries that use the most and add all their data centers combined, then the sum of cloud computing energy usage would rank 5th globally. According to Greenpeace, Cloud Computing worldwide consumes more energy than all but four of the largest economies (USA, China, Russia, and Japan) do, and only these four countries surpass Clouds in their annual electricity usage. Srirama knows that these datacenters try their best to be greener, attempting to use solar and wind energy. Moreover, they use heat that they themselves generate. Yet, there is still a lot of ground to cover.

"Bitcoin mining is different. It takes a lot of energy and it is not cost-efficient anymore. However, cloud computing is the service we are all benefiting from, and lots of research goes into finding solutions to make it sustainable. I believe it will become noticeably more eco-friendly in the coming decades," he says.



> *Cloud computing is the service we are all benefiting from, and lots of research goes into finding solutions to make it sustainable. It will become noticeably more eco-friendly in the coming decades.*

When we consider smart cities, transportation and homes into account, as well as autonomous vehicles, then we get a picture of where we are heading. "We are solving each individual problem as it arises, but we must ask ourselves - what will the effect on the environment be? It is not fully researched yet., but we are working on it."



Cloud Computing Manifesto

Srirama and his team are collaborating extensively with scientists all around the world. Usually, the projects are funded by the European Commission. Srirama was one of the creators of a very important document – he gathered 25 experts from across the globe to publish the "Cloud Computing Manifesto[1]" which highlights the challenges the field faces over the next ten years. "It also shows that we are all working together to solve the important problems that we are facing. I am proud that we have produced this document," he says.

There is also interest from private sector; Srirama mentions Telia, who supported the creation of the IoT Lab as part of Mobile & Cloud Lab[2] at the Institute of Computer Sciences in the University of Tartu. There, they offered their technology and supported the purchase of infrastructure.

"We must have SME's (small and medium sized enterprises) in our European Union projects. It is a field of research with a great deal of interest from companies."

Srirama adds that the field is very much in focus all around the world. "We need to get smarter, right?" he argues. Getting smarter requires more

investments in the solutions and standards as well. "We are certain that we will continue to get funding. There are a lot of resources to be used before we succeed."

We wouldn't be ready for tomorrow

We started this article by talking about science fiction, but what if we woke up tomorrow morning and realised that our home, city, and office were all as smart as they possibly could be, like we have imagined. Srirama reminds us that we are not yet ready. We know what is needed to reach the goal though, he believes that we are only a tenth of the way there.

"Think about that. Estonia is a very technologically advanced country, but now let's consider India, with over a billion citizens and a landmass almost the size of Europe. It takes a lot of infrastructure to cover all that area, and yet nobody has been prepared for this," he says.

But are smart devices and smart cities meant for everyone? Srirama estimates that at least 10 percent of people still wish to live a rural life in forests and between fields. We need to find a balance whilst also educating our population to be ready for such a dramatic shift. "Their concerns must be heard and addressed. They need to understand the change. Governments need to do massive investments, and then there is the issue of security. It is great thing that my fellow colleagues in EXCITE are tackling these issues with quantum and post-quantum cryptography and so on. Whatever we do, people need to be prepared first and foremost. If there was a smart city tomorrow, people would be naturally apprehensive," suggests Srirama.

[1] https://doi.org/10.1145/3241737
[2] https://mc.cs.ut.ee

WHAT DOES THE FUTURE HOLD FOR THIS FATHER AND HIS DAUGHTER?

Father Toomas (30) and daughter Emma (5)

Toomas and Emma will learn of big cloud-data centers that produce zero carbon footprint. This means these centers would be able to recycle the energy along with the heavy usage of green energy, which is also thanks to the support from the EXCITE in carrying out the research on energy consumption optimisation across a wide range of devices, ranging from Android devices to the cloud data center.

Because of this energy consumption reduction, the cost of the services offered by the cloud provider would reduce significantly, allowing Toomas and Emma and their businesses to come forward and adopt the cloud ecosystem. Over time, the research community and businesses are able to increase the battery capacity. With significant progress on energy efficient Android applications, we can see the increase in the battery lifecycle and therefore this will have a direct impact on further cost reduction on Android devices.

"We have envisioned continuing this research on IoT devices as well. If we progress at the current pace, I see a future where the configuration of a smart home with access to the cloud services with several IoT devices would come at an incredibly reasonable price, it would be affordable for every household," he says to the father and daughter.

"But I worry about what these smartphones and other smart devices do to our psychology. This has not been studied fully, because there has not yet been a generation that has grown up using only smart gadgets. Young people are not enjoying the outdoors as much as I did when I was young. What is the outcome of that? We will have to wait and see."

The other dimension of Srirama's research on energy consumption optimisation is generating significant progress towards building a healthier and greener environment with a minimalised carbon footprint. There are a number of researchers investigating the average carbon footprint while manufacturing a smart device. For instance, a smart phone creates 55 kilograms of carbon emissions during its manufacture, equal to 26 weeks of doing laundry. So, if we can increase the lifespan of the smartphones and other smart devices, we would be able to reduce the total global energy footprint caused by smart devices, which is predicted to be 14% by 2040.

"I also see the significant intervention of IoT devices in our daily lives that will lead to the adoption of a number of smart services, such as smart cities, smart homes, smart lifestyles, smart elderly care and healthcare," he says. "To abstract the complexity of dynamic data routing through an array of available intermediate devices from the end user, we are focusing on data pipeline architecture. We predict the result of our research will play a major role in the future in achieving a highly sophisticated smart environment, where all the devices worked in a seamless and coherent manner," Srirama adds.

With such developments over the next century, Emma and her children will be surrounded by a smart environment: cities with zero carbon emission, smart vehicles interacting with each other and dynamically re-route themselves to reach their destination. Additionally, citizens with smart homes where all the electronic devices that are sufficiently autonomous as to repair themselves. There will also be smart secure communities, a smart governance system with zero paperwork, meaning no individual needs to visit any specific public office, thanks to affordable cloud services for e-governance.