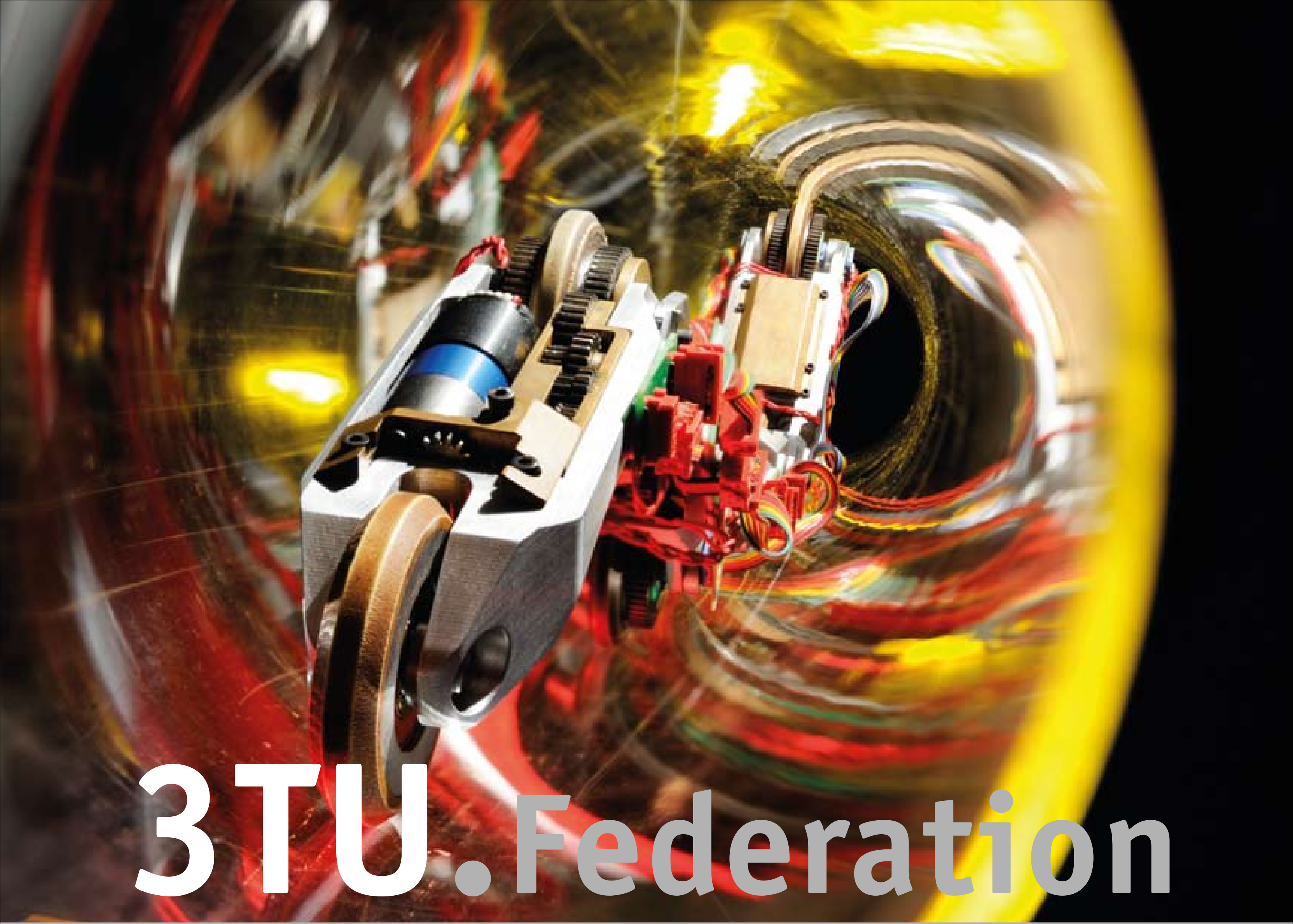

3TU.Federation

JOINING FORCES TO SHAPE THE FUTURE

3TU.RESEARCH HIGHLIGHTS

3TU.Federation

TU Delft Delft University of Technology

TU/e Technische Universiteit Eindhoven University of Technology

UNIVERSITY OF TWENTE.

PREFACE

The three universities of technology in the Netherlands - Delft University of Technology, Eindhoven University of Technology and the University of Twente - have joined forces to establish the 3TU.Federation. Its aim is to maximise technology innovation in the interests of the Dutch knowledge economy and to enhance the country's competitive global position. This is achieved by combining and concentrating the strengths of all three universities in research, education and technology transfer. The 3TU.Federation wants to boost the value of the three cooperating universities for both students and researchers as well as industry and society as a whole. One of the key underlying objectives of the federation is to strengthen the focus and mass of research, and to this end the federation started joint 3TU.Centres of Excellence in research domains that are central to national and European research agendas.

This book contains highlights of the research performed by the six joint Centres of Excellence, with special attention paid to applications in industry and society.
The ethical aspects of technological innovations are an integral concern in all our research domains.

Top researchers tell enthusiastically about their top-notch projects that will make our expectations for the future come true. These same researchers look to intensify partnership with industry to promote the social and economic application of the technology knowledge developed within the universities. They also play a leading role in encouraging supporting new business start-ups by young technology entrepreneurs. The time has now come to roll out and develop these successful joint activities and to form a united front for the interests of the Netherlands as a high-tech country. We will raise the level of the research through partnership and coordination, creating a more internationally competitive environment.

Joining forces to shape the future.

A.H. Lundqvist,
Chairman of the Executive Committee
3TU.Federation

prof.dr.ir. J.T. Fokkema,
Chairman of the Managing Committee for Research
3TU.Federation

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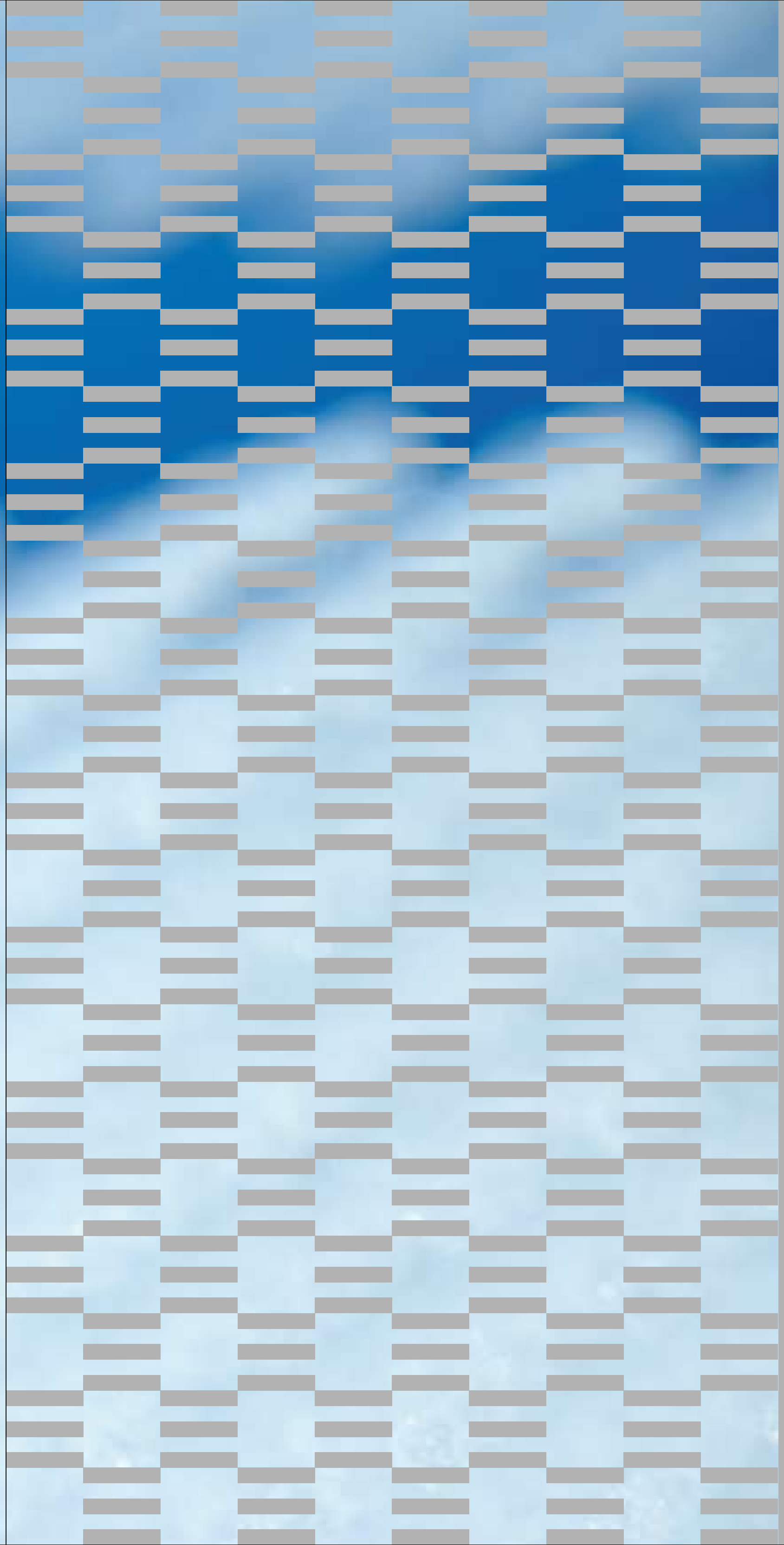


PROF.DR. HUUB SALEMINK
SCIENTIFIC DIRECTOR
3TU.CENTRE FOR BIO-NANO APPLICATIONS

In the past decades, a wave of miniaturisation has rolled through technology - and this wave is not coming to an end. In addition, a ‘convergence’ of physics, chemistry and biology is following in the wake of nanotechnology research due to the fact that the relevant building blocks at molecular/ nanometre scale can no longer get uniquely assigned to a particular discipline. Furthermore, at this point in time, the applications in electronics, nanofabrication and genomics and life-sciences are starting to overlap.

The 3TU.Centre for Bio-Nano Applications focuses on these next steps in miniaturisation and in convergence towards applications in life sciences. We assist in the development of revolutionary technology for medicine/pharmacology, instrumentation and treatment. It is our ambition to valorise the leading position held by nanotechnology in the Netherlands into valuable applications.

With the 3TU.Centre for Bio-Nano Applications the three universities of technology unite their relevant excellent research. A mild form of self-organisation, based on reinforcing existing expertise, allows us to leverage synergy and develop sufficient momentum to deliver high-quality education and research. Together we aim to develop this research field through a balance of competition and complementarities. This 3TU strategy is founded on the awareness that we are competing on a global rather than domestic level. The choices made in recent years, in terms of personnel and infrastructure, have given our three technology universities, through this 3TU.Centre, a very strong global position.

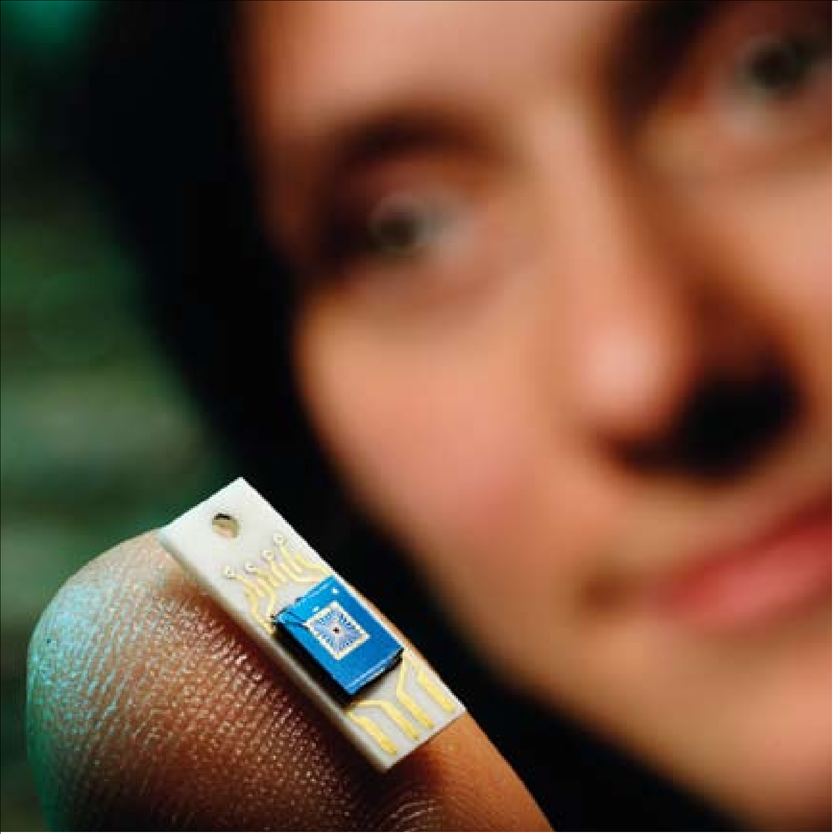
PROF.DR. HENNY ZANDBERGEN - HIGH RESOLUTION ELECTRON MICROSCOPY
DELFT UNIVERSITY OF TECHNOLOGY

SEEING ATOMS MOVE

'Seeing how atoms and molecules move in living and non-living matter', is how Henny Zandbergen, professor in Electron Microscopy at Delft University of Technology, describes the research he and his group conduct. They use the electron microscope not just to see things but also as a tool to build things on the nanoscale.

In collaboration with the Delft University of Technology researchers, the Dutch company Philips was the first to have a serial production line for electron microscopes. The fact that electrons have much smaller wavelengths than even X-rays allows you to see things with much more detail than with a light microscope. The electron microscope can even now be used as a tool, for example to move atoms around. The Delft University of Technology has played, and is playing, an important role in the further development of these instruments and in finding new applications. One of these new applications is using the electrons to create holes a few nanometres in diameter in thin membranes. A nanometre is one millionth of a millimetre. Technology developed for microchip manufacturing can be used to make thin membranes of around 100 nanometres in size. In this 'big' membrane, a hole of, for instance, 5 nanometres can be sculpted with a focused electron beam in an electron microscope. Such a hole can be used as a single molecule detection system. Eventually it might be used to determine the sequence of a DNA-molecule, or other long polymers.

'These nanopores are being used, for example, in the department for Bionanoscience to research the interaction between DNA and enzymes', says Zandbergen. 'My colleagues Cees Dekker and Nynke Dekker are for instance using the pores to study how a single DNA molecule coils and uncoils. For this they use a DNA-molecule that is trapped in a pore on one end and to a magnetic bead on the other end. By playing around with the magnetic field strength you can make the molecule coil up, not unlike the cord on a telephone. If you then thread the DNA molecule through the nanopore, you can see if and, if so, how fast it uncoils under the influence of a given enzyme.'



MARIA RUDNEVA
DELFT UNIVERSITY OF TECHNOLOGY

This research, which is carried out in the department of Bionanoscience, does not just provide insight into the fundamental workings of DNA, but also helps to figure out the method of action of anti-tumour drugs. You can see the activity of the uncoiling enzyme being inhibited by the drug. This in turn stops cell division and thereby the growth of tumours.

The passing of a DNA molecule, or another polymer, through the pore can be measured by observing a change in current. The length of the molecule and the shape in which it passes through the pore is reflected in the time and amplitude of the change in resistance. Zandbergen: 'The next step is to not just measure the change in resistance, but to determine which DNA bases pass. This would allow the direct determination of the DNA sequence and be a giant step towards the sequencing of individual genomes.'

Such a characterisation is one of the holy grails of the National Institute of Health of the USA, a large funding organisation for medical research, that is investing large amounts to get the '1000 dollar genome' within reach – having a person's genome sequenced for 1000 dollars.

Electron microscopes are not just useful for the study of biomolecules, they are also still used to study non-living materials. Catalysts, for example, compounds that when added in tiny amounts, can make reactions that normally don't happen, happen quickly; like the conversion of crude oil – and to an increasing extent, green source materials – into useful chemicals. Together with Fredrik Creemer, assistant professor of Micro-Electro-Mechanical Systems, Zandbergen has developed a nanoreactor in which the working of catalysts can be studied with atomic resolution. Zandbergen: 'Using transmission electron microscopy you can, as I said earlier, visualise particles with atomic resolution. The problem is that this form of electron microscopy works best under vacuum, so the electrons you use for looking at things are not disturbed by gas molecules. In the nanoreactor we got around this by creating a small vessel around the sample and maintaining the vacuum in the rest of the microscope. Using extremely thin membranes we confine gases in this vessel and can let gases flow in and out and a reaction can take place between a solid – a catalyst in our case – and the gaseous reactants. We can follow this reaction using the electron microscope.'

One of the reactions one can follow this way is how a metal oxide, like platinum or copper oxide, reacts with hydrogen. Zandbergen: 'One looks through the two membranes and the specimen. This allows you to see the effects of gas molecules adhering to the metal oxide and how the reaction then progresses. This is very interesting for the chemical industry because this knowledge allows for a design of better catalysts. It is also interesting for developing materials for hydrogen storage, for example instead of a gas tank in cars.'

Currently, the nanoreactor can be used to monitor reactions at the molecular level under pressures of up to 1 bar and temperatures as high as 500 degrees. It has been used to, for example, study the way copper/zinc catalysts work. These are used in industry to convert methane into methanol. Researchers from the University of Utrecht have used the reactor to work out the reaction mechanism of the Fisher-Tropsch reaction – the conversion of carbon monoxide and hydrogen into liquid fuels.

Zandbergen: 'The nice thing of our research is that we collaborate with researchers from many different disciplines; not only within Delft and the 3TU.Federation, but also with medical faculties in Rotterdam and Leiden and the Dutch Cancer Institute. Internationally, we collaborate with other centres for high resolution electron microscopy, both in Europe and the rest of the world. Eventually, we all want to see what is happening at the atomic level, whether we are chemists, biologists or material scientists.'

MARIA RUDNEVA
DELFT UNIVERSITY OF TECHNOLOGY

Maria Rudneva (24) studied physics at the Moscow Engineering Physics Institute, one of the most prestigious universities in Russia.

She specialised in the physics of nanostructures and for her PhD-subject she was looking for a project in which she could use electron microscopy to investigate natural phenomena. She is now studying electromigration: the transport of material caused by the gradual movement of the ions in a conductor due to the transfer of momentum between conducting electrons and the material.

Rudneva: 'As electronic devices get smaller and smaller, electro-migration becomes increasingly important. If a connection on a microchip is 50 nanometres wide (one nanometre being a millionth of a millimetre), the current density in the wire is much higher than if the wire was 10 micrometres thick. The higher the current density, the higher the momentum; this means the ions migrate faster. This results in a shortening of the usable life of the connection, thereby limiting the lifetime of the device itself. If you can find out what exactly goes on, you can start looking for ways to avoid these problems.'

The proces of electromigration can also be used to our advantage. Rudneva: 'It is possible to intentionally destroy a wire with a high current density. This can result in the formation of a nanogap with a width of 1 to 5 nanometres.

A molecule can be trapped inside such a nanogap, allowing the study of the electrical properties of this molecule. By doing all this in an electron microscope the position and orientation of this molecule can be determined. We are performing such experiments together with the Molecular Electronic Device Group. It is still rather fundamental physics, but does offer scope of a whole new generation of electronic devices.'

Rudneva's plan was always to join a prominent research group. During her first visit she became enamoured with the city of Delft. 'What got me the most was that nearly everybody in the Netherlands speaks English. It is a given that English is spoken within the university, but even on the street market or at the bakery you can converse in English.'

PROF.DR. MENNO PRINS - MOLECULAR BIOSENSORS FOR MEDICAL DIAGNOSTICS
EINDHOVEN UNIVERSITY OF TECHNOLOGY

FISHING FOR MOLECULES

The whole world is hunting for biomarkers; molecules in bodily fluids such as blood, urine and saliva that give an indication of a person's state of disease. Finding a biomarker, though, is only half the story. The other half is finding a way to measure it, that is quick, accurate, reliable and practical. Menno Prins and his collaborators are looking for smart techniques to map the molecular state of our body.

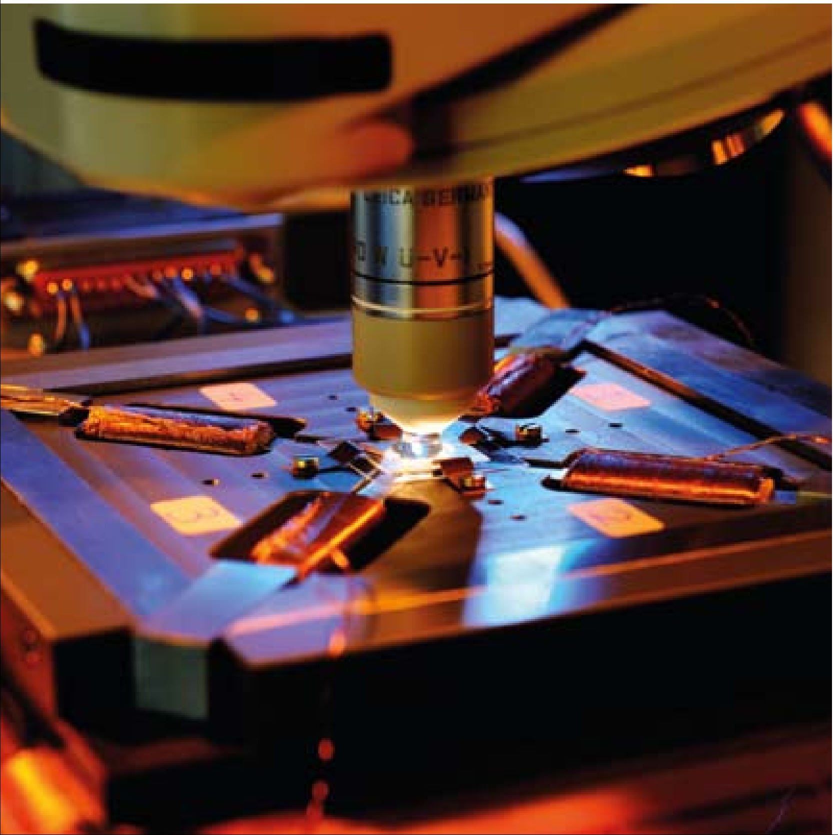
On the table in front lies a heart-shaped object about the size of a keychain, with a display and two buttons: the reader. A small strip with a coloured tip has been inserted into the reader: the cartridge. 'This here is the most used biosensor in the world', says Menno Prins. 'The glucose sensor. If you want to know your glucose level, you drop a minute amount of blood on the cartridge. A series of biochemical reactions take place and within five seconds one gets a read-out of the blood glucose level. This allows diabetes patients to determine the exact amount of insulin they need to take.'

The focus of Menno Prins' research group is on leaps forward in biosensing. 'The concentrations of biomarkers that we want to measure are very low. If you want to compare it to glucose, it is like measuring glucose levels in an Olympic-sized pool after throwing in a few grains of sugar. The big challenge for us is to develop biosensors that are many orders of magnitude more sensitive, but as quick, reliable, small and economical as the glucose sensor.'

One of the important applications is to test drivers for the use of illegal drugs. Another application is to measure protein levels in the blood to determine the condition of the heart. Biosensors will also play a key role in the development of personalised medicine. Prins: 'Patients can react very differently to drugs. One person can suffer from side effects much more than the next. For some people the medicine will not even work. Using biosensors you could biochemically determine how a patient is reacting to a drug and adjust the dose of the medication accordingly.'

As is typical for universities of technology, Prins does not just give lip service to finding potential applications. He is actually working on them because he is, in parallel to his professorship,

employed by Philips Research. This gives him a commercial as well as a scientific radar. ‘To be commercially viable, one needs to develop a technological platform that can serve many applications, starting with a few large opportunities and later opening many smaller applications.’
The biochemical heart of the biosensors are antibodies, molecules that capture biomarkers in a very specific manner in so-called immuno-assays. ‘In traditional immuno-assays the read-out of binding events is often done using a biochemical reaction that generates light, but for the type of sensor we are envisaging that is too laborious.’ An alternative that is being investigated by Prins is the use of magnetic particles. The particles are superparamagnetic, which means that they become magnetic only when exposed to an external magnetic field. This makes it possible to turn the magnetic moment of the particles on and off. Prins: ‘The magnetic particle is decorated with antibodies specific to the biomarker. The particle binds the biomarker through these antibodies. Next, the whole complex is bound to a second antibody attached to a chip. This gives a kind of sandwich wherein the antibodies are the slices of bread and the biomarker the jam sitting in the middle.’
Next to sandwiches with a biomarker topping, empty sandwiches are also formed where the antibody on the magnetic particle is bound to the antibody on the chip, instead of both being bound to the biomarker. By applying a magnetic force to the magnetic particles, the particles bound (loosely) to the antibody on the surface without the biomarker will float off. The particles in a sandwich with a biomarker molecule still stick. Then the number of particles left behind is a measure for the biomarker concentration in the original sample.



‘Working with magnetic particles offers further opportunities’, says Prins. ‘For example, we are looking how the molecular structure of the magnet-antibody-biomarker-second antibody reacts when you use the magnetic field to apply a force and a torque on the complex. At the moment we are studying what the physical effects are and the next stage is to extract the biochemical information. The response to the force reveals important details of the captured biomarker molecules.’
‘The study of molecular interactions using physical techniques is the theme for the collaborative effort within the 3TU.Federation’, says Prins. ‘The focus differs – Delft emphasises interactions between nucleic acids and proteins, whilst Twente has a strong interest in the formation of protein aggregates – but the methods and tools are comparable. We are all trying to gain biological knowledge using physics techniques.’

XANDER JANSSEN

EINDHOVEN UNIVERSITY OF TECHNOLOGY

Combining hardcore physics with medical applications is what Xander Janssen (28), who finished his PhD in Menno Prins’ group in November 2009, finds exciting about his research into next generation biosensors. ‘If I had only been researching magnetic phenomena, I probably would not have been half as interested’, says Janssen. ‘One of my earlier internships was at the Academic Hospital of Maastricht. This strongly motivated me as it really showed me the potential applications of my work.’
After school he chose to study Applied Physics at the Eindhoven University of Technology. ‘Slowly but surely the interest in biomedical aspects crept in and I was lucky enough to eventually work on this topic during my PhD.’ That research – broadly speaking – involves the development of second generation biosensors. The aim of this new generation of biosensors is to not only detect biological molecules (so-called biomarkers) at picomolar concentrations and lower but to also unveil functional properties of the biomarkers. Biological tests generally use antibodies that bind to biomarkers with very high specificity.
The antibodies that Janssen uses have been attached to micrometre sized superparamagnetic particles, which allows for the direct physical measurement of the presence of the biomarker.
‘Many more things are possible’, says Janssen. ‘Since the particles are magnetic, one can use a rotating magnetic field to turn and twist the whole construct of biomarker, antibody and particle. That way one can deduce how the biomarker binds to the antibody, which in turn can provide information on the biological functionality of the biomarker, hence the name functional biosensor.’
Xander Janssen has been given a postdoctoral position to do related biophysical research for an additional three years after finishing his PhD. Not in Eindhoven, but at the Delft University of Technology, in the department of Bionanoscience to be precise. The transition will be quite smooth, he thinks. ‘The advantage of the collaboration between the three universities of technology is that I already know the people and what they are working on. This means I can hit the ground running.’

PROF.DR. VINOD SUBRAMANIAM – BIOPHYSICAL ENGINEERING
UNIVERSITY OF TWENTE

ORIGAMI AND ALZHEIMER

Intrinsically disordered proteins are believed to play an important role in the emergence of neuro-degenerative disorders such as Alzheimer's and Parkinson's disease. Using various visualisation and quantification methods, Vinod Subramaniam and his colleagues are trying to work out how the aggregation of these proteins takes place. This research could lead to understanding the fundamental biophysical principles underlying these protein misfolding and aggregation processes, and potentially to the identification of biomarkers for the early detection of these disorders.

For most of his academic career, Subramaniam has been intrigued by the phenomenon of protein folding. 'Strictly speaking, proteins are no more than a linear chain of amino acids', he says. 'The properties of each of the individual links and the order in which they sit in the chain, however, cause it to fold into a three-dimensional structure. This structure often serves as a lock in which a very specific molecular key fits. When the key is put in the lock, this may, for example, cause a particular biochemical reaction to take place.'

The importance of this folding becomes apparent in cases where it goes wrong. One example is cystic fibrosis, a hereditary disease in which just one amino acid is mutated causing the whole protein to misfold and not carry out its function any more. Also the prion diseases, such as the infamous BSE in cattle, are caused by misfolding of proteins.

Most of the proteins in the human body require a three-dimensional fold to perform their function. 'There is, however, a class of proteins that is intrinsically disordered', says Subramaniam. 'They have no well-defined three-dimensional structure. It is believed that these proteins can fold in different manners, based on requirement. This allows them to have multiple functions in the cell. Like a jack of all trades that can be deployed according to need.

We do encounter some of these intrinsically disordered proteins in Alzheimer's and Parkinson's disease where they form an important part of the amyloid plaques; protein aggregates in the brains that are characteristic for neuro-degenerative disorders. If you study the brain of

deceased Parkinson's patients, you will see so-called Lewy-bodies, which are clumps of aggregated protein. If you analyse those further you will see that for a large part they consist of fibrillar aggregates, which in turn are made up of a specific intrinsically disordered protein.'
The most important protein in Parkinson's disease is α-synuclein, which forms wiry structures tens of nanometres in length. Subramaniam is trying to mimic the formation of these aggregates in the laboratory. Using genetically modified bacteria, relatively large amounts (a few milligrams) of this protein can be made. The formation of these wire-like aggregates, how fast or even if they form, is then studied under a range of conditions.
'We use a whole host of different techniques to visualise and quantify the process; from electron microscopy to a range of spectroscopic techniques. In that regard we can't be narrow-minded. One of the big advantages of the 3TU.Federation is that you do not just have the different equipment available, but also the expertise to help you push the limits of detection. You could call it a joint voyage of discovery, which by now has mapped large parts of this unknown area of research.'
One of the discoveries made is a 'description' of the early events of aggregate formation. 'It is this first phase which is incredibly important', says Subramaniam. 'Until a few years ago research into Alzheimer's and Parkinson's diseases was focused on the study of large aggregates as a probable cause of symptoms. Recently, however, it has become more apparent that the smaller aggregates, so-called early aggregates or oligomers, which may consist of around 50-70 proteins,

BART VAN ROOIJEN
UNIVERSITY OF TWENTE

The combination of technology and biology is what makes research into fibrillar aggregates and their role in the development of diseases like Alzheimer's and Parkinson's so interesting for Bart van Rooijen. He hopes to gain his doctorate in this subject by the end of 2009. 'Initially the focus of my project was on developing techniques, most notably the use of Atomic Force Microscopy', he says. 'That is kind of obvious because my background is in Applied Physics. My research quickly took a more biological turn and now I am studying the way in which the fibrillar aggregates affect the membrane. The techniques I use are now much more tools to visualise these biological processes. I have now broadened my technological scope beyond using just Atomic Force Microscopy and use all kinds of visualisation methods. The biological question has become the focal point of the research, instead of the technique as such.
Van Rooijen also enjoys the fact that neuro-degenerative disorders and the role of certain proteins herein attracts a lot of other research interest. 'This has made it a highly competitive area in which you are continually challenged to find and push the boundaries of what is technically possible. At the same time the research is highly relevant. 1% of people will develop Parkinson's disease in their life and 2-3% will get Alzheimer's disease, which means that in these times of an ageing population, the incidence will increase dramatically. No drugs are available for Alzheimer's disease and the only thing we can do for Parkinson's patients is to ease their symptoms. My research is very fundamental, but I do keep in mind that I am contributing to the solution of a large burden, both on society and on the individual patient.'

BART VAN ROOIJEN
UNIVERSITY OF TWENTE

are likely to be involved in cell death. The large aggregates may be a defence mechanism of the cell to neutralise these smaller oligomers by turning them into larger clumps.'
An interesting question is what damage these small oligomers do to the brain. Subramaniam: 'There is an indication that they puncture holes in the cell membranes – the so-called amyloid pore hypothesis. Our results suggest that oligomeric α-synuclein interacts with lipid membranes. We don't think that α-synuclein interacts with the cell membrane itself but rather with organelle membranes, like those of mitochondria, for example, the cell's power plants. If these become leaky, the cell no longer gets energy and dies.'
To study what these oligomers do to membranes exactly, artificial vesicles are used. These are small fluid-filled sacks surrounded by a lipid membrane, which behave in an organelle-like manner. By filling such a vesicle with a fluorescent dye, it becomes possible to visualise what happens on the nanoscale. Subramaniam: 'We hope to figure out what kind of lipids these small protein aggregates bind to, how the lipids reorganise and how holes are then formed. One remarkable observation is that the leakage of the content out of the vesicle can be observed with the membrane itself appearing intact. This could indicate a specific transport mechanism, but we do not understand yet how it works.'
Research into visualising and quantifying biological processes at the nanolevel is of a very fundamental nature. Applications are not within easy reach. They do, however, exist and form an important motivator for this research into intrinsically disordered proteins. Subramaniam: 'In neuro-degenerative disorders, like Alzheimer's and Parkinson's disease, a lot of damage is done at the cellular level before any symptoms become apparent in a patient. If we can map how fibrils form and how they react with membranes, we could start looking for new biomarkers. A small change in the blood, saliva or other bodily fluid which could indicate the process has started. That type of research is also being performed within the 3TU.Federation. A better insight into the mechanism of the disease will also provide new targets for the development of drugs that could nip the disease development in the bud. We are not close to these prizes, but they are important motivators for this research.'

CENTRE OF EXCELLENCE

DEPENDABLE ICT SYSTEMS

PROF.DR. PETER APERS
SCIENTIFIC DIRECTOR
3TU.CENTRE FOR DEPENDABLE ICT SYSTEMS

Information and communication technology can often be unreliable, as we experience almost every day. For example, when we have to reset the computer or close a programme. That's usually not such a problem. But it can be more serious if it happens in a traffic control system. Let alone the dangers that ICT problems in an aircraft or a nuclear power plant could cause. ICT systems are so complex that, in many cases, their operation is no longer transparent. These almost organic systems are controlled from different locations, and operate as parts of extended networks. Our society has an extremely high level of dependency on them. If the internet is not accessible for a few hours, the resulting problems are almost impossible to contemplate – almost every conceivable system will be out of operation.

Scientists at universities can carry out research into the causes of the problems we experience today. But this is not sufficient for the 3TU.Centre for Dependable ICT Systems: it aims to raise the bar even higher. The challenge is to really solve this ICT problem.

By itself, a single university has insufficient critical mass and expertise to take an influential position in this research field. But together, it is possible to find good partners with which we can jointly develop fundamental solutions. The professors have been recruited, there are intensive collaborations between the chairs and industry is keen to participate in our research.Together with a large number of European partners, we have recently submitted a proposal to the European Institute of Innovation and Technology (EIT) for a Knowledge and Innovation Community (KIC) in the field of ICT. It is the first time that top European universities, excellent research partners and leading companies have joined forces on such a large scale in the field of ICT.

PROF.DR. ARIE VAN DEURSEN - SOFTWARE ENGINEERING RESEARCH
DELFT UNIVERSITY OF TECHNOLOGY

THE PARADOX OF SOFTWARE EVOLUTION

'Software is continually evolving in an attempt to adapt to social changes. These changes, however, lead to an erosion of the fundamental structure of the software, eventually resulting in further evolution becoming impossible. Evolution inhibiting future evolution; that is what we call the software evolution paradox', says Arie van Deursen, professor in the Software Engineering Research Group in Delft. 'Breaking this paradox is the main driving force behind our research.'

Thousands of software engineers write programs every day to keep a multitude of systems operational: from mega-computers that keep track of bank accounts to the computers in a washing machine that ensure the delivery of soap to the laundry at the right point in the washing cycle. Furthermore, software engineers are working on adjusting existing programs to, for example, fix bugs in older versions. However, more often than not alterations are needed as a result of changes in the environment in which the program has to function.

'Software is continually being adjusted', says Van Deursen. 'A company like ASML, a manufacturer of machinery to make microchips, is the owner of around 10 million lines of code. It is locked in a continuous battle with its competitors to make their product just that little bit better so that the microstructures on a chip can be miniaturised by a few more nanometers.

Or take the Inland Revenue as another example. They too own many millions of lines of software code. If a new law is passed in the House of Commons at least some part of this code has to be altered in order to implement this law.'

The changes, which are often introduced under severe time pressure, can lead to the erosion of the original structure of the program. Van Deursen: 'You could compare programming to laying a mosaic floor. A programmer writes code like the maker of the mosaic puts small stones in rows. Just like the mosaic, the program has a structure. Adjusting the code in a program can be compared to the re-laying of certain stones in the mosaic. If you do this, there is a chance you disrupt the original picture of the mosaic. The same happens in software; if you start playing

with individual lines, you can disrupt the overall structure of the program.'
ASML employs 300-400 programmers to move the small stones in its 10 million lines of code.
Van Deursen: 'It is like having 400 people move stones simultaneously in a mosaic the size of ten football pitches. The problem is exacerbated by the fact that companies often used temporary labour. Not because they are less able, more because they tend to be very transient as a workforce. This results in a significant drain of knowledge of the system. The core question is how one can prevent the structure, the original mosaic picture, from disappearing completely. Finding an answer to that is a not just a question of correctness and performance, but also of dependability of ICT systems. This is something we are researching as part of the 3TU.Federation.'
The collaboration dates back to 2001 when research groups in Eindhoven, Twente and Delft decided to set up the Embedded Systems Institute, together with TNO, the Netherlnda Organisation for Applied Research and several companies, in order to address the large-scale, high-complexity software problems that are encountered in industry. This meant industry itself acted as the test tube to solve its real-life problems.
One of these problems is the maintainability of the programs, a key property of dependability. Research is being done into aspect-oriented software development to improve upon this.
Van Deursen explains: 'A good way to improve maintainability of software is by modular programming. This means that you build a program consisting of various modules, rather than one big unit. If something needs to be altered, only one or a few modules have to be adjusted.

ALI MESBAH
DELFT UNIVERSITY OF TECHNOLOGY

Or, so goes the theory. In practice, it is impossible to harness certain cross-cutting functions in a single module. Logging, registering the status of a program at a given point in time, is an example of a cross-cutting function. Security and dealing with errors, the infamous error messages, are also examples of such tangled functions.'
'Together with the other technical universities and ASML, we have developed a method to modularise even these general functions by making them like a cassette, which can be slotted into specific modules. If you want to change the program code for such a function, you modify the specific cassette once and it will weave itself into all the modules that require its specific function.'
One of the functions the research group in Delft look at is error handling. Van Deursen: 'For the complex machines that ASML makes, it is essential that error codes are correct. A reported Error 103 has to be a real Error 103, otherwise the system manager gets the wrong advice, or an ASML technician flies out to a chip-manufacturing plant in Korea with the wrong part.'
Despite this need for a correct error handling, mistakes are still being made. This is partly due to the sheer amount of code dedicated to this task – between 10 and 15% of the total code – and partly due to the fact that programmers find the programming of error handling a tedious task. It needs to be done to strict guidelines, but is executed without much fervour. This results in one or two mistakes creeping into every thousand lines of code or so. Van Deursen: 'We have developed technology to look through all modules of a program for errors in the error handling.'
Another theme in Van Deursen's research group is the testing of new versions of existing programs. Among them the Ajax technology, a new way of programming in which a range of functions are bolted onto the Internet browser. Like the e-mail and office functions Google offers that simply run in the browser. 'Very handy', is Van Deursen's opinion, 'as it makes it fairly easy to work on the same document in different locations.'
A drawback is that the Ajax technology is very error prone. Traditionally – as far as that term is applicable in this field – errors were traced by 'crawling' through a host of different states of the browsers with its various add-ons. Unfortunately, the traditional way of crawling cannot be applied to modern Ajax applications. Not without a measure of pride, Van Deursen mentions that his group has developed a new type of crawler, which can tackle Ajax and conduct sanity checks to spot errors in Ajax applications. Google has since shown interest. 'That just goes to show that by cooperating smartly, you can achieve big things in a small country.'

ALI MESBAH

DELFT UNIVERSTITY OF TECHNOLOGY

Compared to ten years ago, web applications have become much more interactive. 'Very pleasant for the user, but a disaster for the programmer to manage the complexity', says Ali Mesbah (30). In 2009, he earned his PhD with honours on analysis and testing of web applications.
He developed a software tool that automatically tests interactive websites as if it were an erratic user. 'If you were to do this by hand, it would take a few million clicks for large applications such as Gmail. This is too much for a programmer to do. Our software tool does it automatically. This means you can also test at the night or in the background.
Aside from saving time, automatic testing of websites makes them safer and more reliable, as they can be tested exhaustively.'
Ali Mesbah came to the Netherlands from Iran aged 15, because his father was doing a PhD at the University of Wageningen. When his family returned after four years, he decided to stay here and study Computer Science in Delft. 'After my MSc in 2003 I started working for a software engineering consultancy firm. Initially, this was very challenging, but after a while it became routine. That is why I contacted Arie van Deursen in 2005 to see if he had any PhD positions available.
Luckily he did and it was in the area of my favourite topic, web applications. After gaining my doctorate in 2009 I was able to stay on as a postdoc, which I like a lot.'
The tool developed by Mesbah works a bit like a robot, but neither the application, nor the browser in which the application is running recognises it as such. To them it appears as a normal user. 'Crawljax', which is the name of this tool, compares each renewed page after a click to the page it should have been according to the requirements. In 2009, the paper that Ali Mesbah wrote with his professor Arie Van Deursen on Crawljax won the prestigious Distinguished Paper Award at the International Conference on Software Engineering. 'A once in a lifetime experience, comparable to winning an Oscar or an Emmy Award in film or television.'

PROF.DR.IR. WIL VAN DER AALST - ARCHITECTURE OF INFORMATION SYSTEMS
EINDHOVEN UNIVERSITY OF TECHNOLOGY

REALITY AS A MODEL SYSTEM

Data logging has undergone explosive growth over the last ten years. Not just data about operating procedures in industry and public services, but also data about machines themselves. Wil van der Aalst reckons these event logs, which are mainly generated automatically, are a reflection of operating reality. 'Those data can be used to check existing models or to automatically generate new models as well as to improve the working of machines and operating procedures. Since the information is about processes, the gathering and analysis of these data are not called data mining, but process mining. Together with other groups, both within and out with the Centre of Excellence, we are developing these tools for this growing industry.'

Van der Aalst uses medical devices of Philips Health Care, which are used in hospitals all over the world, as a prime example of the use of event logging. 'In principle, they are all connected to the internet and are sending a constant stream of detailed information on what is happening with the machine to the home front. Those data can be used to develop a model for the working of the machine. If you then take this model and compare it to the original model, which served as the basis for designing the machine, you can figure out whether the initial assumptions were correct and what changes could be made for the device to work even better.'

Operating procedures of businesses can be analysed in a similar manner. Van Der Aalst: 'Booking a trip on the internet takes about five to ten minutes at most. During that time at least four or five companies are involved in the transaction: the airline, the travel agent, the web host, the hotel, the payment service and a few banks. The whole process is logged in great detail and provides an avalanche of events that in turn can be analysed using tools such as ProM. In the ProM group developers and users work closely together, free of vested interest. It is an open source alliance. On the one hand, process mining can be used to figure out what events exactly took place, and on the other hand the data can be used to deduce a model of the operating procedure, which again can be tested against the existing model – a conformance test – or it

ANNE ROZINAT

EINDHOVEN UNIVERSITY OF TECHNOLOGY

Anne Rozinat (30) loves solving problems together with industrial partners. This is a very good thing considering that she started the company Fluxicon together with her former colleague Christian W. Günther in September 2009. They help companies and institutions with innovative tools and services for analysing and improving their processes. With support and guidance from the Innovation Lab of the Eindhoven University of Technology, Fluxicon is now making its way into the marketplace. During her PhD, Rozinat experienced how motivating it can be for people when they realise how the processes in their business actually work: 'Information about business processes is in the heads of many employees. Using process mining we get an overview of the whole process. In addition, processes often do not take place the way they are described in the books – and people know that. But once they see how the process looks – in reality, this is a real eye-opener and a lot of creativity ensues.'
Rozinat did her studies at the prestigious Hasso Plattner Institute for Information Technology at the University of Potsdam (Germany), a close collaborator of the University of Technology Eindhoven.

During her doctorate (together with people of the electrical engineering and industrial design department) she also researched soft reliability. Rozinat: 'Products are increasingly taken back to the shop without actually being broken. One of the reasons is that people use their products in a different way than the designers had intended. This is a problem, because it does not just cost money when a product does not meet expectations, but it is also bad for the image of the producer. Using a multi-disciplinary approach we developed a series of techniques to bridge the gap between designer and end user and to increase the soft reliability of products. For example, we developed a technique to gather and analyse data on the actual use of products by consumers. I learned a lot from the collaborations with fellow researchers and with people from industry. At Fluxicon, I now want to use this experience to help companies solve their problems.'

can be used to design a new model more closely matching reality.' Process mining tools such as ProM have, amongst other things, been applied to the exam results of the Eindhoven University of Technology. The event logs record which student is taking which module exam and what the results are. Van Der Aalst: 'Based on those data, we have automatically generated a model of the curriculum, as organised by the students themselves. This shows, for example,
that students tend to postpone the exams they consider difficult, sometimes by more than a year. This reality-checked curriculum can be compared to the curriculum the course organisers had in mind initially. It also allows you to determine the bottlenecks and the points where students run into delays. You can even predict how long a student will take to finish his degree or what the probability is that someone does not finish at all.'
The concepts applied to the school curriculum can also be applied to devices. The event logs of, say, an X-ray machine can be used to generate profiles – fully automatically – for testing existing and new machines under more realistic working conditions. Van der Aalst: 'We can also use process mining to find out the conditions under which the X-ray machine can malfunction. What makes one machine work fifteen years without any hiccups in one hospital, but needing regular maintenance in another? We can discover the behavioural patterns leading up to the malfunction and use that data to adjust the use of the machine so it can be prevented.
It is even possible to predict upcoming problems. For example, it is possible to avoid a problem, by telling a system manager to replace a certain part, as otherwise there is going to be – with

a certainty of 95% - a malfunction within two weeks.' Process mining tools have been used by many companies to improve the working of both devices and procedures. One city council used them to improve the procedure for handling complaints about council tax based on the analysis of event logs. Also the procedures required for paying speeding tickets have been analysed by process mining, as well as the procedures for paying out unemployment benefits. Van der Aalst: 'Event logs showed that the employees of a given organisation had a tendency to cut the work close to the legally required deadlines. Even minor events could therefore cause them to miss these deadlines, which caused a whole host of other procedures to have to come into effect.'
Automatic analysis of process data sounds easier than it is. Not for the lack of data, but quite the opposite: there is too much data. Systems used by companies for enterprise resource planning (ERP) can easily yield over 10,000 events. This is similar to the activities required to diagnose disease in a patient, when multiple tests are required. To complicate matters further, the data are often defined in their own specific manner, depending on the ICT system used. Therefore, the cooperation with the group of Henk Corporaal, one of the other groups in the 3TU.Centre for Dependable ICT Systems, is valuable. Together, they look at better ways of logging events. A lot is therefore demanded of the process mining tools. ProMimport, a tool developed by Van der Aalst's group, has the capability to extract relevant data from this sea of information. The tool forms part of the Process Mining
software that is being developed with the partners of the ProM group, where developers and users work closely together without claiming intellectual property rights. ProM also includes software for data analysis and – not unimportantly either – software for presenting the data. Moreover, the ideas realised in ProM are being adopted by several tool vendors. In fact, recently several dedicated process mining start-ups were initiated (e.g., Futura Process Intelligence, Fluxicon and ProcessGold) illustrating the relevance of the topic.
According to Van der Aalst, process mining is an important method for improving the quality of devices, operating procedures and the corresponding ICT systems – whether these are embedded or non-embedded. 'The wealth of data allows for a whole range of process mining techniques; from process discovery to conformance checking. Application of these techniques usually results in immediate improvements of the processes. It also provides a reality check for those involved in process modelling.'

ANNE ROZINAT
EINDHOVEN UNIVERSITY OF TECHNOLOGY

PROF.DR. JACO VAN DE POL – FORMAL METHODS AND TOOLS
UNIVERSITY OF TWENTE

PROVEN RELIABILITY

Society is becoming increasingly reliant on ICT systems, which therefore have to remain functional. At the same time the chance of errors in software, hardware and the combination of the two is rising. 'Such mistakes could cause rockets to explode, airplanes to crash or the complete disruption of train traffic in the rush. 'The question we work on is how to keep these systems functioning correctly. And, more importantly, how you can prove this to be the case', says Jaco van de Pol, professor in Formal Methods and Tools.

It is not something we pay too much attention to, but over the last few decennia we have become increasingly dependent on properly functioning computer systems. Take the Maeslandtkering, the intelligent dam in the Nieuwe Waterweg near Rotterdam, for example. If a storm is blowing in South-Westerly direction, there will be a risk of flooding in this area. The system controlling the dam will decide itself whether to close or not, based on the calculated risk of flooding. A wrong decision could have massive consequences. Not closing the dam, when it should be closed, increases the risk of flooding in the polders that lie behind it. Closing it without significant enough risk results in an enormous unnecessary loss of income because ships cannot leave or enter the harbour.

'The correct functioning of ICT systems has become a matter of life and death increasingly often', states Van de Pol. His own research focuses on train protection systems, which control the track switches and signals, resulting in orderly and safe railway traffic. 'A system like that has to function 100% correctly on two fronts. For a start, it must not make errors, as that could lead to fatal accidents. And it has to always work because if it fails, trains can no longer run. For a railway as busy as that of the Netherlands, that would mean tens of thousands of people arriving late at school or work.'

As ICT systems get more complex, the chance of errors increases; not just software errors – error-free software is an illusion according to Van De Pol – but also hardware induced errors. As systems get smaller, for instance, the chance of cross-over and bit flips increases.

The use of wireless communication between systems increases the chance of errors too as data can be lost in transit.
Another important source of errors stems from the fact ICT systems are not solely used by experts and human operators can sometimes accidentally introduce errors that make the system unreliable.
In the aim to develop dependable ICT systems, the Fab Four form the important guideline. Not the Beatles, but the fabulous four 'F's of dealing with errors. The first one is fault avoidance: prevent the introduction of faults by improving the design process. The second is fault tolerance: add redundancy to avoid service failure, for example, by using multiple systems. The third is fault removal, both during the design and implementation as well as during operation of a system.
The fourth and final 'F' is fault forecasting: predict faults and future occurrences. That completes the circle as that leads back to fault avoidance.
The research of Van de Pol and his colleagues is aimed at developing techniques for improving the design process, thereby preventing errors and increasing the error tolerance.

MARK TIMMER
UNIVERSITY OF TWENTE

The first step is to make a model of the system that is to be designed. Van De Pol: 'It is the same as what an architect or civil engineer does when designing a house or a bridge. Based on the requirements of the customer we make a model of the system and then calculate how it will behave in a range of different situations.'
Making a model isn't trivial, as it basically represents the translation of everyday requirements onto the computer system. Van de Pol: 'Take, for example, the communication system of the emergency services during a disaster in which normal telephone communication has been lost. To work out the parameters of the model you need to very precisely know what the protocol is of the emergency services under such conditions; how many people need to be able to communicate at the same time, which communications are to be prioritised if the bandwidth is too small. All those requirements – and many more – need to be recorded unambiguously and preferably in a way that they can be used to probe the system.'
Based on the list of demands of the system, a model is developed. This model is subsequently challenged by a model checker; a piece of software to test the system requirements. For instance, a railway route may only be reserved if all points on it are in a safe position and all conflicting signals are red. The model checker must verify that this holds good under all circumstances – such as defect hardware – and in all possible scenarios, such as the order in which trains arrive or the order in which operators reserve and free parts of this and conflicting routes.
Van de Pol: 'One can imagine that an ICT system controlling signals and switches will run into many different situations in which it has to keep functioning correctly. There is a large number

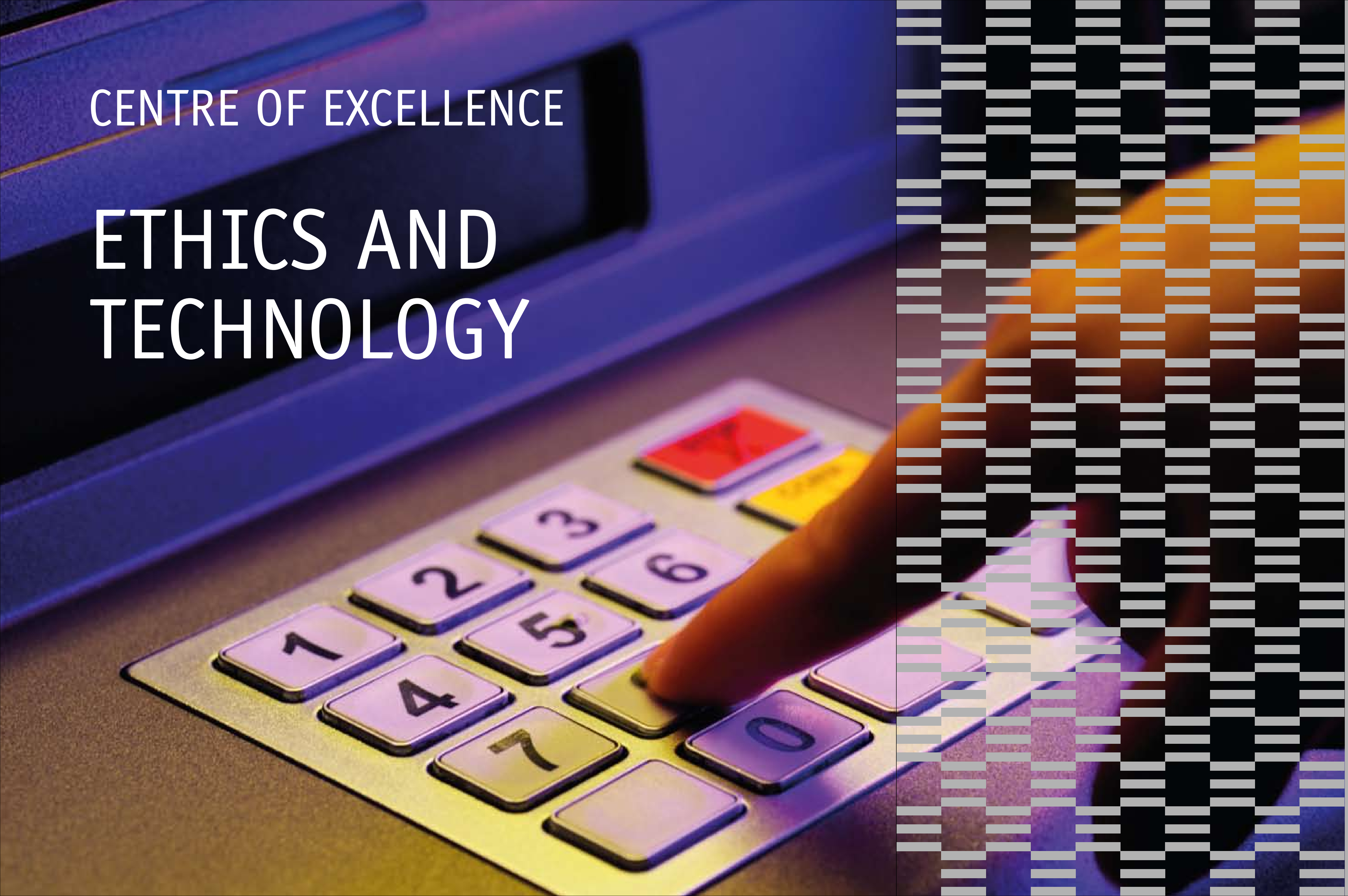
of variables, especially if the network is large. To check this, one would have to calculate through an astronomic number of scenarios. At the moment the number of scenarios is usually ring-fenced by experienced people estimating which conditions are relevant for a particular system. In the long run, however, this process will have to be automated as train traffic is getting more and more complicated and this specific expertise is vanishing.'
Since calculating an astronomic number of scenarios would take a considerable amount of time, the model checker limits itself to checking transitions from one state of the system to another. As this links specific phenomena together, the number of situations becomes a tractable number and therefore more manageable for the computer to calculate. Moreover, many situations may be provably equivalent. If the computer can deduce that equivalency, it can decide to skip these situations. Van de Pol: 'Brute force calculations are still required to work out all the transitions, but at least it is deployed in an intelligent manner.'
As mentioned before, Van de Pol focuses mainly on the correctness of the systems and the verification thereof. He does this work in close collaboration with other research groups within the 3TU.Federation, studying safety, security and maintainability. Van De Pol: 'The smooth operation of all ICT-controlled processes is essential for the economy and for safety. In other words: 'the non-operation of these processes has a direct economical impact and in some cases can be life threatening.'

MARK TIMMER
UNIVERSITY OF TWENTE

Mark Timmer (25) has a very infectious kind of enthusiasm. The subject of his PhD, developing methods to prove that ICT systems are working right, is not the most accessible. Luckily, he has no issue with trying to explain it again. And again. Some gentle probing discovers that even during his degree in Computer Science at the University of Twente, he was already giving tutorials to other students and still he enjoys the teaching. This combined with the full marks for his final year research project made a PhD the obvious choice.
During his degree he developed, together with Mariëlle Stoelinga, a framework to evaluate the reliability of system tests. Timmer: 'When you test an ICT system, you have it go through a series of procedures and check whether the outcome of the procedure corresponds to the predicted outcome. When you are finished testing, you are still not 100 per cent sure the system is faultless. This would require an infinite umber of tests. We have developed a method that allows you to say a system is reliable with a certain degree of confidence, say 95%.'
For his PhD he does not want to test existing systems, but models for systems that are yet to be built. Timmer: 'We are developing mathematical tools to see if the system model meets the required standards and how reliable it is. In principle, you would have to test all the states of the system. This involves huge numbers, which is beyond the calculation power of existing computers. Especially, if these states are not determined by the data alone, but probabilities also play a role.
Like 'in this state, the probability that certain behaviour is enabled is 50 per cent.'
During the first year of his doctoral studies, Timmer developed a formal language that allows the reduction of this enormous number of states – the state space – to a size that makes verifying whether a model meets certain requirements feasible, without compromising on the reliability of the result. Timmer: 'This tool, which we are developing further, allows you to efficiently model and verify complex ICT systems in which data and chance both play a part; like a mobile phone network. This is highly useful for improving the reliability of the system.'

CENTRE OF EXCELLENCE

ETHICS AND TECHNOLOGY



PROF.DR. JEROEN VAN DEN HOVEN
SCIENTIFIC DIRECTOR
3TU.CENTRE FOR ETHICS AND TECHNOLOGY

Many technological applications are developed because at first glance they appear to offer benefits. Like the smart electricity meter, which produces energy savings. It's smart, but not quite smart enough to anticipate objections from society. The roll-out of the meter has been deferred by the Dutch parliament because of its potential threat to the privacy of citizens.

The task of the 3TU.Centre for Ethics and Technology is to consider these ethical and societal issues at an early stage, when changes or adjustments can still be made in designs, materials and products. Not only is it possible at this stage to check whether the desired functionality can be offered but it also allows anticipated moral objections to be addressed. Our work focuses primarily, but not exclusively, on the technology domains of the other 3TU.Centres of Competence and Centres of Excellence. A major theme in our research is value-sensitive design – design that takes into account societal, political and moral values. Other topics that we work on are, for example, the ethics of technological risk, responsibility distributions in R&D networks, human enhancement, technology and the good life, the ethics of technology for developing countries and for future generations, neuroethics, nanoethics and ethical aspects of genomics.

The 3TU.Centre for Ethics and Technology is the world's largest institute for the ethics of technology. We are very successful in generating external funding for our research. Several of our members hold prestigious VENI, VIDI and VICI grants from the Netherlands Organisation for Scientific Research (NWO). In the first round of a new NWO funding scheme on socially responsible innovation (the MVI programme), the 3TU.Centre for Ethics and Technology obtained funding for seven new research projects, worth more than three million euros. Recently the 3TU.Centre received a highly competitive grant from the NWO for its graduate programme.

PROF.DR. JEROEN VAN DEN HOVEN – PHILOSOPHY SECTION
DELFT UNIVERSITY OF TECHNOLOGY

VALUE SENSITIVE DESIGN

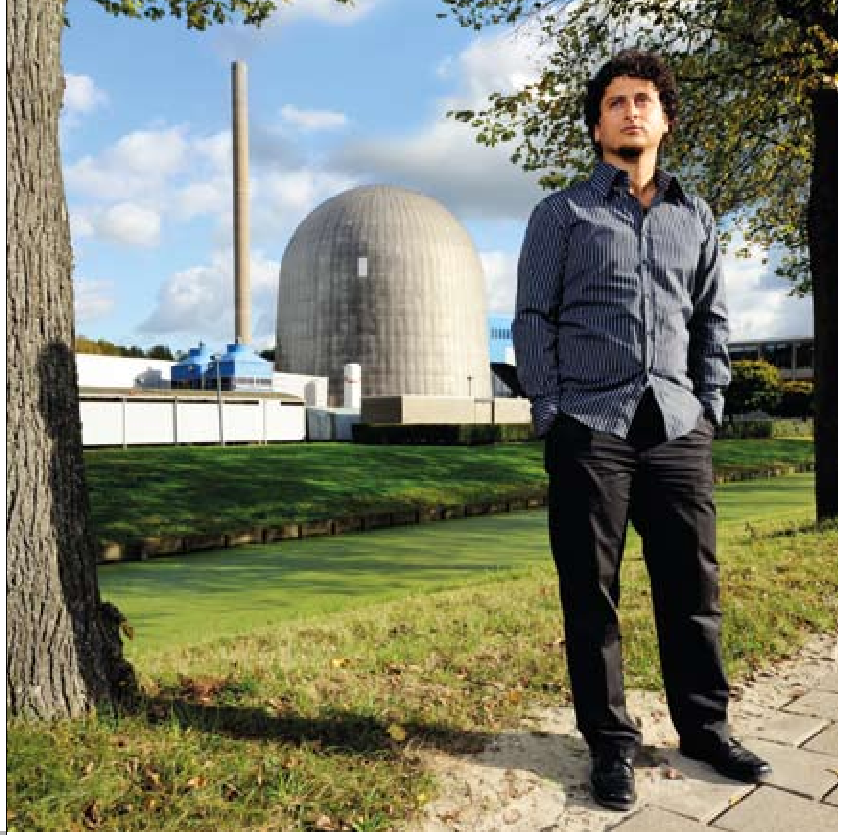
'The question we focus on is how you can design things in such a way that it will allow people to thrive, i.e. to have the capabilities to lead healthy and meaningful lives. This means that very early on in the design process of, say, ICT systems we question the values informing or shaping the design.' This is how Jeroen van den Hoven describes his research into the moral issues of the use and regulation of technology at the Centre of Excellence. 'As a result of the collaboration between Eindhoven, Twente and Delft, we are not only the largest, but also the most prominent centre for ethics and technology research in the world.'
Ethics deals with the Good and the Bad, the right and the wrong. When you translate this to technology, according to Van Den Hoven, this results not just in the study of the values inherent in technical systems, but also in how you can design them so that moral dilemmas are solved or avoided. This approach requires the study of technology and its uses. Van Den Hoven: 'Debates in society are often just an exchange of the pros and cons of a given topic. You are pro-nuclear energy or against it; pro-GM or anti. These discussions can take years and usually end in trench warfare. Studying ethics requires us to analyse a topic in depth and find out which values are more or less inherent in, say, the design of a nuclear power plant or the design of a GM-crop. Instead of looking in black and white, we try to find the subtleties, the shades of grey, with the aim of a more refined debate about the values of everybody involved.'
This method of analysis can be applied very well to the Electronic Patient Files (EPS), according to Van Den Hoven. This is the central storage and exchange of patient data by care providers. The setting up of the EPF database has led to some heated debates in the Netherlands, in which the values of privacy and good medical care seem to collide head on. Van Den Hoven: 'Repeating the pros and cons does not solve this argument, the disagreement over the value of privacy is too deep to overcome in the context of this debate. The approach needs to be more subtle. For example, by addressing who needs which data and what can they use it for. Is the hospital porter, for example, allowed to see laboratory test results and does he have the right to change these?

Of course not, but what about nurses? They can see these results but not alter them. By refining the questions asked, mini-ethical issues are created, wich allows not only for the answers to be specific but usually for solutions to these issues, too.'
This refinement is very educational for the designers of the system. It confronts them with their own, often implicit, values and offers them handles to get a grip on the better design of a system that not only offers enough privacy but also furthers the provision of good medical care. Van Den Hoven: 'This refinement is also very educational for people, often politicians that deal with ethics in Big Words, in this case the ethics of the Electronic Patient Files. These words sound rather hollow if you do not mention the context in which the objections to the EPF are to be placed. 'Transparency', or 'patient centredness' for example is a meaningless term if you do not design your system in such a way that it is clear what everybody's responsibilities and powers are.'
These powers and responsibilities have a tendency to shift under the influence of new technological developments. An example, according to Van Den Hoven, is the shift in the medical profession where for every doctor there is now an engineer working behind the scenes. Van Den Hoven: 'In the old days, the doctor was the hero in the white coat, who could heal patients with his knowledge, experience and insights. This is still his – or her – job, but the modern hospital is much more technology-driven and the role of the doctor has changed whereby he or she is much more of a highly-skilled team player.'

BEHNAM TAEBI
DELFT UNIVERSITY OF TECHNOLOGY

'Asking engineers relevant questions from a philosophical and ethical perspective and helping them think about the technologies they are developing.' Behnam Taebi (32) studied Materials Science and Engineering at the Delft University of Technology, but after finishing he looked for opportunities to look at technology in a wider social and philosophical perspective. A PhD position at the 3TU.Centre for Ethics and Technology provided him with this opportunity. Irritation was the motivator for choosing his specific subject: nuclear energy.
Taebi: 'The ease with which people say they are for or against nuclear energy without indicating the mindset that has led them to their judgement really annoys me. The question whether nuclear energy is a serious option for our future energy supply is much too complex to judge it either black or white. Answering this question starts with understanding the technology and distinguishing between different production methods, as they bring about significantly different considerations for the present and future generations. In my research I look at the effect of a once-through and a closed nuclear fuel cycle within the philosophical framework of justice between generations.'

In a once-through cycle the nuclear fuel is used once and then stored underground. This involves relatively large amounts of waste that remain radiotoxic for 200,000 years. In a closed cycle, the nuclear fuel is reprocessed and re-used. The toxicity is then reduced 20-fold; also the waste volume is reduced considerably. Taebi: 'The once-through cycle is relatively safe for our generation, but we are transferring the risks for a very long period of time. A closed cycle reduces the burden on future generations – it is even scientifically possible to reduce the lifetime to 500 years. The downside is that we as the present generation are more at risk of a radiation accident or – more importantly – of proliferation as the waste can be turned into nuclear weaponry.'
Working on the assumption that nuclear fuel is a serious option for the near future, we need to question, according to Taebi, 'whether, and if so which, obligations we have towards future generations. How do these relate to the interest of the current generation, particularly when it is conflicting with future interest? These are all questions that are best considered now and not after the technological choices have been made and the debate has been reduced to a yes-no argument.'



BEHNAM TAEBI
DELFT UNIVERSITY OF TECHNOLOGY

'This new role cannot remain without consequences for the modus operandi and the culture in a hospital. When a medical mistake has been made, an individual culprit is still often sought. The whole ethical and legal thinking is still based on this approach. But it is no longer possible to ignore the high tech and organisational setting of the hospital; the design of the system preempts certain choices of individuals and this affects their capacity to take responsibility. To prevent future errors, it is a much better idea to analyse how the error came about than it is to look for an individual scapegoat, which will only cause everybody to become defensive and prevent valuable information from being produced.
It usually turns out that a medical blunder is the result of an accumulation of systems errors, and joint or collective decisions as well as human errors.'
Values can change with time, often under the influence of technological developments. Privacy, for example, appears less important to the younger generations, who display their entire personal lives on Facebook. How can values be taken into account when designing systems, when they continually shift? Van Den Hoven: 'We could use a meta-system for this, which means that we do not lumber future generations with airtight systems. Or, that we design systems in such a way that they can be altered with the changes in our value systems.'
'At the moment 'security' appears to be a much more prominent value than 'privacy', as highlighted by the fact that every Dutch citizen applying for a new passport will have their fingerprint data stored. If 'privacy' were to become the dominant value again in a few years, the system needs to have been designed in such a way that, at the push of a button for example, all this fingerprint data can be deleted. The same goes for any website carrying personal data; you should be able to delete the data yourself. This way those embarrassing holiday snaps from your Club 18-30 holiday in Spain won't haunt you for the rest of your life.'
The 3TU.Centre for Ethics and Technology is not just the largest in the world, but with its research reflects the changing role of the ethics researcher; most notably when it comes to technological developments. Van Den Hoven: 'In the past ethics research was first and foremost about the analysis of a theoretical problem. We now also see it as our job to be much more involved in the design process associated with practical problems and analyse the implicit and explicit values that are at work. The closer we are involved, the more we have a feel for what is actually happening during the design process. The role of ethics researchers here is to prevent people from simply follow their gut feeling or the received wisdom of the day. Emotions and traditions are not necessarily bad councillors when it comes to new technologies like nanotechnology or genetic modification, but they should not be the only ones.'

PROF.DR.IR. ANTHONIE MEIJERS - PHILOSOPHY AND ETHICS OF TECHNOLOGY
EINDHOVEN UNIVERSITY OF TECHNOLOGY

ETHICS AND INNOVATION

'Innovation is too important to just leave it to engineers. The aim of our research is to involve ethics researchers, psychologists and sociologists as early as possible in the development of new technologies', says Anthonie Meijers, professor at Eindhoven University of Technology. 'Technical artifacts are not isolated objects; their function is a result of the way the user interacts with them. This gives rise to moral questions. If you take social, psychological and ethical aspects into account early on in the development, you get better products.'

As a philosopher, Meijers exemplifies this 'ethical parallel research' approach with a case study on persuasive technology, technology that is explicitly designed with the intention to persuade people to change their behaviour. His case is the development of an automated braking system for lorries. The project is financed by NWO, The Netherlands Organisation for Scientific Research, and is carried out in collaboration with prof. Maarten Steinbuch of the Department of Mechanical Engineering and prof. Cees Midden of the Department of Industrial Engineering and Innovation Science at Eindhoven University of Technology. DAF Trucks and TNO are external stakeholders of this project.

Meijers, who himself is also trained as a mechanical engineer: 'Car and truck manufacturers are researching systems that can harvest the energy when the car brakes. This recovered energy can be converted to electricity and stored in a battery. The amount of energy that can be recovered is highly dependent on the way the driver brakes. The difference can be as much as ten per cent. This potential energy gain has motivated designers to develop automated braking systems that always brake optimally. This research has been done by the Department of Mechanical Engineering.'

Although technically feasible, an automated braking system carries psychological, legal and ethical implications. To a large extent these result from the so-called 'reallocation of control', that is the extent to which control is transferred from the driver to the automated braking system. This reallocation raises questions about the responsibility for the vehicle when it is

going through an automated braking procedure. Meijers: 'Most kinetic energy can probably be recovered if the automated braking system were to take over completely and automatically stick to the optimised braking curve. If something were to happen though – say the car crashes into the car in front – who then is responsible; morally and legally? The driver? He has transferred his autonomy to the automated system and cannot really be held responsible. But who can? The designer? The manufacturer? The owner of the truck company sending his drivers out with the automated braking system?'
To aid the development of the automated breaking system, a simulator is built shaped like the cabin of a truck. Test subjects will try out the system and their behaviour will be studied by psychologists. Meijers: 'Apart from a system that completely takes over braking, we are also looking into other, less far-reaching ways to deploy such a system. One could, for example, stimulate people to follow the optimum braking curve by showing them how much energy they are saving, or by using light indicators to simulate the ideal braking pattern. An ethical issue arising from this is how far one can go to persuade people to behave in a certain manner. When does persuasion become manipulation?'
For projects on a much larger scale, i.e. the construction of large infrastructural projects, ethical issues come into play that should also be discussed from a very early stage onwards. Meijers uses the example of wind farms and other, often capital-expensive infrastructures for generating renewable energy. 'When the decisions are made whether to invest, future costs and benefits are taken into the equation. It is pretty much standard procedure to introduce a discount rate of around four per cent per year. Say a wind farm generates 20 million euros in profit in a year; we calculate the profit for the next year to be 19.2 million, four per cent lower. The further you move into the future the lower the projected profits are.'
A few years ago, the British economist Nicholas Stern started a debate on the automatism with which we value the current and future yields of renewable energy projects. Meijer: 'Stern's report was really on the economics of climate change. In this huge report he maybe spends ten pages discussing how to value future costs and benefits. With these few pages he has managed to start a huge debate on the subject, amongst economists and amongst ethics researchers.
According to Stern the discount rate is much more than a multiplication factor. It also has intrinsic ethical values because the discount rate reflects our view on what future generations may justifiably claim of the Earth's limited resources and on the money they would need to spend to live in a relative state of wealth. To meet their demands, he reckons we should lower the discount value to about 1.5 per cent. The result of this would be that future profits would be projected much higher, thereby making the investment in renewable energy projects much more attractive.'
Quite a plausible argument, which was duly embraced by former Prime Minister Tony Blair and formed the basis of his ambitious climate policy. This in itself also raises certain ethical questions on how to deal with uncertainty. Meijers: 'Climate policy is based on the assumption that anthropogenic CO_2 production is causing the atmosphere to warm. This quite small rise in temperature is believed to have a lot of different effects that will push the temperature up even further, maybe even up to 6 degrees over the next century.'
These climate scenarios are all based on models that use algorithms to harness current knowledge of the climate and the mechanisms that play a role in it. Meijers: 'Since it is impossible to know everything, and since the phenomena we are talking about are probabilistic in nature, we know the model carries uncertainties that can influence the predictions to varying degrees. In this case it is very important that the people who actually build and use these models, the engineers or the climatologists, are very clear about the initial assumptions they used. The ethics researcher then has to take it a step further and has to look for uncertainties and hidden assumptions they are not even aware of. It is the same as with products. If you study the ethical aspects of models from early on in their development, it not only has a positive effect on the quality of the models, but also on the policy decisions based on these models.'

MECHTELD-HANNA DERKSEN
EINDHOVEN UNIVERSITY OF TECHNOLOGY

MECHTELD-HANNA DERKSEN

EINDHOVEN UNIVERSITY OF TECHNOLOGY

Like an anthropologist studying an unknown people; that is how Mechteld-Hanna Derksen (30) studied the biomedical engineers working on tissue engineering. In particular those working on growing a living heart valve that can be implanted in newborn babies with a heart condition. 'What I noticed is that the engineers approach the subject primarily from a technological angle. They focus on the heart valve and the technologies they develop to engineer heart valves; the body, and let alone the person, is far removed from their work.'
This tunnel vision can be explained by the sheer number of technical difficulties one encounters when trying to grow the cells for a heart valve. 'But they still need to realise that they are not just working on technological problems, but also on normative ones', argues Derksen. An example is choosing umbilical cords as a cell source for engineering heart valves. Derksen: 'From a technological perspective the choice of umbilical cords seems straightforward: the cells can be harvested during pregnancy allowing doctors to engineer a heart valve that is ready at the birth of the child needing this valve. Yet, there are also normative aspects: it implies no longer developing a technology for treating children with a heart problem, but developing a technology that will intervene in healthy pregnant women who are in fact not patients.'
Derksen, who got her bachelor's degree from University College Utrecht and obtained her master's degree from the University of Wageningen, is intrigued by the technological way in which biomedical engineers perceive the body. 'The engineers consider the body as a machine. Cells to them are a resource for engineering. They do not realise that their work is not only technical but normative too; their technological choices influence the way humans experience their bodies.'
In her PhD thesis, which she defended in 2008, she concludes that biomedical engineers have a professional responsibility for the way their (tissue) engineering influences humans in how they experience their bodies and their possibilities. Derksen: 'One of the ways in which to take that responsibility is by having more direct contact with patients and with the daily running of the healthcare system. That might lead them to realise that the body is much more than a vehicle for carrying their technical innovations.'

PROF.DR. PHILIP BREY – PHILOSOPHY
UNIVERSITY OF TWENTE

TECHNOLOGY AND THE GOOD LIFE

'The ethics of technology has traditionally focused on the protection of individual rights and interests in the development and use of technology. With our research we want to create a framework from that also looks at the broader implications of technology for the quality of life and the quality of society', according to Philip Brey, Professor of Philosophy at the University of Twente and Twente representative of the 3TU.Centre for Ethics and Technology. 'The resulting assessments are not necessarily made from any ideological point of view, but are instead based on a thorough insight into the impact of a technology on the individual and on society.'

An example of such a broad approach is, according to Brey, the phenomenon of internet purchasing. This results in people visiting their local shopping areas less and less. Is this a good or a bad development? Brey: 'The classical approach would state that shopping online is not morally problematic because it does not violate the rights or interests of others. Our approach does not just look at it as an isolated event, but also at the possible consequences of it on the cohesion of the social fabric. If online shopping were to result in the fraying of it– something you'd have to research first – then it might lead to a reduction in quality of life, which is not morally neutral at all.'

Ethics of technology is becoming increasingly important to the social and political debate, according to Brey. This has a variety of causes. 'Society is being privatised; ethical behaviour is no longer being enforced by law alone, but individuals and organisations are required to act responsibly themselves. Companies no longer get away with justifying their actions with the sole argument that they were not illegal. A second important change is caused by new developments in the fields of biotechnology, nanotechnology and information technology. These are high-impact technologies that are having a large impact on society and are generating many new ethical questions. Lastly, there is an increased need for ethical reflection amongst engineers themselves. To achieve the status of chartered engineer in the United States, you need to have

AIMEE VAN WYNSBERGHE

UNIVERSITY OF TWENTE

While testing technical complications in telesurgery as a Bachelor's student at the University of Western Ontario (Canada), Aimee van Wynsberghe (28) started to think how the technology was perceived by surgeon and patient. There and then she decided to obtain a master's degree in Applied Ethics at Leuven University in Belgium. After that she did another MSc in Bio-ethics, an Erasmus Mundus, which took her over the course of one – hectic – year to three European universities. 'By that time I was really interested in the ethical aspects of human-robot interactions especially in health care.'
In 2008, Van Wynsberghe started her PhD at the University of Twente on the topic of care robots and the good life. 'This may sound contradictory', she says.
'Robots – surgical ones too – are part of the objective, hard and technological world, whereas care is part of the subjective world of loving relations with vulnerable people. This contradiction is easily resolved. Robots are capable of taking on a range of care tasks, like hoovering, grabbing objects you cannot reach and even getting someone from their bed to the toilet and back. They do not require sleep and can therefore provide their services around the clock.'
This all sounds very practical, especially in a time where the population is ageing and the number of people working in care is going down. Many institutions and companies are therefore working on the development of care robots. At the same time some ethical questions are looming that deal with the interaction between human and robot. Is it, for example, ethical to lead people to believe they are developing a meaningful relationship with a robot by giving the robot human traits? Does the presence of the robot lead to social isolation because the children visit less as mum or dad is being cared for so well anyhow?
Van Wynsberghe: 'Thinking about these questions forces you to think about the role care plays as part of the good life. What are the core values of care and, if we can define these, can we embed them in technology? Raising these issues in a very early stage of the technological development, a type of value sensitive engineering, is very inspiring.'

followed an ethics course. In the Netherlands both students and teachers are pushing for the inclusion of ethics into the engineering curriculum. The founding of the 3TU.Centre for Ethics and Technology too shows that engineers are increasingly aware of the ethical and social implications of their work.'
The problem is, of course, that we often cannot envisage the impact of new technological developments. Brey: 'We are often dealing with technologies that are still in their infancy. For nanotechnology, for example, we cannot begin to fathom what opportunities it will offer in ten or twenty years, let alone what our opinions of it will be at that time. Still, the government of the Netherlands is organising a national debate about nanotechnology as decisions need to be taken regarding regulation and investment in research and development of it.'
To prevent the whole debate falling on deaf ears – the parties not understanding each other – Brey sees it as the job of the ethics researchers to, where possible, lift the debate to a higher level. An important condition is that the technicians involved realise that technological artefacts implicitly reflect the values and beliefs of their designer. A simple example, according to Brey, is the automatic teller machine. 'It has been designed so it can only be operated if you are Dutch or English speaking, literate, not visually impaired and taller than 4½ foot. It is understandable that this design excludes some users, but it has to be recognised that this is a value-laden choice and that the machine could also have been designed in a more inclusive way.'
Brey himself has investigated the implicit and explicit values incorporated in internet search

engines. 'At first glance search engines have little to do with ethics and politics, except when governments or organisations impose censorship on them by blocking certain pages. On a more fundamental level, however, they really influence the way in which information is made available. Suddenly it becomes apparent that the page rankings can be influenced by wealthy information providers. Another value that can be infringed upon is user privacy, for example by the search engines storing the search patterns automatically. Those data are not just interesting to companies, but to law enforcers as well.'
Privacy is proving to be a shifting example. Brey: 'Partly due to the Internet thoughts on privacy are changing. Thirty years ago people would refuse to take part in the census because they were afraid their information would be abused, but amongst the younger generations the fear of Big Brother seems to have subsided. Thanks to applications like Facebook and Hyves everybody can play Big Brother, so it seems.'
That statement fits well within another large research project headed by Brey within the Centre of Excellence, on how to evaluate the way in which information technology changes society and everyday life. Brey: 'People evaluate the impact of information technology on everyday life both positively and negatively. You could conduct surveys and gather data about which percentages of which groups are positive and which are negative. For ethics research it is much more interesting to figure out the internal frame of reference people use to arrive at their judgement. What is a good life and what is meant by a good society and to what extent is that influenced by ICT?

Someone for whom the good life means comfort and enjoyment is more likely to think positively about ICT than someone whose core values are based on spirituality. This way you can detect values that are important for the developers of technology and for the designers that make the objects.'
Ethics of technology has undergone an empirical shift in recent years according to Brey. This means that ethics researchers are increasingly resorting to technological and social studies to work out the impact of technological developments on society. As this often involves new technological developments of which you can at best make assumptions on the potential impact, case studies are often used. Brey: 'When you start talking about those, opinions often become much less black and white about a given technology. You can talk about a 'care robot, friendship robot or military robot', rather than simply 'the robot'. The debate then stops being about prohibition of a technology and starts being about what aspects are more or less desirable and how engineers can meet these criteria. It all becomes a bit more pragmatic and a bit less ideological.'

CENTRE OF EXCELLENCE

INTELLIGENT MECHATRONIC SYSTEMS

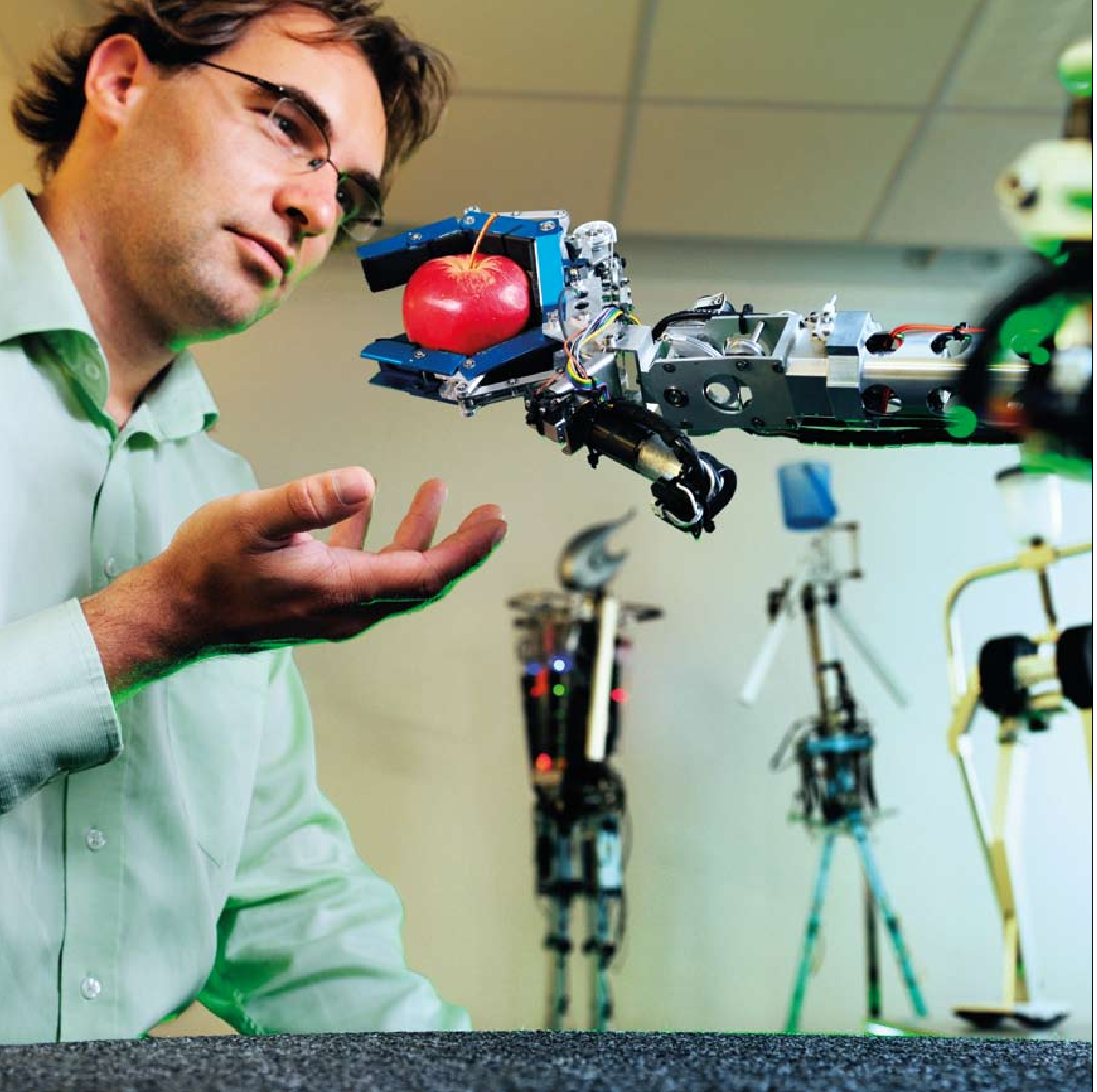
PROF.DR.IR. MAARTEN STEINBUCH
SCIENTIFIC DIRECTOR
3TU.CENTRE FOR INTELLIGENT MECHATRONIC SYSTEMS

In the future, we will need new solutions that help us to maintain our quality of life. In these new solutions robots will play an important role. For example, robots helping the elderly remain independent for as long as possible. The Intelligent Mechatronic Systems (IMS) centre has a long-term vision of robots that carry out tasks normally performed by humans but with greater precision, using extensive interactive and sensory abilities and with an energy efficiency superior to that of all existing applications.

To put that vision into practice, the 3TU.Centre for Intelligent Mechatronic Systems is focusing today on research into and the design of advanced (movement) systems. For example, microsystems and precision robots for applications in mechatronics and the automotive and medical fields. The qualification ‘Intelligent’ underlines the innovative nature of our work, in which we make use of advanced software and control algorithms.

Research at the 3TU.Centre for Intelligent Mechatronic Systems has four focal areas. Robotics: the development of intelligent robots / machines. Precision Systems: the design of high-end mechatronic systems subject to extreme performance demands of speed and precision. Microsystems: the realisation of miniaturised devices with very high precision. Distributed and Embedded Systems: the discipline of control technology to enable the control of complex systems.

The multidisciplinary research field of IMS makes an important and innovative contribution to the high-tech systems industry in the Netherlands. The advanced knowledge of the universities supports and promotes innovation by industry in this field, and also ensures a constant stream of young graduate engineers and PhDs.



DR.IR. MARTIJN WISSE – MECHANICAL ENGINEERING
DELFT UNIVERSITY OF TECHNOLOGY

SMART MOVEMENTS

A robot can beat you at a game of chess, but if you were to ask it to carry a cup to the kitchen, it would fail. 'Human-like movement could help robots develop a form of intelligence more like our own', believes Martijn Wisse, associate professor in Mechanical Engineering, who uses biology as the inspiration of his research into robotics.

A few years ago, Wisse and his colleagues not only made the journal Science, but also the national and international press. The reason for this publicity was Denise, a robot that walks like a human. Where other robots move on wheels or by alternating standing stably on one of two legs, Denise moves – just like us – by falling forward in a controlled manner. Gravity is used to take the next step, which means this mode of transport uses up very little energy. The upper body and arms of Denise move in opposite direction to the legs, making Denise remarkably stable. Denise models the concepts of what Wisse refers to as 'biorobotics', a term which carries a double meaning: 'On the one hand we want to let biology inspire us. On the other hand it refers to the surroundings in which we want the robots to function. Industrial robots do their work in highly defined surroundings where everything, down to the last screw, is in place. Our biorobots have to be able to function in domestic situations, or even in a hospital, where not everything is so tightly ordered. This means they have to be able to adapt to their surroundings. On top of that they have to be safe for those surrounding them. An intermediate scenario is a greenhouse; where robots can be deployed to, for example, pick tomatoes. On the one hand this is factory-like, but because the tomatoes do not always hang in the same place, it requires the robot to have adaptive ability also.'

Human-like locomotion is not only smoother and more efficient, but could be the key to a type of machine intelligence more closely resembling human-like intelligence. 'There is a group of developers – myself included – that believes in embodiment. We think that intelligent behaviour stems from the interaction between brain, body and surroundings. You can develop artificial intelligence all you want, but if this intelligence is not grounded by means of a body, it will

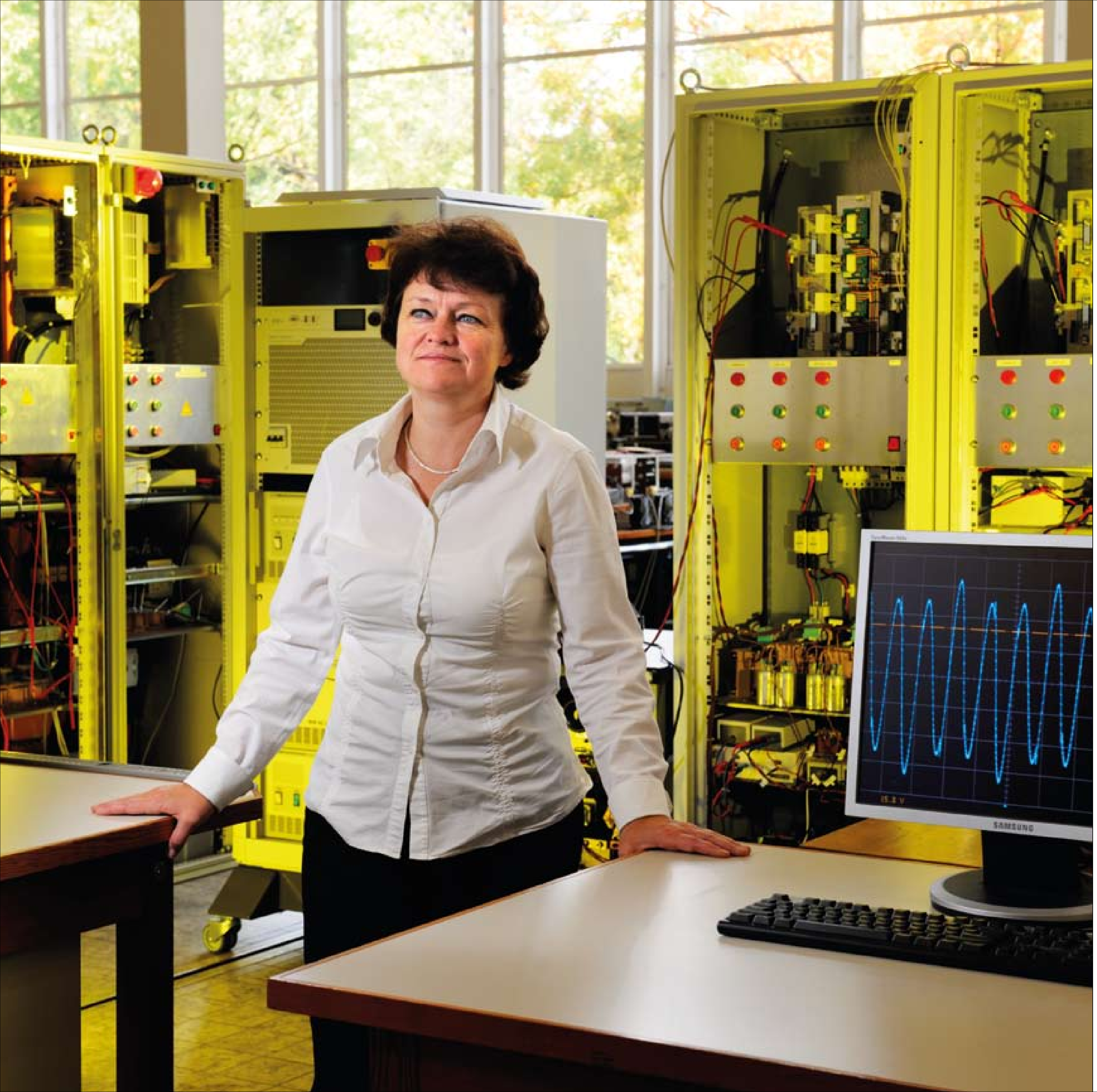
remain artificial. And with that the communication between man and robot will remain unnatural.' Wisse does emphasise that embodiment is not a rigid scientific concept. Some indications exist that human intelligence, at least partly, is rooted in our ability to move. If a robot is to carry out domestic or medical tasks independently, where he needs to anticipate human needs and feelings, it would help if he occupied this world in a similar manner. Wisse: 'You could compare it to humans that have been blind from birth. To them, for example, colours such as green or red have a completely different meaning than they do to us.'
To test the embodiment hypothesis – learning through movement – you need biorobots that move in a similar way to humans. Denise was one of the first examples, but nowadays she has a few offspring, including Tulip, the robot footballer. 'A big difference is that Denise still had pneumatic muscles, whereas Tulip has muscles based on an electromotor with a spring. It requires a lot more technology to regulate this, but does make the movements much more supple and natural.'
As a straight-up mechanical engineer, it is Wisse's aim to control the movements of the biorobot with as simple mechanics as possible; so without using sensors and feedback systems. The electronics used for the locomotion of Denise, for example, are no more complex than those in a simple mobile phone. Another example is the robot hand that can pick up eggs without crushing them, but also pick up bricks without dropping them. 'Purely mechanical', says Wisse.

TOMAS DE BOER
DELFT UNIVERSITY OF TECHNOLOGY

If you use a human as your source of inspiration for a walking robot, you have to remember it can trip over. PhD student Tomas de Boer (27) is looking at how to incorporate reflexes into the robots that walk human-like. 'When we trip over, we most of the time manage to stay upright', says de Boer. 'The question is how we do this and it is my job to try to answer this. It sounds much simpler than it really is. The compensatory movements we make in a reflex action are incredibly complex. Together with the physiologists at the Vrije Universiteit we are working out how humans do this. Then I try to translate these results to the robot. '
The results of this research are also relevant to Tomas de Boer's other research topic: the robot footballer. 'TUlip is a platform the three universities of technology are developing in collaboration. There is a TUlip in each of the universities and everything we develop we exchange with one another. We are also going to take part in the Robocup, the world cup for robot-footballers.
TUlip has reached the stage where he can now take penalties; ball on the 12 yard spot and go. But when he trips, he falls, which is something we still need to improve on.
What interests de Boer the most about the research is analysing how humans move; the interplay between pushing and pulling forces that are so finely tuned to each other, allowing us to make incredibly complex movements. Like the trip reflex, which we make without even realising. 'That in itself is fascinating', says de Boer. 'It gets even more interesting if you translate those analyses to a machine. Man, or even nature, as inspiration for technology; that is what makes it a very challenging field.'

TOMAS DE BOER
DELFT UNIVERSITY OF TECHNOLOGY

'Each of the six fingers consists of two segments, which can deliver a constant force. The hand thus has six degrees of freedom and by using a sixfold differential, all fingers can be controlled with a single motor. The hand is being developed further for use in a robot that can pick tomatoes.'
Developing mechanical representations of human movement is also providing new perspectives for research into human movement for a group of physiologists at the Vrije Universiteit of Amsterdam. Their speciality is the precise analysis of movement. Wisse: 'Sometimes they find things that we can use for the development of mechanical movement; sometimes we discover something that is useful for them.'
An example is the physiological research on the walking movements of kids suffering from spasticity. Wisse: 'The commonly accepted theory is that spastic children have such difficulty walking because the primary signals are not coming through. They often trip over because, one used to think, their muscles are permanently tightened. When developing our robots, we helped to analyse the walking gait and showed that the non-supporting leg undergoes a passive pendulum movement. The only active component is the bending and subsequent straightening of this leg. Children suffering from spasticity often keep their knees slightly bent, of both the moving and the supporting leg. This results in the pendulum no longer working.'
The smooth-moving biorobots currently being developed by Wisse and his research group are the first step in the realisation of his dream: a small army of robots that help us perform many useful, but quite boring, tasks. From picking tomatoes in a greenhouse to building brick walls, cleaning in the house and helping the elderly remain independent for as long as possible.
Wisse is the first person to point out that this time has far from arrived yet. 'Robots are too expensive and stupid', he says. 'A lot of research and development is still needed before robots can perform useful tasks in a heterogeneous environment.'



PROF.DR. ELENA LOMONOVA - ELECTROMECHANICS AND POWER ELECTRONICS
EINDHOVEN UNIVERSITY OF TECHNOLOGY

THE ELEPHANT AND THE MOUSE

Demands for increased speed of production and higher accuracy put more and more pressure on the performance of machinery. In order to stabilise equipment at higher power levels they are also getting heavier and heavier. 'The elephant is moving the mouse', states Elena Lomonova, 'more and more heavy equipment is reaching its operational limit. That is why our research is going right back to basics: the underlying physics.'

The research of Lomonova's research group is divided into a series of different clusters. One of these is 'power quality' and looks at the quality of the electricity. Lomonova: 'This is an important theme for stand-alone systems, such as airplanes, which are controlled pretty much fully electronically (fly by wire). For electrical grids stability is crucial too. Due to the rise of renewable energy, such as wind and solar power, the production of electricity is increasingly decentralised. This implies that the supply is of a much more variable nature, so to align the variable demand with the variable supply a smart electricity grid is needed. Within the EPE group a multi-port converter has been developed to convert electricity from a range of different sources into electricity of a constant quality, with very high efficiencies.'

A second cluster works on contactless energy transfer for, amongst other things, charging electrical vehicles. This simplified design does not need contacts and avoids complex wiring. Therefore, it is becoming increasingly important, especially for newly developed plug-in vehicles that have to be charged in a large variety of circumstances. Furthermore, different vehicle on board workloads, as can be caused by acceleration or deceleration, have to be trapped in storage devices. Lomonova: 'We are working on bi-directional systems, which allow for the storage of the energy to be released when the car slows down. These energy recovery systems already exist, but are mainly based on conventional technology. As such, we are researching contactless charged new electric drive train configurations to minimise the number of electric conversions.'

The third cluster within the group looks at contactless movement for high-precision production systems to make things like wafer steppers, electron microscopes and other high-precision

BART GYSEN

EINDHOVEN UNIVERSITY OF TECHNOLOGY

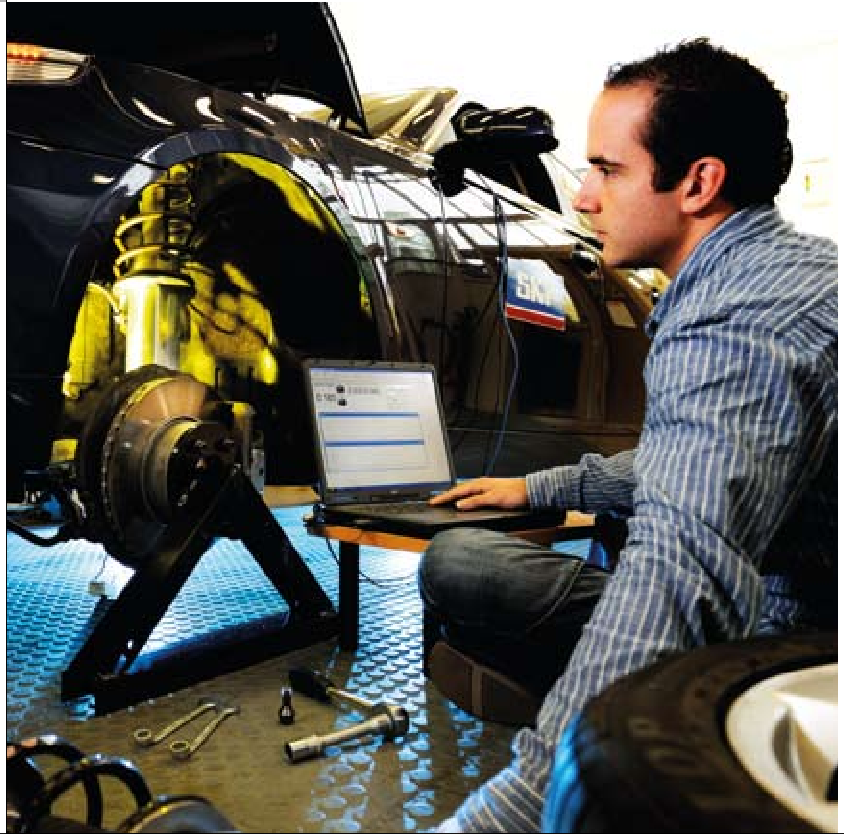
Going for a drive in your own study object; a realistic prospect for Bart Gysen (25). The object he is studying as part of his PhD research, an active electro-magnetic suspension, will soon be built into a BMW owned by the supporting company SKF. Gysen: 'We hope to be ready to take the car out next year. Not on the road – that is not allowed – but on a circuit instead.'
The current generation of cars with active suspension is usually fitted with hydraulic (or sometimes pneumatic) suspension systems. These have their limitations, like the need to be kept at pressure at all times, which costs energy. They also do not respond quickly enough to bumps in the road. In technical terms, they are said to have a relatively low bandwidth. This results in the driver feeling the bumps on the road, say the riblike road markings at a traffic light. A further problem is that the current suspension systems are not very suitable for cars with a high centre of gravity and a small footprint. This can result in the car becoming unstable, or even tipping over, in corners and during sudden evasive manoeuvres (the moose test).

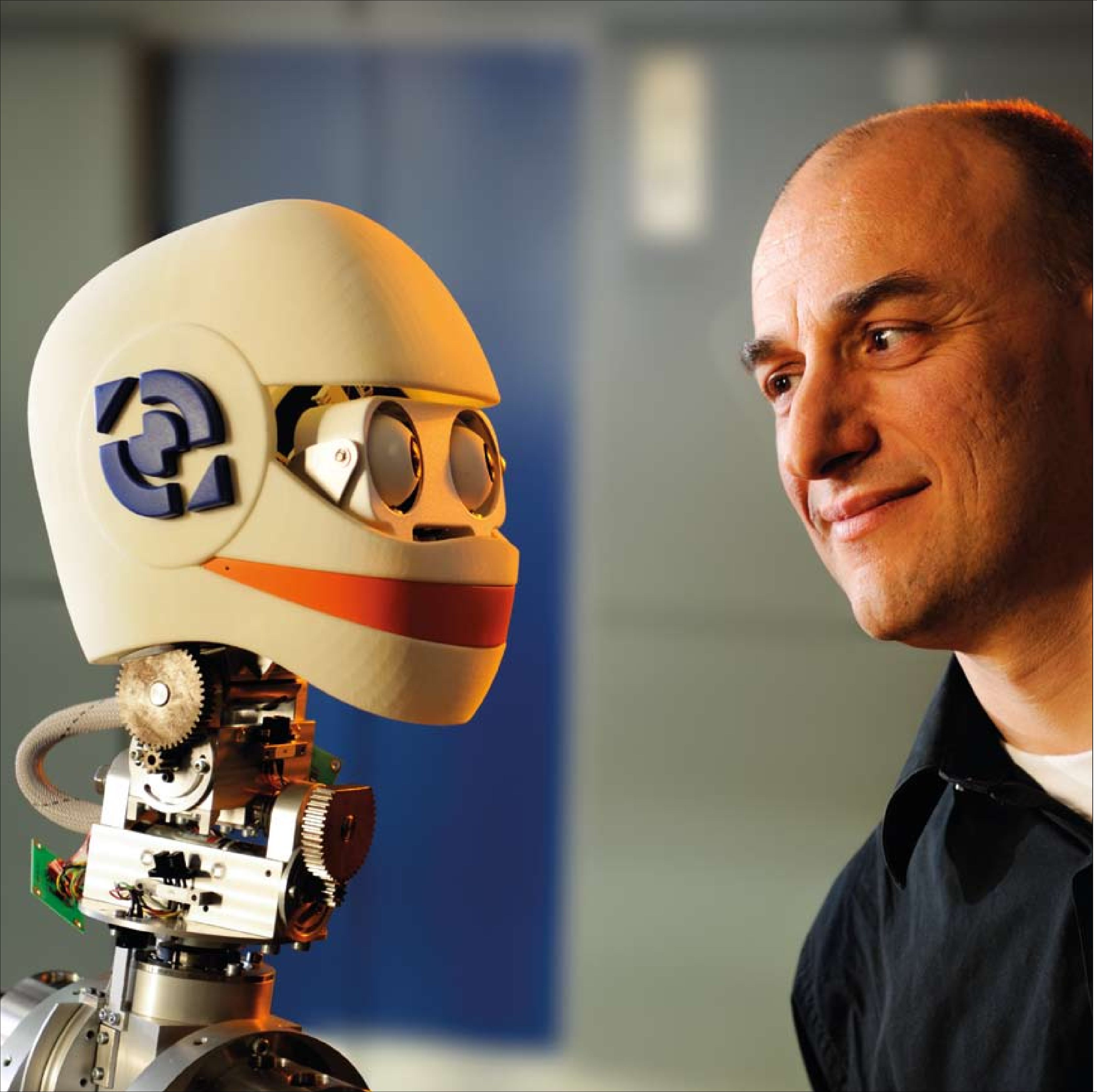
The active suspension system, which is being developed together with SKF Automotive, aimes to make the car safer and more stable, as well as increase the driving comfort. Gysen: 'The system consists of a combination of a mechanical spring with a tubular permanent magnet actuator; a bit like a translating electromotor. The bandwidth of the system is higher, allowing it to respond to bumps in the road much more quickly. This could be beneficial for ambulances since the patient can be transported in a fast and comfortable way. The actuator is also powerful enough to prevent the leaning of the car in corners, thereby removing the risk of it tipping over. An added bonus is that the electromotor can function as an alternator, which can generate electricity to charge the battery of the car when driving over a bumpy road.'
What Gysen likes about his research is that it combines theory and practice. 'It is a problem the automotive industry has been struggling with and for which we have now provided a solution. This makes it all very tangible, and with that, highly motivating. Although I might be driving with it, this does not mean that the system will be fitted on real cars anytime soon. The car industry is never one to move too fast.'

equipment. One of the practical issues when making these machines is the prevention of vibrations. Not just external vibrations, but also those caused by electric motors – actuators – needed to provide accurate motion of the production apparatus. Especially with processes like microchips manufacturing, in which nanometer precision is required, these vibrations need to be suppressed. One of the things Lomonova's research group is looking at is a production method that does not cause vibrations. One of the more spectacular developments aimed at eliminating external vibrations is a floating ceiling robot for industrial and medical applications. Magnetic repulsion causes the whole instrumental set-up to float in mid-air and information and energy are fed into the system completely wirelessly. In the event of an unforeseen power cut, the instruments will simply stick to the ceiling, because of magnetic forces that compensate the gravity.
This challenging concept is being developed because current high-precision manufacturing techniques are reaching their limits. Lomonova: 'Due to an increase in the production speed required, the processes run faster and faster, which means larger forces are required and higher energy levels are necessary to power the processes. As acceleration is equal to the force divided by the mass, and the mass is becoming ever more critical. What you see now is that in order to stabilise an item weighing 3 grams, an apparatus weighing 3000 times that amount is required. And it will keep getting worse. If you want even higher accelerations, you need even heavier equipment. It is a vicious circle that we need to break soon.' The higher accelerations also put greater strains on the actuators, the electrical machines that drive the systems. On the one

hand there is a push towards miniaturisation for use in, for example, robot fingers; on the other hand, however, they need to be ever more powerful to deliver the required forces and torques. Lomonova: 'Classical linear actuators have limited force density. Alternatives, like the non-linear reluctance actuators, do exist, but to provide very accurate repetitive motion a lot of physics related material research is still required. Another possibility is to use superconducting materials, but that too is technologically very difficult.'
These higher forces and torques in combination with the miniaturisation of the motors are leading to problems that can no longer be solved in a traditional manner. Lomonova: 'Until recently, designers and manufacturers used very intelligent controls, but the limits of those are in sight. You run into more and more electromechanical and magnetic issues, like dampening eddy currents, phase shifts and other non-linear phenomena that cannot readily be controlled.' It is for that reason that Lomonova is advocating a back-to-basics approach; a multi-disciplinary approach based on looking at the underlying physics. An example of this approach is the so-called model-based design. Lomonova: 'What it boils down to is to describe the complex physical manifestations that form the basis of the behaviour of the actuator as accurately as possible and use it to make a model. Then you need to carefully simplify the model, as most of these models are far too complex for real-time control.' By 'careful' she means that you have to select parameters and interparameter relations that are relevant to the prediction of the behaviour of the system. The simplified model can then be used to design high bandwidth systems, which can anticipate the behaviour of the various components under the conditions of use.
One example of model-based design is the electromechanical active suspension that was developed by Lomonova's group. It consists of a tubular actuator, which is a permanent magnet inside a coil that acts as an anti-vibration dampener, combined with a mechanical spring. The novelty about the design is that the behaviour of the dampener combined with the spring has been accurately modelled. This allows for active control of the system. The invention has been patented.
Another example of a current project proposal, in a completely different field, is the development of a six-fingered robot arm for the precise aim of high-frequency beams to treat tumours generally located less than 4 cm from the skin (Hyperthermia therapy). Lomonova: 'To maximise successful clinical outcomes, you want to aim the beams as accurately as possible. Currently, patients have to remain motionless for extended periods, but that still is not enough because they will always move a little bit, even if just to breathe… Using model-based design we hope to be able to adjust the position of the beam real-time based on the patient movements and to allow for patient movements, so as to achieve maximum treatment precision and patient comfort.'

BART GYSEN
EINDHOVEN UNIVERSITY OF TECHNOLOGY





PROF.DR. STEFANO STRAMIGIOLI – ADVANCED ROBOTICS
UNIVERSITY OF TWENTE

USEFUL MACHINES

'We're at the dawn of a robotic wave', says Stefano Stramigioli. 'It is no longer a question of 'whether', but a question of 'when' robots will populate our houses, hospitals and care homes to lend a helping hand. Together with our colleagues in Delft and Eindhoven we are working on the concepts and underlying technologies that will allow robots to move safely in a constantly varying environment.'

The whole world knows the story of little Hansje Brinkers, the boy that saved the Netherlands by putting his finger in a hole in a dyke. This is of course a fairy tale. In reality the dykes in the Netherlands are guarded by levee patrollers, but only when the water levels are high. Stramigioli: 'This inspection of the dykes would be a perfect task for robots. We are currently working on a project where a swarm of robots, similar to the Mars Rover, continually monitors the strength of a dyke. '

Using robots as levee patrollers is just one of numerous examples of robots working at providing services. Another example of this is the Pirate, a robot that can check gas pipelines for leakages. These kinds of inspections need to be carried out every five years. Stramigioli: 'Normally, this inspection is done on the surface using sniffers that detect escaped gas. It would be much better to be able to inspect the pipelines from within for weak spots before a leak has even sprung. An additional advantage is that when you know exactly where the weak spot is, you can dig a much smaller hole to repair it. Checking for leakages is quite a complex task and the robots need to be able to travel independently through long stretches of pipeline. That means that it has to be recharged by induction. It also has to be able to recognise and navigate bends in the pipe and T-joints.'

Pirate and the Levee Patroller are two examples of robots leaving the highly organised industrial domains and venturing into the public arena, where not everything is fixed in place. They are part of the new robotic wave that will lead to robots populating our personal lives too. In terms of the interaction between human and robot, it is important for robots to behave as humanly

as possible; these robots are referred to as humanoids. Stramigioli is developing a humanoid head which will be one of the parts used in the 3TU project Bobby that could keep single elderly people company and check whether everything is still going well. The first version of the head can move more smoothly and quickly than existing robot heads. It can follow humans and make simple movements like nodding 'yes' and 'no'.
'For the interaction with humans it is essential the robots can really see', says Stramigioli. 'Seeing is more than just observing what is happening in its surroundings; it also involves recognition and interpretation of those observations. The humanoid has to be able to recognise emotions, using, for example, facial expressions and stance. The software for this is being developed by a different group within our faculty. We mainly focus on the mechatronics.
When you're talking to a robot, it's nice if it would look at you. We are making sure the cameras in its eyes are not looking past its conversation partners but at them.'
The head can also be used as part of a complete humanoid. One that can walk, make coffee, clean and, for example, program the DVD player. The next step is the development of the limbs. The three universities of technology are also collaborating intensively on this. Each of the universities is in possession of a TUlip, a 4-foot tall lightweight robot that walks like a human and is taking part in the Robocup, the football world cup for robots. Football-playing robots may sound frivolous, but the competition is generating a lot of knowledge that can be applied elsewhere. For example, in robots that are used in healthcare. Stramigioli: 'One of the applications is TeleFlex, a system that allows a surgeon to perform remote controlled invasive keyhole surgery. These are operations that only require a few small incisions for the operation to be carried out using a flexible, controllable endoscope. Teleflex consists of an exoskeleton, a sort of flexible harness, the surgeon is connected to and that directly translates his movements to that of a robot, a remote-controlled slave.
Our research focuses on haptic feedback by the slave. That means the surgeon not only gets visual feedback, but also feels what he is doing.'
Another application is the use of robots for physical therapy. Stramigioli together with other colleges at the University of Twente work closely on this with the R&D department of the Roessingh, an institute for physical therapy. Knowledge of the walking gait has led to the development of LOPES (Lower-extremity Powered Exo-Skeleton), a robot that can be used to rehabilitate patients after a stroke. Stramigioli: 'The unique feature of this research is that it is not the technology that forms the core of the research but the learning and training process of the patient. It is turning out to be remarkably effective.' The development of prosthetic limbs is another considerable challenge for mechatronics researchers.
Stramigioli: 'One of the projects we are researching is the Reflex Leg, a prosthetic leg for people who have lost their own leg. The Reflex Leg gives patient feedback on the position of the leg using vibrations or electrical signals. This means they do not have to continually check the position of the leg visually. Aside from that we are also trying to make the prosthetic auto-generative, which means that it would draw its energy from the walking movement thereby removing the need for batteries.'
Stramigioli thinks that the switch robots are making from an industrial setting to the public and private space has led to an exponential development in robotics. 'It has not always been this way', he says, 'but robotics is hot right now with both students and – not unimportantly – financers. When the robots will actually be assisting us in everyday life, I can of course not predict, but I think it will be much sooner than we think.'

MICHEL FRANKEN
UNIVERSITY OF TWENTE

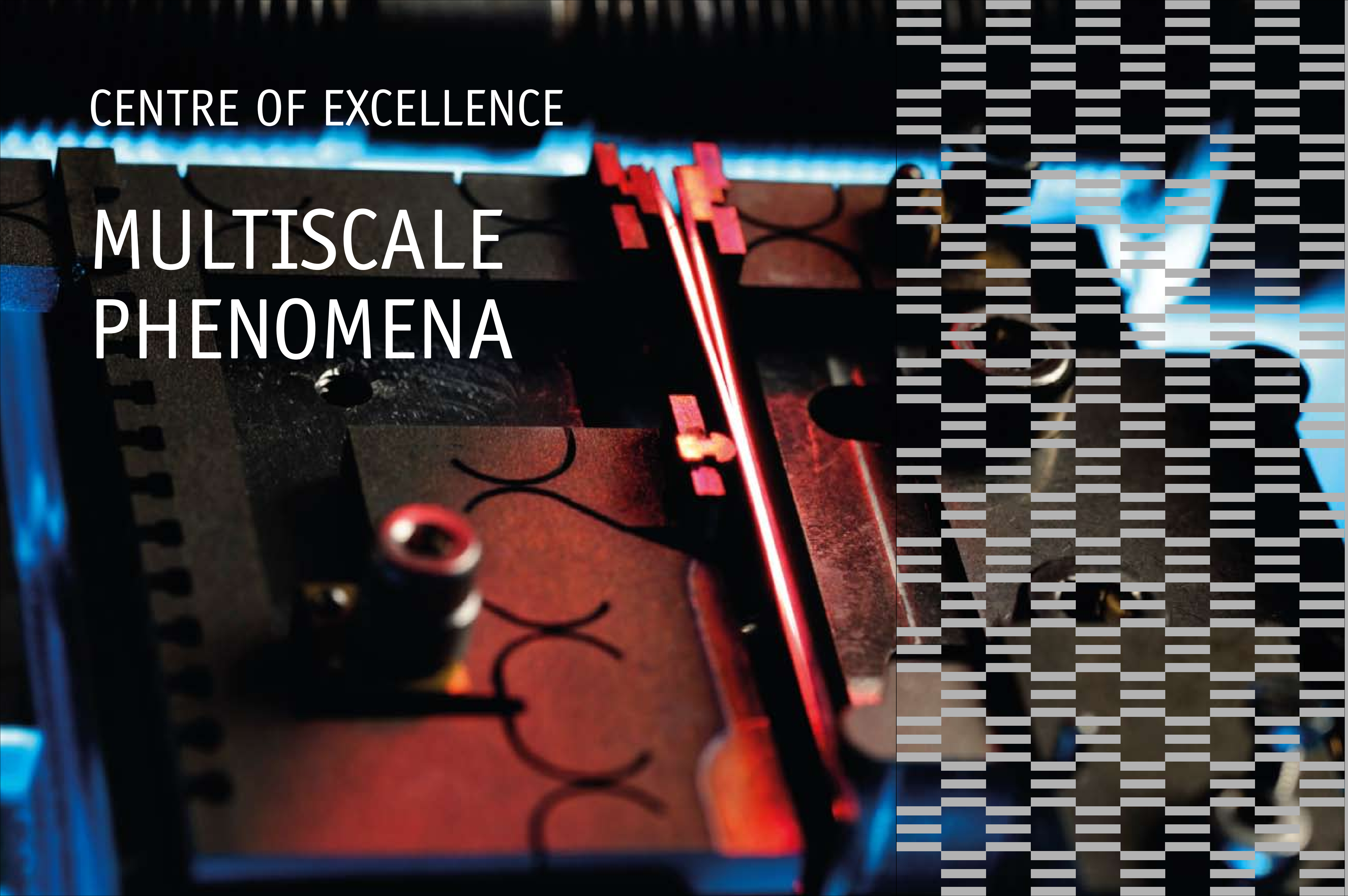
MICHEL FRANKEN

UNIVERSITY OF TWENTE

Less than two weeks after finishing his MSc in electrical engineering at the University of Twente, Michel Franken (26) had already plunged himself into research into a fundamental problem of bilateral telemanipulation: how to deal with time delay in the communication channel. Franken: 'Bilateral telemanipulation is a major research area in surgical robotics, e.g. the TeleFlex project. It means that information on a particular movement is sent from the surgeon to the robot. The robot then sends information back about the resistance it is encountering. This information transfer always involves a time delay, even if it is just a few micro-seconds.Small time delays should not be a big problem, but when these time delays increase (e.g. communication over the internet) conventional control schemes experience major stability problems.
Due to those time delays 'virtual' energy is generated inside the communication channel as it were. In practise this 'virtual' energy causes jerky, oscillating forces to be generated at both the surgeon and patient side. As we deal with a fully closed loop, this oscillation can carry over to the other side and can even be magnified so that the entire system breaks down. And that is not what you want during an operation.'
The solution to this problem that Franken is working on is the subdivision of the communication channel into information on exchanged energy and information on the desired behaviour of the system.
The aspect Franken enjoys most about his research is the puzzles he has to solve. 'You are faced with a complicated problem that you need to solve in an elegant fashion. What makes it extra exciting is that we try to solve the problems by leaving the beaten track. This provides a creative challenge. For me personally, the fact that I am solving problems that can help a surgeon in performing his procedures better is also a great motivator. Meeting surgeons, attending operations; those are things that makes me realise what you are in it for, despite the fundamental nature of the research.'

CENTRE OF EXCELLENCE

MULTISCALE PHENOMENA



PROF.DR.IR. GIJSBERT OOMS
SCIENTIFIC DIRECTOR
3TU.CENTRE FOR MULTISCALE PHENOMENA

The objective of the 3TU.Centre for Multiscale Phenomena is to achieve a better understanding of the macroscopic behaviour of gases, fluids and solids on the basis of the underlying structure and forces on the mesoscopic and microscopic scales. Linking experiments and models at different scales into integrated simulation tools is considered to be an important scientific challenge. We need the knowledge to better understand the behaviour of wide-ranging but essential topics concerning us all: from the flow of gas and particles in a reactor to the mechanical behaviour of flexible displays.

One example is the flow in a fluidised bed, a chemical reactor used in the process industry. In this reactor gases are passed under pressure through a catalyst particle bed. At the most detailed level the flow of the gases is calculated at a much smaller scale than that of the particles. The results provide information about the interaction between the gas phase and the particles. This information is used to calculate the interaction between the particles at a larger scale. Finally the information is used in the continuum model, which describes the flow in the entire fluidised bed. The exchange of information based on the phenomena at different length scales makes it possible to predict the flow behaviour of gas and particles in the reactor accurately.

The centre's research will lead to models and computer programmes for use in practice. Knowledge transfer also takes place through doctoral candidates who, after completing their studies, find employment in companies and technology institutes. An important added value of the 3TU.Centre for Multiscale Phenomena is a further strengthening of the collaboration between the groups working in this field.

PROF.DR. ROB MUDDE – MULTIPHASE FLOWS
DELFT UNIVERSITY OF TECHNOLOGY

MULTIPHASE EYES

Multiphase flow systems are encountered regularly in industry. In process industries, for example, various combinations of gases, liquids and solids can be found that need to be mixed. Also in pipeline transport, when gases and liquids travel through pipelines together. 'Our studies into multi-phase flow lie on the interface of theory and application', says Rob Mudde, professor in Multiphase Flows at the Delft University of Technology. 'Using experimental and numerical techniques we try to develop tools for the design of efficient and safe installations.'

Through the 3TU.Federation, Mudde's group owns a unique installation to map flows in so-called fluidised beds where a fluid or gas can be passed through a powdered solid, such as finely ground coal or a powdered catalyst for the cracking of crude oil. This can be done at high pressure. Gas flows from the bottom of the vessel upwards, resulting in the powder starting to behave like a fluid. The main advantage of this fluidised bed technology is that the contact between the powder and the injected liquid or gas is much better than in a fixed bed reactor. 'In order to optimise the reaction conditions, we'd like to know exactly what happens in such a fluidised bed', says Mudde. 'The problem is that mixtures of powders and gases or liquids are not very transparent. One-phase flows have been beautifully imaged using lasers and high-speed cameras, but normal light doesn't penetrate further than about 3 particles into a two-phase flow. That is why we use X-rays to record the movements of the mixture.'

Recently – funded by the 3TU.Federation – a room was made with floors, walls and ceilings consisting of 5 mm lead plates. The room contains three industrial X-ray sources, which are set up in a triangle. At the centre of the triangle is a glass tube containing very fine sand. By blowing air or water into the vessel from below the sand will begin to float, which results in a fluidised bed. Mudde: 'As the system is in motion, you cannot rely on single photos, but instead you need to take a continuous stream of pictures. The experiments are a bit like taking CT scans of the fluidised bed, where we measure direction and flow speeds every ten milliseconds.'

ÖZGÜR GUNYOL

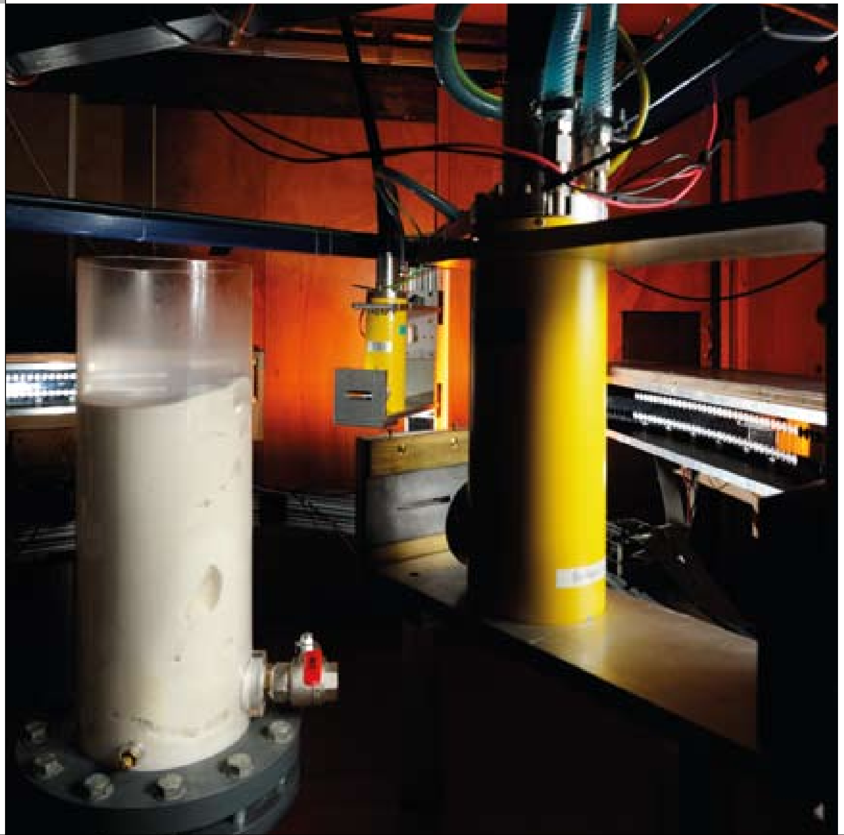
DELFT UNIVERSITY OF TECHNOLOGY

During his BSc Chemical Engineering in Turkey and MSc Process Engineering in Hamburg (D) thirty year old Özgür Günyol's favorite subject was fluid dynamics. Being a chemical engineer, mass transport and chemical reactions are also fundamental parts of his profession. 'The subject of my PhD research in Delft, the hydrodynamics of fermenters, provides the right balance of these topics', he thinks. Günyol is researching a numerical model for large-scale fermenters. These are basically stirred bubble columns in which feedstocks, like sugar and oxygen, are converted by micro-organisms into the desired products, like antibiotics or chemicals. Günyol: 'It is important that the oxygen and feedstocks are distributed well throughout the reactor so all micro-organisms can be provided for. It can be modelled as a two-phase flow, where gas bubbles rise through the liquid phase and perturb it. These perturbations are further amplified by large stirrers (impellers). These elements combined lead to a complex combination of large and small-scale phenomena, a fully turbulent flow, all of which I am trying to model on the computer.'

The matter is complicated further by the fact that micro-organisms convert the sugar into carbon dioxide, the product and biomass (more micro-organisms). Günyol tries to incorporate these conversions into his models for predicting sugar concentration and oxygen levels. 'In principle I could use my model to calculate the sugar concentration and oxygen level at any point in the reactor at any time after the start of the reaction. In practice, this requires too much computer power, which is why I make use of approximations. The eventual goal is to establish the parameters required for designing an industrial scale reactor, such as inlet positioning, shape of the vessel, stirring power. By choosing these parameters correctly, you could prevent dead zones, where sugar concentrations and/or oxygen levels are too low, as this is where the yield of the process is limited and unwanted side-reactions may take place.'

The high-level industrial X-ray sources used to make the CT-scans are like those used to scan luggage at airports. Mudde: 'The X-ray equipment used in hospital isn't quick enough to image the motion of the mixtures; at least, not with the level of detail that we require. We have to detect perturbations in the paths of the X-rays with a series of detectors instead of taking a picture. Using these we make a three-dimensional computer model of the flow patterns in the fluidised bed reactor.'
Using this computer model, Mudde and colleagues try to answer questions with regards to, for example, the effect of the speed of the inflowing gas on the progress of the reaction. Or what the perfect shape of the reaction vessel and/or the gas nozzle has to be to prevent so-called hot spots, areas where insufficient mixing occurs. Mudde: 'Combining experimental data and numerical models provides information that can really help the people that design the installations. They do still need to use their vast experience, as there is still very much an art to designing these installations.'
The demand for optimising reactors has increased, especially in the bulk chemistry sector. Mudde: 'The investments needed there are large, but the profits per kilogram are small. The margins are very narrow, meaning that there is a real need to get the most from the installations and the source materials. The chemical industry is also subject to very tight environmental regulations, which could be met by end-of-pipe purification. It is usually cheaper and more efficient to prevent emissions in the first place through a well-planned reactor design.'

Since the end of the 19th century, when the Gist and Spiritus factory was founded in Delft, a lot of research time has been devoted to bioreactors and the flow phenomena herein. This mainly involves the multi-phase flow of gases and liquids. Mudde: 'One of the classical processes is the conversion of sugar into alcohol using baker's yeast. This is performed in reactors a few hundred cubic feet in size. The yeast cells are suspended in water to which sugar is added continuously as molasses. At the same time air is blown into the vessel from the bottom. These air bubbles need to be distributed evenly throughout the vessel otherwise oxygen-depleted pockets will form in which unwanted by-products can be produced. We try to model these processes too so the designer can improve them.'
Another application that is being researched in Delft is the transport of liquid-gas mixtures through pipelines. Natural gas, for example, consists of a mixture of gases and so-called condensates, compounds that condensate when the gas is transported from deep in the well to the surface. During horizontal transport, for example to get the gas to shore, the gas will flow faster through the pipe than the liquid does. This difference in speed can cause slugs to form; large plugs of mostly gaseous or liquid materials. Some slugs will grow as they travel the pipeline, evaporate or dampen out and disappear before they reach the outlet.
If large slugs reach the outlet of the installation at the end of the pipeline, it can become overloaded and possibly damaged. A slug catcher can be used to prevent this by catching the slug before it reaches the installation. Mudde: 'Slug catchers are basically big barrels, usually of quite excessive dimensions as the size of the slug is unpredictable. They take up a lot of space, quite often in space-constricted areas such as drilling rigs. It would therefore be worth a lot to the oil and chemical industries if they could prevent, or at least predict, slug formation.'
The Group in Delft owns a 400-foot pipeline that can be used to study the slug phenomenon. Mudde: 'We measure flow speeds, in this case those of a mixture of air and water. When the difference in speed gets too large we start to see waves forming. At a given point the wave amplitude gets so large that the waves touch the top and the sides of the pipe and cause a – temporary – blockage. The pressure from the gas rushing through, however, is so high that this liquid plug is blasted through the pipe at very high speeds. We try to model this process and use the models to suggest measures to prevent slug formation. For example, the application of ridges in the pipe can break up the slug. Again, the designers can use the knowledge we have gained to their advantage.'



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PROF.DR.IR. MARC GEERS – MECHANICS OF MATERIALS
EINDHOVEN UNIVERSITY OF TECHNOLOGY

BRIDGING SCALES

Mechanical properties of materials, like stiffness, strength and damage tolerance, are not simply determined by their chemical composition, but also by their underlying microstructure; the way the crystalline and amorphous phases are arranged, how they are connected and how they deform in relation to one another when the material or product is subjected to strain. Understanding and, more importantly, predicting the behaviour of materials and high-tech products based on this underlying microstructure is the aim of the Mechanics of Materials research group.

'Prediction of the mechanical behaviour of materials and constructs is usually based on conventional testing techniques like tensile, compression, shear or bending tests', says Geers. 'These experiments basically rely on deforming, loading or even breaking individual samples in a commercial testing machine. Those classical tests are widely used in industrial practice to determine strength, stiffness, ductility, resilience, etc. They typically allow engineers to quickly assess the properties of materials as they are used in our day-to-day lives, ranging from sophisticated components in aircrafts and engines to commonly-used domestic devices.

From a materials scienceperspective it is more common to investigate materials using different microscopy methods.'

'In trying to bridge microstructures to properties, we aim to construct a bridge between materials science and the mechanical engineering application of materials', continues Geers. 'In doing so, we established a marriage between mechanical testing and microscopic visualisation, complemented by advanced computational models to achieve the desired predictability.

Our multi-scale lab is equipped with different small test frames that can be used in combination with different microscopic visualisation techniques, like electron microscopy, optical microscopy, atomic force microscopy and 3D micro-CT scanning. The observations and measurements carried out at different scales enable us to translate our understanding in advanced models of the materials studied, in which we integrate the explicit role of the microstructure.'

The resulting models enable predictions that are very interesting for a wide range of applications. One example is the research carried out in the Materials Innovation Institute on Corus' polymer-coated steel, which is typically used in the packaging industry for food and beverage cans. Corus supports its clients by providing detailed models that enable them to simulate the manufacturing process. Geers: 'One of the problems in this process is hidden delamination, whereby the polymer coating comes off the underlying steel layer at a small scale, making the cans vulnerable to corrosion. We are analysing what happens here on different scales, resulting in a numerical model of the delamination allowing us to predict the occurrence and extent of delamination events. With properly determined material parameters, these models can be used in process simulations to improve the process, the product or the material itself.'
Another example, whereby the combination of testing and visualisation has potential is in preventing cracks in paperboard packaging materials. 'It may sound low-tech', says Geers, 'but at a small scale, paper has a rather complex unstable microstructure that raises interesting research questions. 'To make a box from corrugated paperboard, you need to fold it. To do this, the paperboard is creased first along its folding line. During folding, the creased paperboard may present cracks that compromise the integrity of the resulting box. The prediction of the occurrence of such cracks is quite difficult: the underlying paper has an exciting fibrous microstructure, the behaviour of which strongly depends on environmental factors, such as

ERICA COENEN

EINDHOVEN UNIVERSITY OF TECHNOLOGY

'After studying Applied Physics for a year, I switched to mechanical engineering. I needed a more practical approach', tells Erica Coenen (28). 'They started with project-based teaching in Mechanics, which attracted me even more. Initially, I focused on energy technology, but as you progress you also get a taste of other areas of mechanical engineering. Suddenly, it just clicked with Mechanics of Materials. That also became the subject of my PhD, funded by the Materials Innovation Institute.' Coenen kept close ties with real applications in mechanical engineering. 'I research the ultimate deformation of materials as it occurs in many manufacturing processes. The deformation can cause damage; micro-cracks that coalesce towards visible fracture.
The research of one of my colleagues, Cem Tasan, has shown that the starting point of these micro-cracks are often small irregularities and defects in the microstructure, typically formed during the processing of the material. My research is trying to upscale evolving defects and cracks from the microstructural level up to the macro level.
In making this complex multi-scale model, we aim to make predictive statements on the occurrence and evolution of damage at large deformations, as relevant for the respective industrial parties invovled.'
In the case of metals, the occurrence of damage is governed by the applied deformation and the internal microstructure. The latter strongly depends on the prior processing steps, including all thermal and mechanical treatments at the factory and the subsequent manufacturing steps towards the final product. 'To complicate matters even further, the intermediate steps by which the metal is formed into its final shape plays a significant role', tells Coenen. 'This is called the deformation path dependency. Stretching first and bending next may yield a different damage level than the reverse operation, bending followed by stretching. This applies to most sheet metal production techniques, as widely used in the automotive industry.'
Coenen started her PhD in 2007. 'What I like is working on an actual problem: the physical damage that occurs when reshaping materials. In this case, our research is rather fundamental, which fits in my interests. I have always enjoyed science and technology, driven by my curiosity in unravelling how things work.'

temperature and humidity.' The ability to predict the mechanical behaviour based on the underlying substructure or material microstructure is also important for the development of a variety of new products. Examples of such applications can be found in ongoing collaborations with companies located on the High Tech Campus Eindhoven: flexible displays, photonic textiles, stretchable electronics and also rollable solar cells. Geers: 'A new generation of electronic devices and applications are currently being developed by mounting the electronics and wiring on a flexible or even a stretchable substrate. The resulting products are therefore exposed to mechanical forces during their normal service life, which emphasizes the critical influence of their mechanical properties. To determine the reliability and product lifetime, it is important to predict the behaviour of these new generation devices under realistic service conditions, including the role of temperature, humidity, incidental impact loads, etc.'
The mechanical properties of a product are in part determined through the processing history of the material used in making that product. Each manufacturing technique alters the underlying microstructure in a substantial way. Within this context, the Mechanics of Materials research group has developed a reconfigurable computer-controlled discrete die that consists of small discrete pins that can be repositioned individually and automatically in order to give the die various possible shapes in a minimal time. Geers: 'This development was part of a PhD project researching to what extent the microstructure is influenced by different deformation routes leading to the same final product shape. The technique allowed us to validate a fairly complex model for metals that accounts for their evolving mechanical properties. What is quite nice is the fact that the PhD student successfully continued this development in a spin-off company that aims to commercialise and upscale the technique.'
Switching between micro-structural and macro-scale properties is not just important for the materials as such, but also the products they are used in. 'Bridging the fields of mechanics and materials science in a mixed numerical-experimental approach is the way to go', says Geers. 'As a result of the ongoing miniaturisation, products or components therein are made smaller and smaller. At these small dimensions, component sizes are in the same range of the microstructure scales, making the two disciplines inseparable'. The focus on multiple scales and multiple disciplines naturally steered Geers' group in maintaining intensive external contacts: first and foremost the other two universities of technology, but also other universities both within the Netherlands and abroad. Close collaborations with industry are also well in place. Geers: 'Our strength is integrated fundamental research: experimenting, modelling and predicting the behaviour of materials towards products. Our links with industry are indispensable to manifesting a direct practical impact.'

PROF.DR. DETLEF LOHSE – PHYSICS OF FLUIDS
UNIVERSITY OF TWENTE

PANTA RHEI

‘Everything flows’ said the Greek philosopher Heraclitus around 2500 years ago. But what exactly happens when things flow and how macroscopic events like vortices relate to the properties of microscopic particles is the subject of the ‘Physics of Fluids’ research group at the University of Twente. Together with colleagues in Eindhoven and Delft they look at heat transfer and the behaviour of droplets in turbulent streams. This may sound highly theoretical, until you realise that these are phenomena taking place in combustion engines, printers, oceans and clouds.

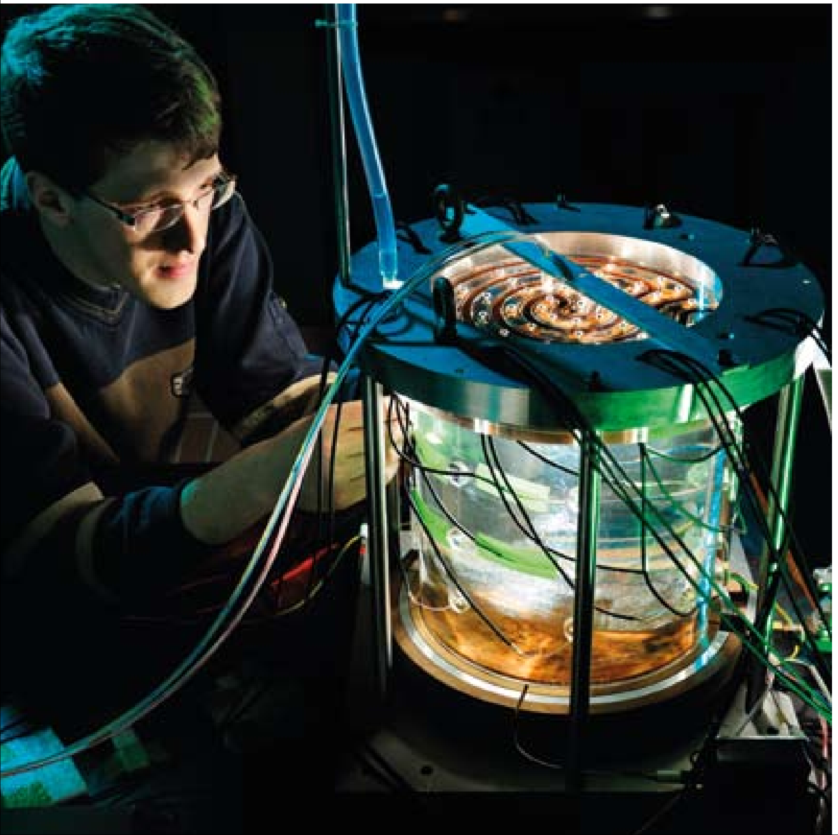
One of the subjects the group of Detlef Lohse studies, together with the Eindhoven University of Technology, is heat-induced turbulence. ‘If you heat a vessel – say a reactor vessel in industry – from the base of the vessel, the heated fluid will rise as it becomes lighter than the colder fluid above it. In reverse, the cold fluid will move to the bottom due to gravitational pull. This results in a lot of, apparently random, convection currents.’

These convection currents can be influenced by rotating the whole vessel around its axis. This creates turbulence: the convection no longer happens in layers – it is not laminar – but moves in vortices. These systems are ubiquitous according to Lohse. As in the Earth’s atmosphere, where the movements of warm and cool air happen turbulently, but also in oceans and even the Earth’s crust, where turbulent convection currents cause the movement of the tectonic plates.

Lohse: ‘In collaboration with the universities of Eindhoven, Rome and California, we have studied how and why heat transfer improves when you heat the vessel from below and spin it round its axis with increased velocity. You can observe the plumes of warm liquid rising and plumes of cold liquid sinking thereby forming a vortex; little whirlpools that get stretched further and further in a vertical direction, thereby drawing liquid away from the bottom as well as the top of the vessel. This results in the heat convection increasing by up to thirty per cent for optimised rotation speeds. We now understand the mechanism and can simulate it on the computer where the flow patterns we calculate fit the experimental data exactly.’

The results lead to a better understanding of geophysical manifestations and can improve the predictive value of climate models, as the heat transfer between the upper and lower layers of the atmosphere forms an important parameter in these studies. The same holds true for the enormous whirls that form when warm and cool currents collide in the world's oceans. Lohse: 'One interesting potential industrial application is separating CO_2 from exhaust fumes in coal or gas-powered power plants.'
Another application of research that may seem rather theoretical at first, but on second inspection poses a lot of practical application, is the study of the behaviour of small bubbles in turbulent streams using two cylinders; one fitted inside the other. The outer cylinder is stationary as the inner cylinder rotates. By measuring the torsion of the inner, rotating, cylinder you can determine how much drag the fluid has on the cylinder. The drag is the force the fluid exerts on the cylinder for a given rotational speed.
Lohse: 'Using a syringe we have injected small air bubbles – about a millimetre in diameter – into the liquid and measured the drag of the liquid. Excitingly, this drag was reduced, or in other words less force was needed to keep the inner cylinder spinning at a given speed. The difference was from eight to – in some cases – twenty to thirty per cent, depending on the level of turbulence. It was known before that bubbles can reduce friction in a turbulent stream, but we were the first to describe the way in which it happens.'
That knowledge could, according to Lohse, be used to reduce the drag ships experience when sailing. 'One could, for example, try to inject micro bubbles at the hull of the ship, allowing them to sail faster or use less energy. Two per cent less drag would mean two per cent less fuel.' Further research, performed together with the Delft University of Technology and the Maritime Research Institute Netherlands (MARIN) showed that just the injection of bubbles-, only has a short-term benefit. Lohse: 'The roughness of the ship's outer wall is most important in reducing drag. If it is very smooth, drag can go down by up to eight per cent. As soon as the wall gets rougher, for example by barnacle growth, the beneficial effect of the bubbles disappears completely. They do not even partly compensate for the increase in drag caused by the ship's rough wall. To be able to utilise the effect of the bubbles – and a lot is to be said for it, due to the need to save energy – we must therefore also look at the microstructure of the metal the hull is made of and to the anti-fouling paints used.'
As well as looking at bubbles in turbulent flows, Lohse's group, together with colleagues in Eindhoven and Delft, has recently started studying the behaviour of drops in turbulent gas flows.

RICHARD STEVENS
UNIVERSITY OF TWENTE



RICHARD STEVENS
UNIVERSITY OF TWENTE

Discovering new phenomena and finding explanations for them. This age-old motivator for many scientists still is as powerful today for Richard Stevens (24). He is studying the phenomenon of convection currents and tries to mathematically describe them. 'Convection currents form when you heat a liquid from below and cool it from the top. The resulting differences in density between the warm and cool water cause the warm water to rise and the cool water to sink.'
Even though this method of transporting heat was already used in Roman times to heat their villas, a lot is still to be discovered. Already during his MSc at the University of Twente in the group of Detlef Lohse, Stevens became intrigued by the question of what happens when you rotate this system. This is not theoretical fancy. 'The influence of rotations on convection currents is of great importance, for example in climate models or to map the Sun's activity. In industry, rotation and heat could be used to separate gases; for example the separation of CO_2 from the exhaust fumes from power plants.'
As part of the 3TU.Federation, Stevens, together with the Fluid Dynamics Laboratory of Herman Clercx and GertJan van Heijst at the Eindhoven University of Technology, is researching the effect of rotation. 'We are building an experimental set-up in Eindhoven, which allows us to spin a liquid-filled cylinder around its axis at different velocities. At very low rotation speeds, not too much happens and the heat is transported through convection currents. If you increase the rotation speed, vortices – small whirlpools – form that are incredibly efficient at moving warm fluids upwards and cold fluids downwards. For the same temperature difference between the plates you have a lot more heat transport than when the system is not rotating.'
Stevens' research looks at not just measuring the heat transport in a rotating vessel, but also simulating it. Using the appropriate mathematical model he hopes to predict where convection currents and vortices will form and how big they will be. This way he hopes to explain previously unexplained phenomena, such as the quick transition from convection-based heat transport to vortex-based heat transport. Stevens: 'To a large extent I am simply satisfying my curiosity, but mainly so this knowledge can be used to better understand natural phenomena and to improve man-made processes.'

The questions posed are of a very fundamental nature, like how drops grow-, or how they join up and break up again. This knowledge is important, for example, in explaining cloud formation as well as for the combustion process inside petrol and diesel engines, where the fuel is injected in a nebulised form. Another application is in inkjets, like those found in printers and copiers. Here the ink flow is converted into miniscule droplets.
Lohse: 'The applications of the physics of fluids are wide-ranging; from clouds to inkjets. What they have in common is that we try to explain turbulent systems on a variety of scales. The challenge is to harness that complex behaviour in a numerical simulation model, allowing the unpredictable to become predictable.'

CENTRE OF EXCELLENCE

SUSTAINABLE ENERGY TECHNOLOGIES

PROF.DR.IR. TIM VAN DER HAGEN
SCIENTIFIC DIRECTOR
3TU.CENTRE FOR SUSTAINABLE ENERGY TECHNOLOGIES

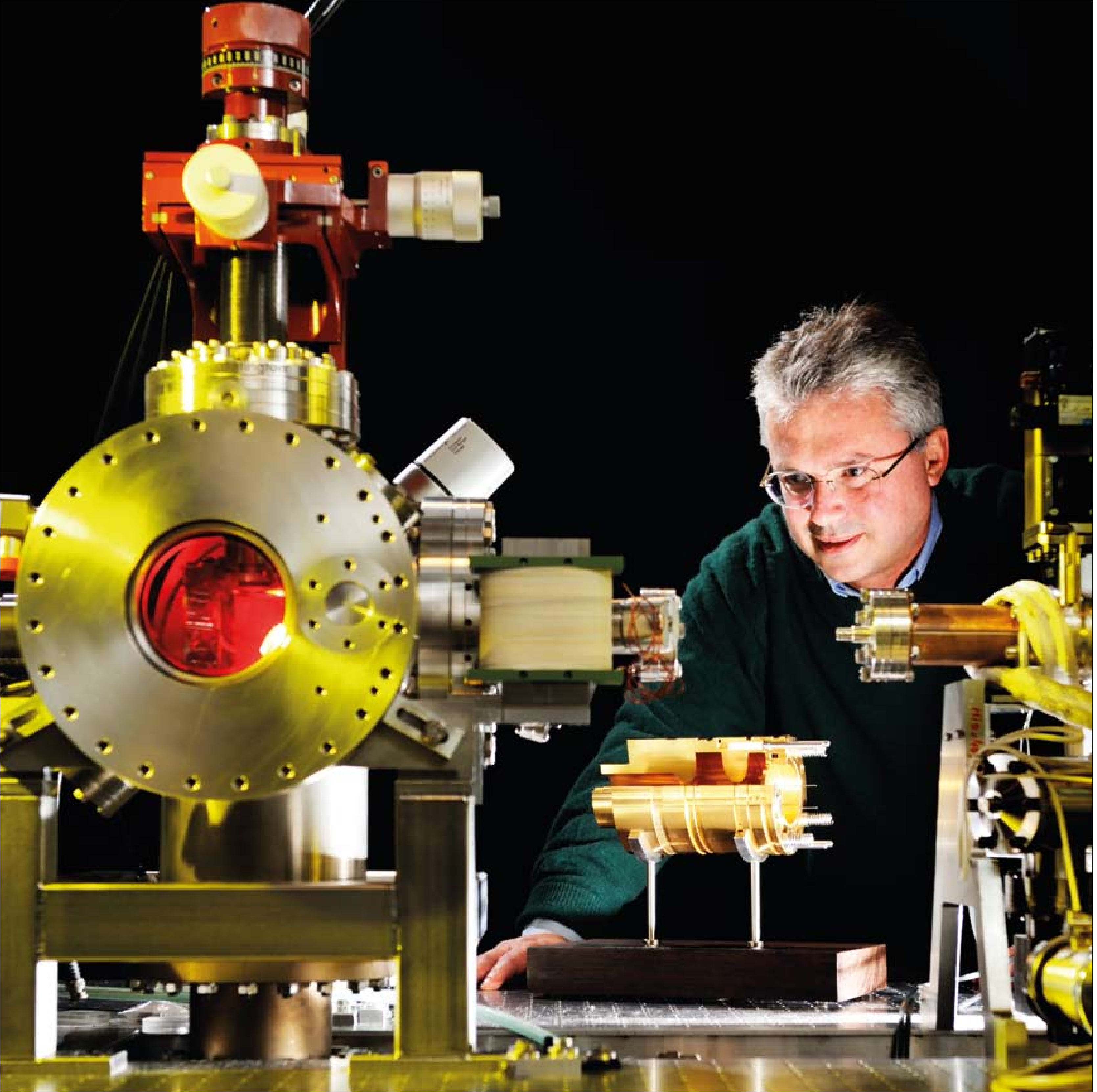
It's a very topical question: what is the sustainable energy source of the future? Will it be solar energy, wind or biomass? And will hydrogen be an important part of the energy mix in the future? In other words, how will we be able to meet the explosively increasing demand for energy while save the environment at the same time.

Unfortunately, nobody yet knows the answers. The fact is that there is quite still not a technology available that will provide an extensive and sustainable energy supply. Fundamental breakthroughs are necessary.

The 3TU.Centre for Sustainable Energy Technologies has therefore set itself the goal of making the entire spectrum of energy sources and storage systems sustainable. Solar cells, hydrogen production, wind energy, storage in batteries, nuclear fission and fusion, refining of biofuels, fuel cells, energy saving... all of them are subjects of the centre's interest and attention.

A lot of scientific research will be required if we are to play a significant role in the coming energy revolution. As universities, we can best do this together. Because none of the universities by itself possesses knowledge about all the possible sustainable solutions. But together we can cover the whole energy supply domain.

The combination of all three universities has many top researchers and professors. The extra effectiveness that gives us has, for example, already enabled us as 3TU.Centre together with ECN (Energy Research Centre of the Netherlands) to set up the large scale ADEM (Advanced Dutch Energy Materials) project. Another significant achievement is the joint Master's programme in Sustainable Energy Technology, which is developing into a highly popular 3TU course.



PROF.DR. LAURENS SIEBBELES – OPTOELECTRONIC MATERIALS
DELFT UNIVERSITY OF TECHNOLOGY

HARVESTING SUNLIGHT

It is a story we all know: the Earth receives more solar energy in a day than 6 billion of us would use up in about twenty years. The question remains, however, how to harvest this solar energy cheaply and efficiently in a form that our society can utilise. According to Laurens Siebbeles, professor in optoelectronic materials at the Delft University of Technology, a lot has already been achieved with conventional silicon solar cells that show an efficiency of around 15 per cent. 'But', he states, 'if we want to meet a much larger chunk of our energy needs with solar energy, cheap and efficient solar cells have to be developed. To realise this, fundamental research into the interaction between light and new materials for the next generation of solar cells is needed.'

The interaction between light and matter and the electrical properties of materials are the research theme of Siebbeles and his group. They do not just look at materials for solar cells. Their research is also important for the development of energy-efficient LED-lamps and FETs (field effect transistors) and so-called nano-electronics.

'Light is made up of photons', states Siebbeles, 'small units of energy of a given wavelength. When one of these photons bumps into a semi-conducting material, like silicon, it can give a kick to an electron in the material. This will convert the electron from a bound to a conducting state where you can extract and harvest it. The electron has a negative charge and removing it leaves a positively charged 'hole'. These holes can also be harvested.'

Even though the present generation of solar cells is far more efficient than the first ones developed in 1946, Siebbeles believes the process can be made even more efficient. 'First of all, conventional solar cells only use a small segment of the light spectrum, only the photons of certain wavelengths. A minimum amount of energy is needed to get an electron from a bound state to a mobile state. If a photon has got too little energy, nothing happens and the photon passes through the material. If a photon has too much energy, then the extra energy is lost in the form of heat.'

As part of the Joint Solar Programme, an industrial partner programme of the Foundation for Fundamental Research on Matter (FOM) with Shell and Nuon, Siebbeles is researching whether the efficiency of solar cells can be increased, for example, by trying to have one photon mobilising more than one electron, so-called multi-exciton generation. An exciton is a combination of an electron and a hole. Siebbeles: 'The American Los Alamos National Laboratory was the first to show that multiplication of charge is possible in quantum dots made of lead selenide.
The phenomenon was later put in doubt, since according to other research groups the effect was much less efficient or was not observed for quantum dots consisting of other materials.'
Last year Siebbeles and his PhD student Tuan Trinh managed to show that multi-exciton generation can indeed take place by the absorption of a single photon in a lead selenide quantum dot. They used photons from a femtosecond laser, which has the ability to shoot light pulses of less than a billionth of a second in length. In order to prevent the unwanted absorption of multiple photons in a single quantum dot, they used laser pulses of very low intensity.
The quantum dots are tiny crystals, a few nanometres in size (a nanometre is a millionth of a millimetre) made up of a few thousand atoms. What is interesting about quantum dots is that their optical and electronic properties are dependent on their size.

ELISE TALGORN
DELFT UNIVERSITY OF TECHNOLOGY

'During my studies, I wanted to save the world. Now, a more scientific interest in solar cells is my main drive. I do, however, still to try to make the world a slightly better place.' Elise Talgorn (27) earned her Bachelor's degree in physical chemistry from the University of Toulouse (F), followed by a special Master in Materials for Energy Storage and Conversion. 'Special' as her and her seven colleagues followed this two-year Master's at five different European universities. This MSc is part of the European ALISTORE research programme, in which fourteen universities are participating, including Delft University of Technology. Talgorn's research is on quantum dots as more efficient and possibly cheaper materials to convert sunlight into electricity. This increased efficiency comes from the fact that the colour of quantum dots can be varied by slightly changing their size. If you can stack several layers of quantum dots with different colours they will absorb the different colours from the sunlight without energy losses. These quantum dot-based solar cells are easier to make (for instance they can be easily ink-jet printed), which would also make them cheaper than current technologies.

Part of her PhD research consists of building a working solar cell based on quantum dots. Talgorn: 'To make a quantum dot solar cell, I first sediment a thin film of nanocrystals on a substrate material. The packing of the crystals is also important: they must be packed very tightly, so the electrons excited by the sunlight can move from one crystal to the next. The electrons have to be harvested as well. At the moment I am trying to find the right materials for this.'
In order to choose the right materials, it is important to figure out what exactly happens inside the quantum dot when it is hit by a photon. Talgorn therefore studies the opto-electronic properties of the material from which the quantum dots are made. Talgorn: 'The combination of, on the one hand, building a working prototype and, on the other hand, studying the fundamental principles of what happens in a quantum dot make this research extra challenging.'

ELISE TALGORN
DELFT UNIVERSITY OF TECHNOLOGY

As part of the 3TU framework, Arjan Houtepen, in the group of Siebbeles, is researching the synthesis of quantum dots to make, what he calls, third generation solar cells. The quantum dots are made by precipitation from a solution. Houtepen has succeeded in making crystals between 2 and 10 nanometres in size. These well-defined crystals will be used to build two and three-dimensional structures. Or, more correctly, they self-organise into these structures.'
Quantum dots have prospects for application in solar cells, tens of nanometres in thickness, that can be applied nearly invisibly to roofs, cars and other surfaces. 'To say that you could spray-paint them onto a wall is probably a tad exaggerated, but we are talking about a new generation of solar cells, which are much easier to make and install in principle and therefore much cheaper than current generations. Again, this is all far into the future; a lot of basic research needs to be done before we get there.'
One issue is how to harvest the mobilised electrons and holes from a quantum dot. In other words: how do you get the current out of a nanocrystal? Siebbeles: 'One of the possibilities is to combine quantum dots with conducting polymers that can act as molecular wires for charge transport. Our research has shown that charges can move along such polymers very rapidly, which would mean we could separate the electron and the hole before they recombine.
At the moment we are building a novel electron accelerator, so we can see in more detail exactly what is happening with the mobile electrons and holes and how we can use this to convert sunlight into electricity.'
It will take a long time before we can expect to see solar cells based on multi-exciton generation in quantum dots. 'It could be ten years, but also fifteen or twenty. We must first learn to control the process of multi-exciton generation and learn to harvest the charges. Once we can do that we have to then design a solar cell that is easily handled and does not degenerate when exposed to air and light. It is very basic research from which we are learning a lot, also for other applications such as LED-lights and novel transistors.'

PROF.DR.IR. EMIEL HENSEN - INORGANIC MATERIALS CHEMISTRY
EINDHOVEN UNIVERSITY OF TECHNOLOGY

FROM WOOD TO PLASTIC

The chemical industry in the Netherlands as well as the rest of the world depends to a large extent on oil. Imminent shortages and growing demand, mainly from up and coming industrial nations, are forcing chemists to look at other, preferably green, source materials. 'Heterogeneous catalysis will play a key role in the conversion of green source materials into useful products', says Emiel Hensen, professor in Inorganic Materials Chemistry at the Eindhoven University of Technology. 'With catalysts, you can convert wood into plastics and liquid fuels.'

Catalysts are materials that, when added in small amounts, can speed up a particular chemical reaction. 'They are used extensively in chemical industry and have', so says Hensen, 'a large multiplier effect. The turnover of the Dutch chemical industry is around 50 billion euros per year. This is largely made possible by catalysts, whose turnover is only a small fraction of this amount. It is therefore not surprising that the Netherlands is one of the leaders in the field of catalysis research. The 'Dutch School of Catalysis' of which the three universities of technology form a key part is renowned worldwide in the field of catalysis.'

The end of catalysis is by no means in sight. Hensen: 'Over the next fifty years the world energy consumption is estimated to double. It is highly unlikely that we can meet that demand using solely renewable resources. The primary task of society now is therefore to use existing fossil fuel sources as efficiently as possible and with as little environmental damage as possible.'

One of the possibilities is to not burn natural gas directly in power plants and in central heating, but to first convert it to hydrogen. The traditional method for this is steam reforming where natural gas (mainly methane) is reacted with steam and, using a metal-based catalyst, is converted to carbon dioxide and hydrogen. The carbon dioxide – a greenhouse gas – could be trapped and stored underground, whilst the hydrogen could be used to generate electricity, for example, by means of a fuel cell.

The process could be made a lot more efficient and environmentally friendly if the carbon dioxide and the hydrogen could be separated straight after or even better during the reaction. The reason being that the starting materials and the products are in equilibrium; by removing one of the products the equilibrium will shift and nearly all of the natural gas will be converted to hydrogen. Hensen: 'Together with the Netherlands Centre for Energy Research (ECN) we are working on a procedure for the simultaneous production and separation of carbon dioxide and hydrogen. The ECN has developed a membrane, whereby the actual reaction takes places within a membrane – a molecular sieve – which allows for the removal of the hydrogen from the carbon dioxide straight after their formation. Using spectroscopic methods we are trying to visualise how the reaction actually happens when using different catalysts. We are especially interested in the role of the structure of the metal nanoparticles on the reaction. The surface structure of these particles has drastic effects on the efficiency of the conversion and the stability of the catalysts.'

As well as using fossil fuels more efficiently we need to consider switching to biomass as an energy source and fuel. This is already happening on a small scale. Ethanol is made from plant starch and diesel from oil-containing crops. Due to competition with plants as food sources, the use of starch and edible oils is not considered sustainable. A lot of research is therefore focused on the use of the inedible parts of plants. Hensen: 'One of the most ubiquitous, and therefore cheapest, green materials is cellulose. It makes up 40 to 80 per cent of agricultural and forestry

MICHEL LIGTHART

EINDHOVEN UNIVERSITY OF TECHNOLOGY

Having grown up in the shadow of the Moerdijk industrial zone, Michel Ligthart (29) has had a love for large chemical plants from a young age. This affinity was further consolidated during his chemical engineering degree at the Eindhoven University of Technology by a study trip to Jurong Island near Singapore, one of the largest petrochemical facilities in the world. Ligthart: 'I did hesitate when it came to doing a PhD because I did not consider myself the researcher type. It was the subject that persuaded me: making a large-scale chemical process more efficient.'

The process he is concerned with is 'steam reforming', a classical petrochemical process where methane is converted into hydrogen and carbon dioxide (CO_2). While the hydrogen is currently being used as a feedstock for a whole range of industrial processes, it is also one of the fuels of the future. Ligthart: 'When you react methane with steam, you can use the hydrogen to generate clean electricity in a fuel cell. The CO_2 could be stored but can also be used as a reagent in other reactions.'

The steam-reforming process currently takes place at high temperatures using a nickel catalyst. Together with the Energy Research Centre of the Netherlands (ECN), Ligthart is researching low-temperature steam reformation. Ligthart: 'We are using a new type of double-walled reaction vessel whose inner wall is a membrane, a sieve, through which the hydrogen can pass but the CO_2 cannot. Removing the hydrogen from the reaction shifts the equilibrium of the reaction, causing it to proceed at much lower temperatures. The nickel catalyst poses problems at lower temperatures, so we are developing a catalyst that is affordable and long-lasting for this new technology.'

Ligthart does the experimental work whilst his colleague, Pieter Grootel, is trying to model what takes place at the metal surface of the catalyst. These theoretical calculations predict what kind of surfaces and particle sizes are needed. Ligthart: 'A combined approach that should result in new mechanistic knowledge and, ultimately, a catalyst for separation-enhanced reforming.'

waste and humans cannot digest it. If you use cellulose as a chemical feedstock or fuel you are not competing with food production.'

A large worldwide research effort focuses on the conversion of cellulose into ethanol using micro-organisms. This ethanol can then be used as feedstock for the chemical industry or as a liquid fuel for vehicles. Hensen: 'We, together with some other research groups, are opting to use catalytic conversion – not microbiological, but chemical – because we think it is more efficient and yields better building blocks (basis of materials for chemical production).'

Chemically, cellulose is converted into HMF, hydroxymethyl-furfural, in two steps – in future a one-step conversion may become possible –using metal chlorides as catalysts. Starting from HMF building blocks can be made for the production of plastics, or for liquid fuels. The efficiency of the conversion lies around 70 per cent which means that this proportion of the cellulose present in the source material, wood or agricultural waste, is converted into HMF.

Hensen: 'We are looking at what exactly is happening during the reaction. It appears that the catalysts 'grab' the glucose building blocks of the cellulose in a certain way and very rapidly converts them to fructose – a molecule related to glucose – followed by a conversion of this molecule into HMF. We can visualise this process using X-rays and other imaging techniques. On top of this, we can use quantum-mechanical calculations to make computer models of the process at the molecular level.'

The goal of all these efforts is to increase the efficiency of the reaction and to improve the quality of the final product, HMF. Hensen: 'Catalysis used to be more of an art than a science. Nowadays, we have reached such a level, however, that we can design catalysts with desired reactivity. For this reaction, for example, we can improve the process by attaching the catalyst to a solid-phase carrier material. The advantage of a carrier is that you can easily remove the catalyst from the reaction solvent, in this case an ionic liquid (a liquid salt), and use it again. A second advantage is that the right choice of solid-phase carrier can increase the surface area on which the reaction can take place, which subsequently boosts reaction yields.'

In 'normal' catalysed reactions, like those used for refining crude oil, zeolites are often used as carriers; a rock-like material that has many small pores, in which the catalyst can attach itself. Hensen: 'The problem with the zeolites that are used as carriers at the moment is that the pores are too small. When you are working with biomolecules, pores in the order of nanometres in diameter are needed (one nanometre is one millionth of a millimetre), whereas the pores of commonly used zeolites are typically below 1 nanometre in size. That is why we are working with mesoporous materials, which have an internal surface of around 1,000 square metres per gram. These materials exist, but it is a challenge to construct them in the right shapes and make them catalytically active. This is building work on a nano-scale.'

PROF.DR.IR. THEO VAN DER MEER – THERMAL ENGINEERING
UNIVERSITY OF TWENTE

PLAYING WITH HEAT

The central theme of the Laboratory of Thermal Engineering is 'playing with heat'. This ranges from the development of efficient methods to convert biomass and waste into useful fuels for producing e.g. electricity to the development of an intelligent reactor that uses heat much more efficiently. Theo van der Meer: 'By using heat more efficiently, we can save a lot of energy.'

One of the research themes is the conversion of waste into oil that can be used in small power plants and ship's engines. This process is called pyrolysis, which is the breaking-down of materials in absence of oxygen. It is a bit like making charcoal from wood, except that in Twente they are using it to produce liquid fuels. This is not a new thing but, according to van der Meer, 'the amazing thing about this process, which is being developed by professor Gerrit Brem, is that the oil produced is exceptionally clean. It does not contain carbon particles and is also less acidic. This prevents complications during combustion. The process can also be performed on a small scale, so you could picture it being used in developing countries to make fuel from waste. This fuel can then be used to run a generator.'

Pyrolysis is especially useful for relatively dry waste streams. Van der Meer: 'For more damp waste streams, like stems and leaves of plants we are developing supercritical gasification technology whereby biomass and water are brought together under such pressures and temperatures that the water becomes supercritical. This means that it is no longer liquid, nor is it gaseous. Under these circumstances the biomass and the water will react to form a gas that is rich in hydrogen, methane and carbon monoxide. This gas is an excellent fuel for a gas motor.'

The group looks not only at making new types of fuel, but also at the burning of them, for example in a gas turbine, furnace or boiler. This study forms part of the nationwide 'Clean Combustion Concept' research programme. Its aim is to develop new concepts in combustion technology that are more efficient and produce fewer oxides of nitrogen. One of these new concepts is flameless combustion. Van der Meer: 'Normally you try to mix fuel and air as

TIMO ROESTENBERG

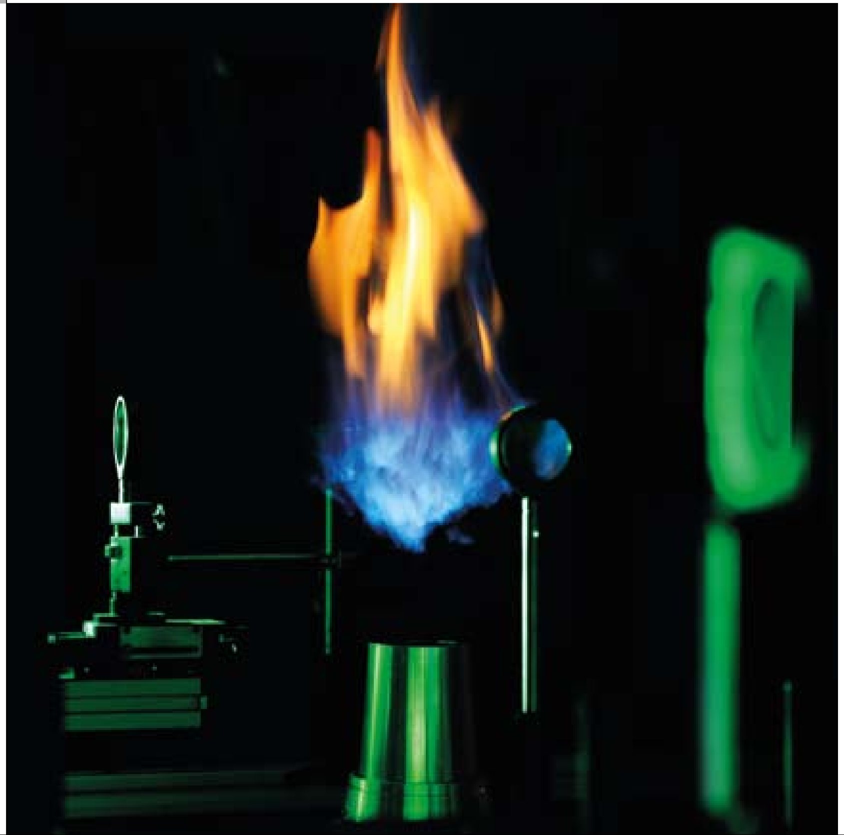
UNIVERSITY OF TWENTE

'If this were to work, it would save the processing industry not just enormous amounts of energy, but also a lot of space. Hypothetically, we could think of converting Europoort Rotterdam into a nature reserve.' It seems near impossible for Timo Roestenberg (26) to curb his enthusiasm for his PhD project: a new type of reactor in which chemical reactions proceed so rapidly that it needs to be roughly the size of a moped engine to still have an enormous production capacity.
'It works a bit like an engine', Roestenberg tells us. 'Inside a cylinder, a free-moving piston moves up and down. This creates very high pressures alternately in the upper or the lower cylinder chamber depending on the position of the piston. This causes the temperature to rise rapidly, the so-called bicycle pump effect. Reactions in the compressed chamber then occur within a few thousandths of a second. Where current systems are big and slow, this reactor is superfast and very small. So fast, in fact, that you need to deliver the reagent streams at nearly the speed of sound to keep up with the reaction.'

It could still be a while before a chemical factory the size of a container (reactor plus supply systems) becomes reality. Roestenberg: 'My research is aimed at the thermodynamics and heat transfer of the reactor. You can imagine that the materials begin to expand when temperatures rise this quickly. If this expansion is different for the cylinder and piston, it can result in a leakage, or the piston getting stuck. If we know more about the thermoregulation, we can design the reactor in such a way that this is prevented.'
Roestenberg, who obtained his Master's degree in mechanical engineering, did not hesitate one moment when he was asked about this PhD position. 'The group is good, the people are nice and – not unimportantly – I get to work on and study this revolutionary design. What may be the most fun about the project is that I get to collaborate with the inventor of the reactor. He is from Russia and is the true inventor type: 100 ideas a day. His drive and my Dutch 'down-to-earth' mentality are a perfect combination.'

efficiently as possible to generate a stable flame. Inside the flame, however, pockets of extremely high temperatures will form. Because the main component of air is nitrogen, nitrogen oxides are formed in these pockets. If you want to prevent them forming you need to prevent these localised areas of high temperature.' The most obvious way to achieve this is not to mix the fuel and air well. This would prevent the pockets of high temperature from forming, in which the nitrogen oxides are formed. A disadvantage is that the combustion becomes incomplete. Van der Meer: 'This can be circumvented by heating the air that you are blowing into the fire so high that the air and fuel react with each other without a flame forming: flameless combustion, which still leads to the fuel being completely combusted.'
The research consists of a detailed analysis of what exactly goes on in the combustion chamber and of what intermediate and final products are formed and at what stage. This is done by LASER-induced fluorescence, as well as other tools. Van der Meer: 'The basis of the experiment is the beaming of LASER light onto the molecules. This gets them in an excited state of energy. When they fall back into their normal state they send out light with a wavelength specific to the molecule in question. If, at the same time look at the scattering of the light with Raman spectroscopy, then you can measure all components in the mixture in only a few nanoseconds.' These measurements are the data used by detailed computer models of the combustion process. Those models in turn are used to optimise combustion processes and develop new ones.
Another line of research focuses on heat transfer in stationary systems. A recent example is ADEM,

the Advanced Dutch Energy Materials Innovation Lab, a large research collaboration between the three universities of technology (3TU.Federation) and the Energy Research Centre (ECN). One of the themes within that programme is the development of an improved heat pump. Van der Meer: 'In order to improve heat transfer, we are developing a coating made of carbon nano-fibres; tiny hairs between 2 and 10 micrometres in length and with a diameter of 60 to 100 nanometres. They significantly increase the surface area, which leads to a marked improvement in heat transfer in the regenerator of a heat pump. The burning of gases in a gas turbine can lead to problems due to vibrations. Van der Meer: 'A fire always rages as a result of the thermo-acoustic effect, which can give fluctuations in pressures ranging from a few tenths of a bar to half a bar. These vibrations are so large that they can cause the wall of the combustion chamber to rupture. It was first observed in the Netherlands about fifteen years ago in a power plant where coal gasification was used. Here a mixture of hydrogen and carbon monoxide is used mixed with air. The problems presented here formed the basis of our very successful research programme. It has produced quite a few PhDs over the years.'
Another project focuses on improving the heat transfer inside a chemical reactor. An interesting spin-off of this project is a new type of reactor, which slightly resembles a combustion engine. The reactor consists of two cylinder chambers separated by a free-moving piston. Van der Meer: 'Using a number of different valves, the reagents are introduced into the cylinder chamber. The piston goes up and the pressure rises to a few hundred bars. At the same time the temperature goes up to a few thousand degrees. As the chemical reaction progresses, the piston is pushed back down allowing the reaction in the other cylinder chamber to progress. The big advantage is that the energy released in one reaction is efficiently transferred to the other reaction. Hardly any heat is lost to the surroundings. The high temperatures and pressures in a small area cause the reaction to proceed very efficiently. The piston moves up and down with a frequency of 200 Hertz, so it sounds like a car engine running.'
The proof of principle of this new type of reactor was succesful and further development is being carried out by a spin-off company. Van der Meer: 'Certain problems arise during the execution, which are partly based on the lack of knowledge of the thermodynamics at the extreme pressures and temperatures found in the cylinder chamber. Together with the inventors we are researching heat maintenance in the reactor. This is important in choosing the materials for the piston and cylinder. It is essential to prevent the piston getting stuck as a result of a difference in the expansion of the cylinder and the piston. This is vital as no lubricants can be used because these would disrupt the chemical reaction.'



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