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TU Graz research

Research Journal of Graz University of Technology

TU Graz
SCIENCE
PASSION
TECHNOLOGY

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Dear colleagues and research partners, and everyone interested in our research,

April showers bring May flowers! With this adage in mind, we have given TU Graz research a makeover. You are looking at the first edition of the new-look publication – either in print form or the digital version for your PC, tablet or mobile. The aim for the relaunch is to give you even more fascinating insights into the world of science at TU Graz. You can read about our latest research findings, watch a video on our new Laboratory for Innovation facility at Campus Inffeldgasse or experience how the new ZombieLoad attack works. We want to use these multimedia options to take you even further inside our labs, workshops and offices, where our researchers are doing outstanding scientific work. And feel free to recommend us to others – they can subscribe to the magazine on our website.

Horst Bischof
Vice Rector for Research
Source: Oliver Wolf

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A FEW LINES OF CODE WITH SERIOUS CONSEQUENCES

Besides reports and project descriptions from our Fields of Expertise (which are now available in English only), the magazine section in each edition will be devoted to a particular topic. This time, we focus on cybersecurity, a field that is increasingly becoming vital in many sectors. We have a group of excellent researchers working on this subject, and their list of successes is too long to be included here in full. This expertise was one of the main reasons why SGS decided to build the Cybersecurity Campus here in Graz. When completed, it will create high-tech jobs for 400 people specialising in certification for the Internet of Things (IoT) at Campus Inffeldgasse. A research centre sponsored by SGS and operated in conjunction with TU Graz will be set up in the same building. This will enable us to achieve critical mass and raise our profile on the international scene. In my view, this is a great example of how crucial basic research is, one which in turn shows that such research will drive our economic development in future.

I hope you enjoy reading this edition of TU Graz research, and I wish you and your families a relaxing summer.

Publication details: Owner: TU Graz. Publisher: Vice Rector for Research. Editor-in-Chief: Birgit Baustädter, Communications and Marketing, Rechbauerstraße 12/I, 8010 Graz. E-Mail: TU-research@tugraz.at Design/layout: Christina Fraueneder, TU Graz. Printing: Klampfer Druck. Print run: 1,000 copies. Our thanks to the authors for providing the texts and photos. The editors reserve the right to make minor changes. Cover picture – source: Core-DESIGN – AdobeStock.

ISSN 2664-1712. www.tugraz.at/research-journal

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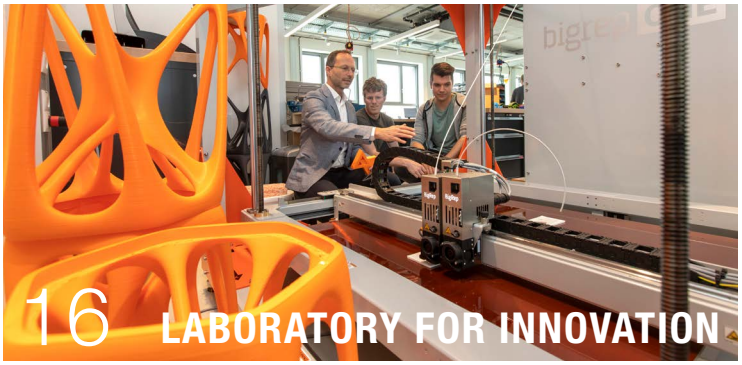

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Battle of the Neuro-Assistance Systems

When users control computer figures with their thoughts, it becomes clear how far research on brain-computer interfaces (BCI) has advanced.

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What is Security in the Digital Age?

With several billion devices forecast to be connected by 2020, security is increasingly becoming a topic of public debate and attracting more and more attention in research circles. Who can listen in on the voice commands that control a smart home? Who is able to unlock a car that has just rolled off the production line? Can someone take control of new production equipment in a networked factory remotely?

Source: Lunghammer – TU Graz; 4: oatawa – AdobeStock

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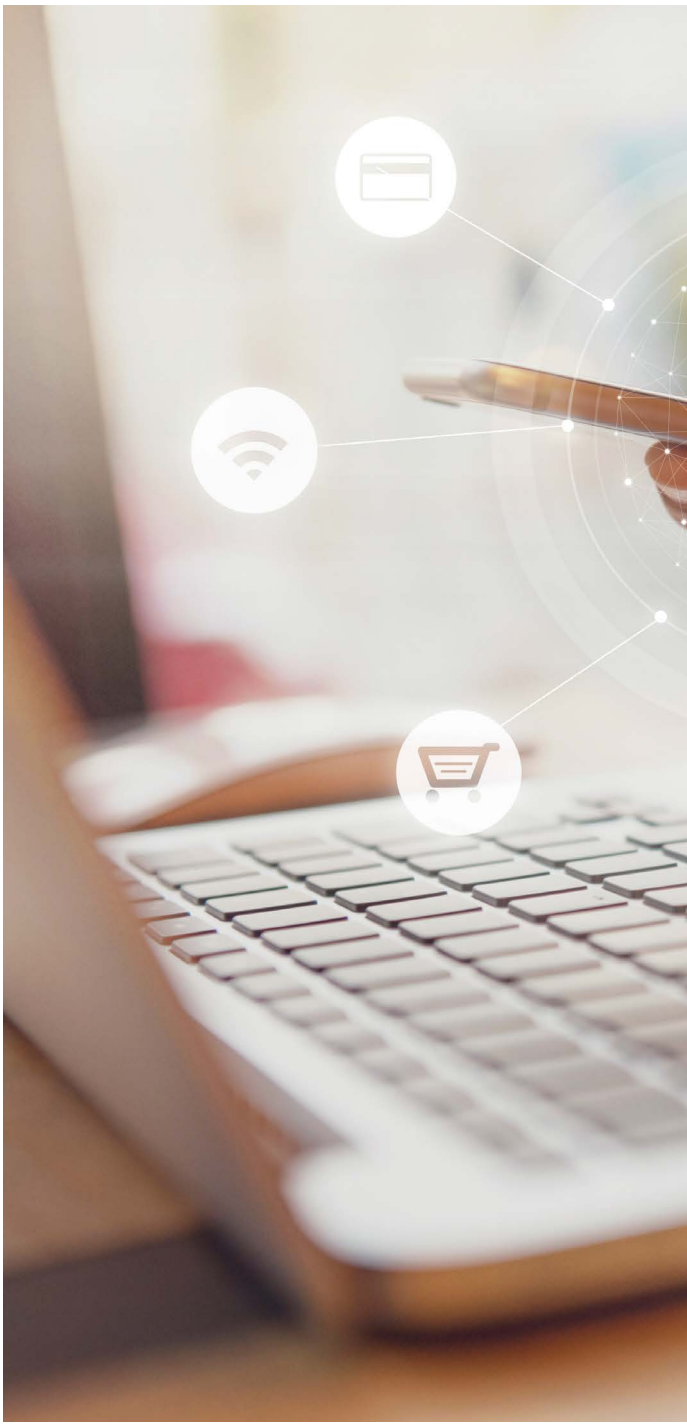
"This isn't the time to rest on our laurels"

Stefan Mangard will be responsible for the research agenda at the new Cybersecurity Campus Graz from 2019.

What is Security in the Digital Age?

With several billion devices forecast to be connected by 2020, security is increasingly becoming a topic of public debate and attracting more and more attention in research circles. Who can listen in on the voice commands that control a smart home? Who is able to unlock a car that has just rolled off the production line? Can someone take control of new production equipment in a networked factory remotely?

Birgit Baustädter



"Play my afternoon playlist!" It's a harmless request you might often use in the familiar and increasingly networked surroundings of your own four walls. Living spaces are now kitted out with more and more smart devices connected to the internet, and the automotive sector, the health service, banks and industry are likewise becoming increasingly networked.

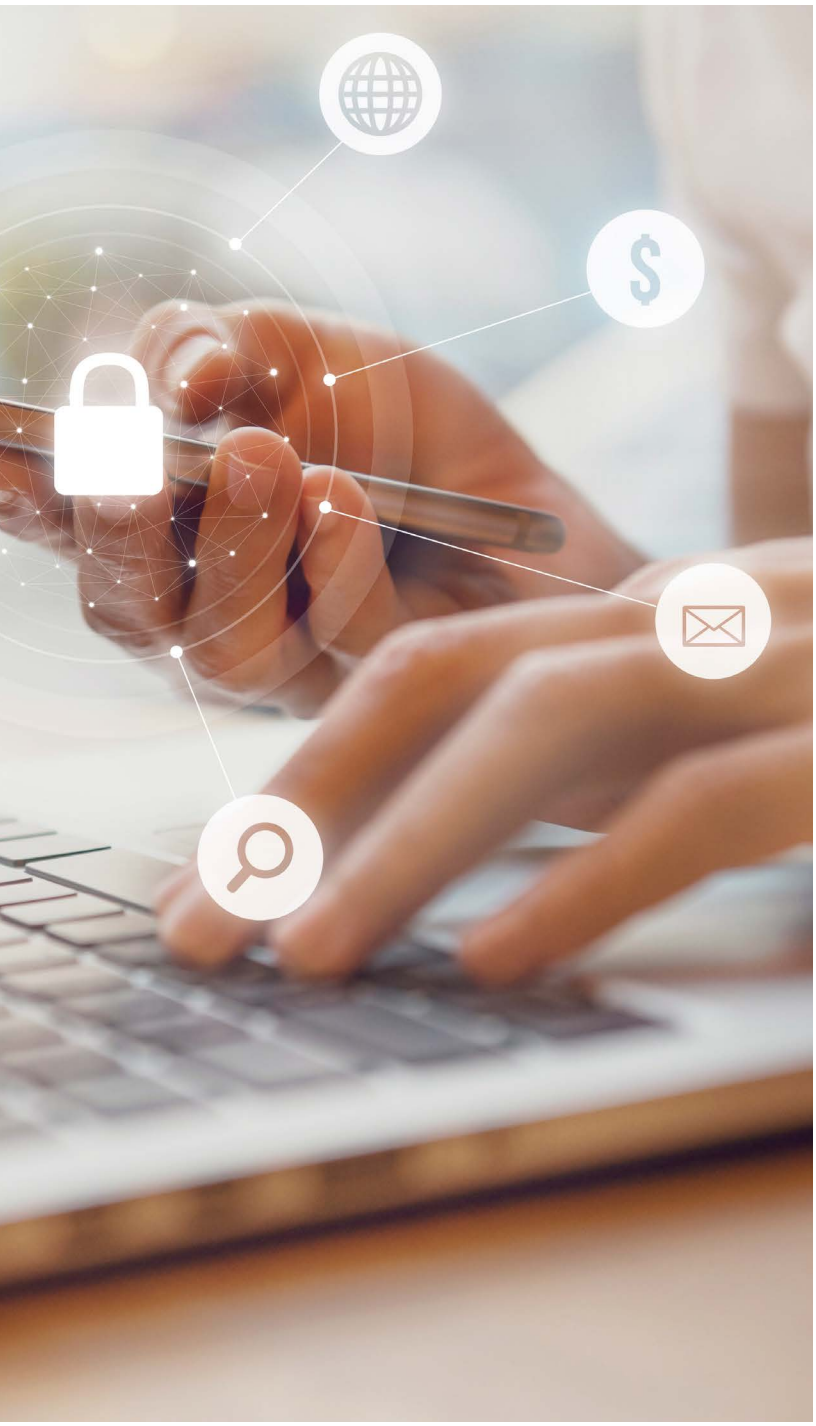
> **Cryptography is the basis, the foundation of all forms of security.**
>
> Christian Rechberger

Too often, we know little about who sees and uses the data that we inevitably generate. But we put our faith in them. We believe that devices are protected against disruption and unauthorised access, and that our data are only seen by people who have the necessary authorisation. That intruders cannot access highly personal aspects of our lives or critical infrastructure.

"But the reality is different. Once data are stored on an international server in the cloud, you lose control over them," explains Christian Rechberger of the Institute of Applied Information Processing and Communications at TU Graz. "We look at it differently from the technological side – it's certainly possible that users can keep control over their data and still benefit from full functionality and cloud services."

SECURE SYSTEM ARCHITECTURE

The more interconnected our world becomes, the more important it is that such connections are secure. Academic research has only just begun to address the idea of cybersecurity over the past few years. And over the last couple of years this topic has come under greater public scrutiny. The discovery of the Meltdown and Spectre security vulnerabilities by an international team which included Daniel Gruss, Moritz Lipp, Michael Schwarz and TU Graz professor Stefan Mangard stoked people's awareness of security.



More and more smart objects are playing a part in everyday life.
oatawa – AdobeStock

"At the end of the day, we'll never be able to make things absolutely secure," says Stefan Mangard, who also heads the Secure Systems Working Group at the Institute of Applied Information Processing and Communications. "But we can take security to new levels by focusing on the way we build computer systems." At the moment, security researchers are in a race against attackers – once a security flaw appears, it needs to be patched up as quickly as possible. "Besides playing cat and mouse, which is due to the way current systems are set up, we're also working on new types of system architecture. Our goal is to make them immune to a particular type of attack in the first place."

As part of the Sophia project, which is funded by the European Research Council (ERC), Mangard and his team are looking at ways to make computer processors secure, as well as analysing unintended opportunities for access and closing off any back doors they find. "It's always a bit of a balancing act – improved security usually goes hand in hand with poorer performance," Mangard explains. The Meltdown and Spectre vulnerabilities were discovered in the course of this project. Cyberattackers take advantage of the fact that a processor pre-empts and prepares processing steps, such as accessing certain data, before access rights have even been verified, for instance. If the user does not have the necessary rights, the prepared data are discarded. A computer does this so that it can work more quickly. But it also has side effects, like time lags, which attackers can take advantage of under certain circumstances in order to identify confidential information. Although the patches released at the same time as details of the two vulnerabilities made computers more secure, they also made them slower.

"One of the biggest problems with security is that it's so hard to quantify," Stefan Mangard points out. "If my PC starts running more quickly or slowly, I notice it straight away. But when I invest in security, subjectively speaking I don't notice any difference to begin with, or at most a drop in speed."

CYBERSECURITY CAMPUS GRAZ

This is where the new Cybersecurity Campus Graz comes into play. Over the next few years, TU Graz will build a cybersecurity research, teaching and certification centre at Campus Inffeldgasse in collaboration with well-known international certification company SGS. Stefan Mangard will be responsible for the centre's academic focus and is currently looking at topics and projects that will be included on the facility's research agenda. "The Cybersecurity Campus should serve as an interface between basic research and industrial application." >

! For further details on Cybersecurity Campus Graz, turn to page 10.

IOT: MINI-COMPUTERS

Cybersecurity Campus Graz will focus on future challenges – primarily the Internet of Things (IoT), which is posing new questions for security research due to the miniature computers it comprises. "We're talking about billions of computers worldwide that you can't even see – in light switches, light bulbs and smartwatches," comments Professor Christian Rechberger, head of the Cryptography Working Group at TU Graz's Institute of Applied Information Processing and Communications. In computers the size of a fingertip, like those built into smartwatches, every last millimetre of storage space is hotly contested, and also pricey – who would want to wear a smartwatch that is a few centimetres thick? "The challenge is guaranteeing security, but at the same time it has to cost next to nothing," Rechberger explains.

He is addressing this challenge by means of new approaches to cryptography – one of the most powerful tools around when it comes to making computer systems secure. Using mathematical methods, data are encrypted and protected so that they cannot be intercepted or tampered with during transmission. "Cryptography is the basis for all forms of security," Rechberger explains. "If the basis isn't secure, anything built on it won't be secure either."

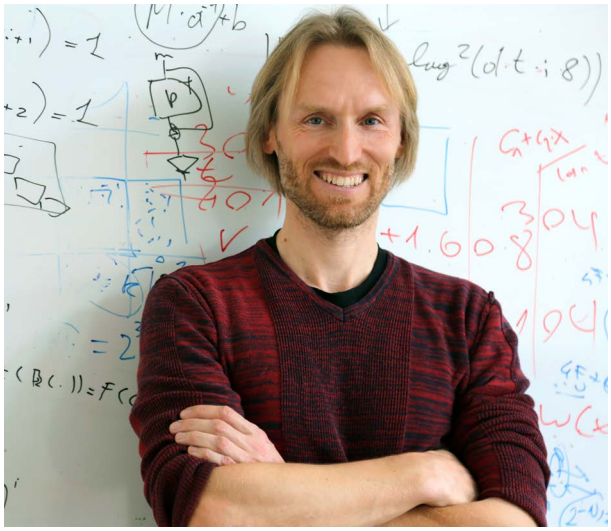
Another international success has just been achieved in the field of cryptography: a team including Maria Eichlseder, a postdoctoral researcher in the field of cryptography, won an international competition with ASCON, a bundle of algorithms that was recommended as the top solution in the lightweight applications category. Lightweight algorithms are processes that run with the minimum possible resources.

> **Security means that it is not a question of luck whether a system works as expected, but that you can rely on it.**
>
> **Maria Eichlseder**

Reinhard Posch oversees the Institute of Applied Information Processing and Communications. An expert on security, he is Chief Information Officer for the Austrian federal government and sits on a committee that coordinates the IT plans of the country's federal provinces and ministries. He played a central role in the digital signature project and other initiatives related to e-government.

The institute's working groups focus on:

- core security (head: Daniel Gruss)
- cryptography (head: Christian Rechberger)
- e-government (head: Arne Tauber)
- Java security (head: Peter Lipp)
- secure systems (head: Stefan Mangard)
- systematic construction of correct systems (head: Roderick Bloem)



Left: IT specialist Christian Rechberger describes cryptography as the "basis of all security".
Source: Baustädter – TU Graz

Right: Maria Eichlseder builds successful encryption algorithms.
Source: Lunghammer – TU Graz

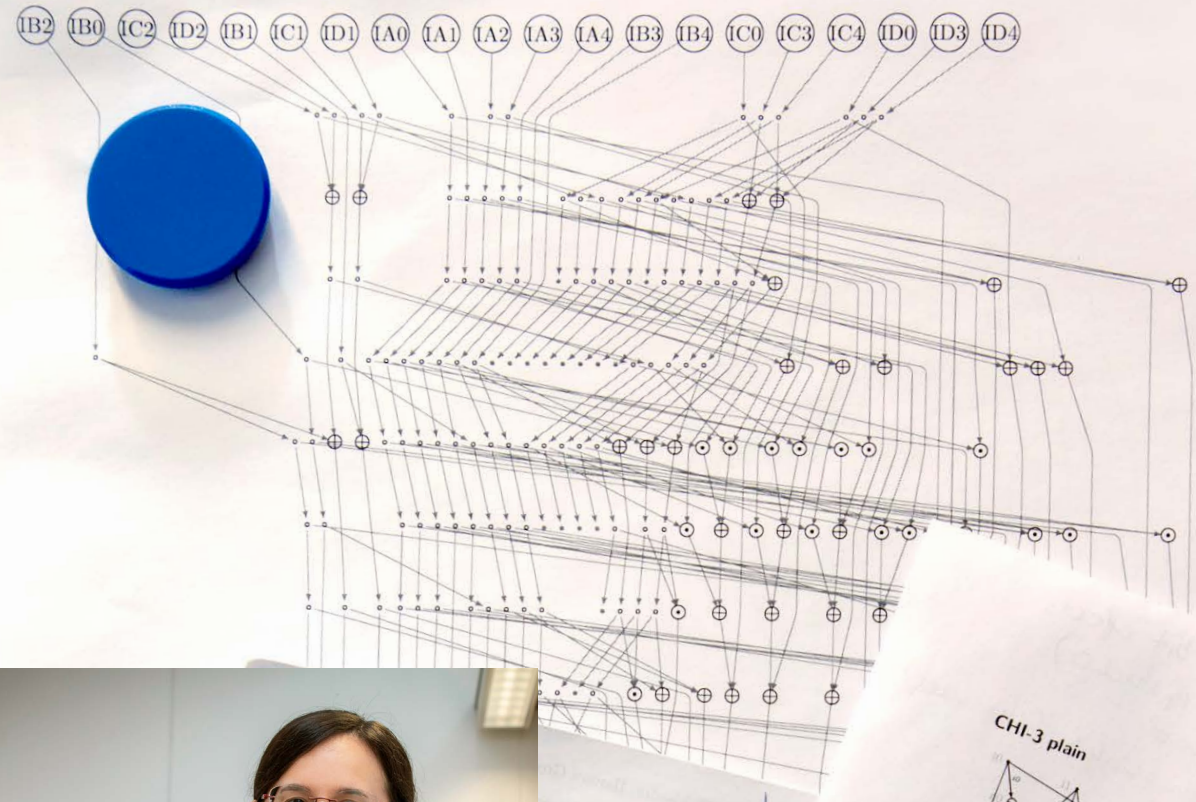
Speaking of this approach, Rechberger comments: "On the scientific side, we ask ourselves what is the smallest number of calculations that we can just about work with and combine intelligently to make the chips secure."

ARTIFICIAL INTELLIGENCE AND QUANTUM COMPUTERS

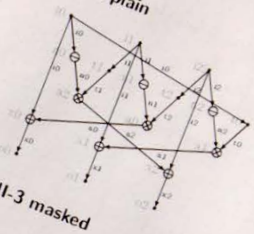
Besides the Internet of Things – which both Mangard and Rechberger believe will be the focus of attention in years to come – other new developments are posing challenges: artificial intelligence and quantum computers.

"From a research perspective, artificial intelligence is a tough nut to crack," Mangard points out. "Learning algorithms are getting better and better, but even the slightest manipulation of the data can throw them totally off-kilter. When artificial intelligence becomes much more widespread than it is today, that could be a big problem." Rechberger gives us the data-protection viewpoint: "Artificial intelligence needs to be fed masses of data. But is it really safe? And does it safeguard privacy? We're now working on a way of providing learning algorithms with encrypted data effectively, and without affecting their learning capabilities." >

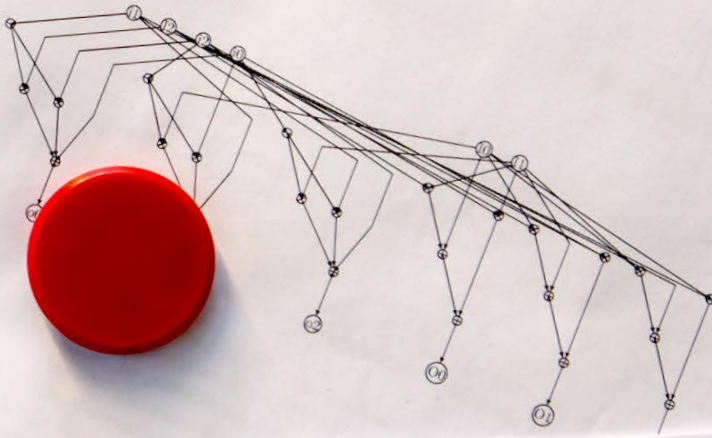
CHI-5 Uniform, reusing gates, sanitized with sinks



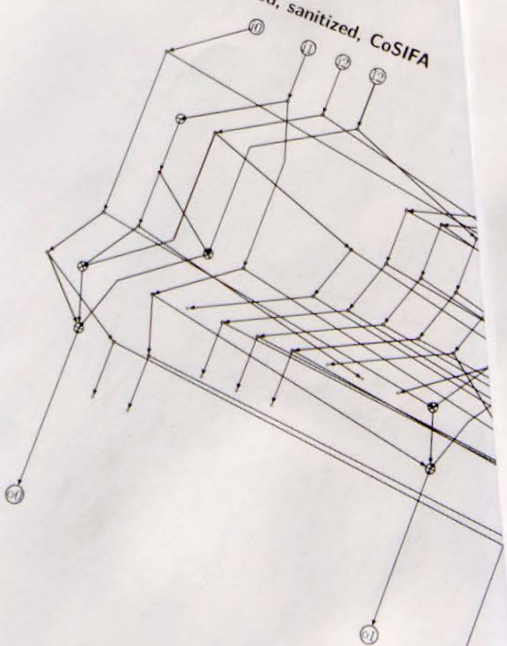
CHI-3 plain



CHI-3 masked



CHI-3 masked, sanitized, CoSIFA



4. Security Analysis

enhance security analysis with existing thir
about florians zero-sum distinguisher for 12

maybe get rid of analysis and only refer to

4.1. Basic Properties

In this section, we give some known prope
ble 14 in Appendix A shows the differenti
and output differences. As can be seen in th
ability of the S-box is 2^{-2} and its different
the biases of the linear approximation defi
masks. The maximum linear probability
number is 3.

Let x_0, x_1, x_2, x_3, x_4 and y_0, y_1, y_2, y_3, y_4 be
where x_0 refers to the most significant b
Then the algebraic normal form (ANF)

$$y_0 = x_4x_1 + x_3 + x_2x_1 +$$
$$y_1 = x_4 + x_3x_2 + x_3x_1$$
$$y_2 = x_4x_3 + x_4 + x_2 +$$

CHARTER OF TRUST

At the Munich Security Conference in early 2018, nine organisations signed the Charter of Trust – a declaration of their intent to carry out more detailed research on cybersecurity. By 2019, the group had grown to 16 members. This year also saw TU Graz become the first university partner of this international initiative to enhance security in the digital age.

Quantum computers still only exist in theory – but many people predict they will have a bright future. Thanks to their revolutionary means of processing, they will be significantly more powerful than all known types of computer system. The major benefits they generate for users could cause even bigger headaches in terms of security. “The methods we are using now are based on the fact that although they can be cracked using current forms of computing, it would take several billion years to do so,” Rechberger explains. “But quantum computers could manage that fairly quickly.”

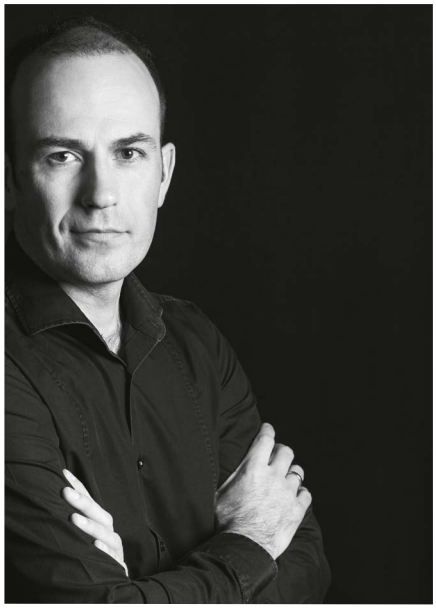
His team submitted two entries for the post-quantum cryptography competition currently being run by US certification body NIST. This competition aims to single out signature, key exchange and encryption procedures that can withstand attacks from quantum computers. Both of the signature procedures, Picnic and SPHINCS+, were named as candidates for the second round in February 2019.

SECURITY AND SAFETY

“The topic of security takes on a new dimension if you introduce safety aspects,” says Stefan Mangard. Security is all about protecting systems against attackers. Safety, though, is a matter of safeguarding people’s health against the consequences of defective computer systems. Safety is a core competence of the Institute of Technical Informatics. The Working Group Industrial Informatics under Georg Macher focuses primarily on safety in industrial applications. Here, too, cybersecurity – from cryptography to side-channel attacks and authentication, and combinations of all three – is an increasingly important topic. Researchers are devising a holistic development approach and engineering processes.

The automotive sector provides an interesting example. “Today, vehicles are already highly networked, which means they offer more and more points of attack. There is virtually no other sector where the importance of the interplay between safety and security is becoming so clear,” explains senior scientist Macher. The most striking example of this is electronic steering locks. “If the locking system is not sure whether to activate the lock or not, there are two ways of looking at it: in terms of system security, it’s better to lock the steering wheel as a precaution. If the system doesn’t do this, the car could become a target for thieves and will be left virtually unprotected in the parking space. From a passenger safety point of view, it’s better not to lock the steering wheel. Someone

> **Nothing is 100% secure. We make it as difficult as possible for attackers.**
>
> **Georg Macher**



The world is becoming increasingly convenient thanks to the Internet of Things. Contactless payments, home automation, autonomous driving and smart factories are just a few examples. New mobile communication standards allow faster interaction between devices, which enables new use cases.

Martin Schaffer
Global Managing Director for Secure Products & Systems, SGS Digital Trust Services

Source: alex.

Consumer products are flooding our markets with very few restrictions when it comes to IT security. Currently, almost no regulations or legislation is in place which addresses this issue. The challenge here is complex, as security cannot be dealt with at one single stage: devices need to be designed securely and remain resistant against attacks throughout their life cycles. This means devices need to be updatable in order to respond to new developments and forms of attack. This in turn requires the availability of backend systems offering corresponding services and secure communication channels between devices and the backend. And even if it is possible to

could be driving the car at that moment and a malfunction could be the reason for the uncertainty in the locking system. So in this case, the steering wheel has to work normally."

In order to create fully functional, secure systems for everyday driving situations and day-to-day factory operations, Macher and his colleagues are focusing on systematic dependability-by-design approaches, which deliver both safety and security. These approaches are partly based on cryptographic primitives that Mangard and Rechberger developed in the neighbouring institute. "Our focus is on devising a secure, comprehensive design and development process for critical industrial systems. Safety and security are important aspects of the overall development, and we've incorporated them into two projects, HyUnify for hydropower plants and MEMCONS for the automotive sector. The system's reliability is not just a matter of developing new technologies, but applying them correctly, a critical mindset among the developers when it comes to security, and the availability of a corresponding development process. Safety and security engineering isn't all about technology, it's a way of life."

> **Our goal is to ensure that security is a given without having to constantly take care of it as a user.**
>
> **Stefan Mangard**

In addition to developing systems that can be implemented in practice, Macher is also thinking about the future of the automotive industry. Launched in 2018, researchers on the Drives project are coming up with visions of what the industry will look like in 2030, as well as outlining new, additional fields of activity and the qualifications and training required by tomorrow's professionals. "One new occupation that will definitely emerge is that of automotive cybersecurity engineer, and that's something we need to prepare our students for. Knowledge of security or the industry alone isn't the key. We need 'T-shaped' developers who have both in-depth general know-how and extensive detailed knowledge," Macher explains.

WHEN SECURITY IS NO LONGER A CONCERN

So the future will pose more and more challenges, each one different from the last, for the security of computer systems and for the people who use them. Stefan Mangard sums up the aim of current research efforts: "Our goal is to ensure that security is a given without having to constantly take care of it, by installing updates for example. But as long as we still have to do that, our solutions aren't good enough. This isn't the time to rest on our laurels. In fact, our work is only just beginning." ■

Georg Macher focuses on the interaction between safety and security
Source: Baustädter – TU Graz

provide secure solutions, how can we be sure that they are properly implemented, configured, deployed and operated?

One way to stop unsecure products entering the market is to implement corresponding legislation, standards and conformity assessment, as in other areas which impact on our day-to-day lives. Cars need to pass crash tests, new types of drugs need to be approved, children's toys are subject to safety checks, and electrical systems must undergo conformity tests – the list goes on. The criteria for conventional conformity assessment are quite static. Physical laws do not change, i.e. a day after a certificate has been released, repeating the test usually results in the same outcome. This is not the case when it comes to cybersecurity. The forms of attack are changing all the time. What is state-of-the-art today may no longer be tomorrow.

Conformity assessment therefore needs to undergo a revolution in response to these new shifting circumstances. This is the reason that SGS set out on its search for a strategic research partner, which it found in TU Graz, and we have collaborated to launch the Cybersecurity Campus Graz. TU Graz has a strong focus on exploring new architectures and concepts to ensure the long-term security of future technologies, and SGS brings expertise in verifiable security throughout the life cycle of a product or system. Soon, everything will need to be continuously checked for resistance against attacks, in ways which are efficient in terms of time and costs. This will require the design of new technologies using methods which are both secure and efficiently testable. It will also require feasible new approaches to testing, inspecting and certifying products, systems, infrastructures, operators, services and cloud solutions.

The Cybersecurity Campus Graz is a great environment in which to join forces to work on disruptive solutions, and invite partners from industry to cooperate and contribute. ■

Security researcher Stefan Mangard is working to boost security in networked systems.
Source: Lunghammer – TU Graz

“This isn’t the time to rest on our laurels.”

The topic of security is only just starting to become truly significant, says security researcher Stefan Mangard. Mangard is working on the ERC project Sophia, where he is concentrating on secure computer processors. In 2018, as part of an international team, his working group discovered the Meltdown and Spectre security vulnerabilities. He will be responsible for research at the new Cybersecurity Campus Graz from 2019.

Birgit Baustädter

Cybersecurity Campus Graz

SGS, the world leader in inspection, testing, verification and certification, and TU Graz, a top IT security research institution, have joined forces to set up Cybersecurity Campus Graz. Researchers at the cybersecurity centre will address key questions in three core subject areas: research on analysing system security and on fundamental new security concepts; education for IT security experts and researchers who are in such strong demand; and testing and certification of product and system security. The Campus will also open its doors to start-ups as well as industrial and scientific partners.

Results from the centre’s basic research will be made available to all. Training and joint projects will also promote the transfer of knowledge from scientific research to industry.

In addition to SGS’s investment in the research centre, the group will also base its subsidiary SGS Digital Trust Services GmbH at Cybersecurity Campus Graz. ■

TU Graz *research*: Is it even possible to make a system secure?
Stefan Mangard: It’s easy to feel a sense of resignation at the major flaws that come up time and again. Why should I invest in security when everything is being hacked anyway? Isn’t it enough to react quickly and patch up any flaws? No! I don’t think that’s sufficient. In the area of security, there is no time to rest on our laurels. For us it’s only just the beginning.

In what areas is this topic particularly important at the minute?
Mangard: The Internet of Things is posing some major challenges. More and more sectors are working on networked products, but often they don’t have the comprehensive security expertise they need. We have to offer these companies easy-to-handle and secure systems from the ground up that don’t have to be configured and secured first.

What is security’s biggest enemy at the moment?
Mangard: Our biggest problem is that we can’t measure security. I can invest heaps of money and still not have the feeling of really having gained anything. If you make a system faster, for example, that’s very easy to measure. In our field, we always need pressure from the market before we actually implement new technologies across the board.

Does that mean every major hack brings you a step closer to creating a secure world?
Mangard: Yes, because that creates awareness that something needs to be done. There might be some very good technological solutions out there, but they’re often not used because people think they are unnecessary.

What’s your personal approach as far as cybersecurity is concerned?
Mangard: As a researcher I am more sensitive and more careful about what apps I install and how they use my data. But at the same time I’m aware that my mobile and PC aren’t perfect. ■

Only a few lines of code can cause big problems: this is how ZombieLoad works.
Source: Lunghammer – TU Graz

A Few Lines of Code with Serious Consequences

In 2018 they discovered the serious security loopholes Meltdown and Spectre as part of an international team. For Daniel Gruss, Michael Schwarz and Moritz Lipp, 2019 got off to a similar start: with ZombieLoad and Store-to-Leak Forwarding.

Birgit Baustädter

ZombieLoad and Store-to-Leak Forwarding are the names of the new exploits which have just been announced by TU Graz security researchers Daniel Gruss, Moritz Lipp, Michael Schwarz and an international team. Like their predecessors, the serious security vulnerabilities probably affect millions of computers.

ZOMBIELOAD

ZombieLoad uses a similar approach to Meltdown. In order to enable faster processing, computer systems prepare several tasks in parallel, before discarding the ones that are either not needed or for which the necessary permissions have not been given. Due to the way processors are designed, they always have to pass on data, even if it is not correct. The check for permission only happens once sensitive processing steps, which depend on assumptions made by the computer system, have already been prepared. “In the split second between the command and the check, using this new form of attack we can see the pre-loaded data from other programs,” explains Gruss. In other words, the researchers can read what the computer is currently processing.

The KAISER patch developed by a team at TU Graz provided a simple solution for Meltdown, which affected the speed of a computer. Coming up with a solution for ZombieLoad attacks could be more difficult, says Gruss: “Every CPU has multiple cores, and each of these cores is also split in two. This means several programs can run simultaneously. We think that one of these two parts of each core will have to be disabled.” That would mean a 50% drop in performance. Or in clouds, which are also vulnerable to this method of attack, 50% fewer potential users on the same hardware.

STORE-TO-LEAK FORWARDING

Store-to-leak forwarding also reads pre-loaded data by exploiting the efficient way in which computer processors function. “The computer assumes that I want to use the data which I have just written to the processor again right away. So it keeps it in the buffer for faster access,” explains Gruss. This functionality can also be used to determine the architecture of the computer processor and find the exact location where the operating system is running. “If I know exactly where the processor is running the operating system, then I can launch targeted attacks against flaws in the operating system.”

The research was funded by the ERC project Sophia, the DESSNET and ESPRESSO projects, and through a donation from the manufacturer Intel. ■

Study Cybersecurity

TU Graz offers three English-language master's degree programmes: Computer Science, Computer and Information Engineering, and Software Engineering and Management. Students can specialise in information security in all three programmes. Advanced courses ranging from hardware security and cryptography to e-government applications are offered. Master's students are closely involved in cybersecurity research at TU Graz. With the foundation of the Cybersecurity Campus Graz, the current range of courses is continuously expanding. New curriculums in which information security is an important component will be introduced for the Computer Science, Information and Computer Engineering, and Software Development Economics bachelor's programmes in the 2019/2020 winter semester. These lay the foundation for specialisation in the master's degree programme. ■

Dependable Internet of Things

The first three years of TU Graz´s Lead Project "Dependable Internet of Things in Adverse Environments" yielded promising results. The team developed a positioning system which works more efficiently and accurately, it ensured cooperation between appliances from various manufacturers in the IoT using an adaptive algorithm, protected the integrated software against security attacks, and developed a predictive system for autonomous vehicle convoys. The research project was extended for a further three years after a successful evaluation at the midway point. ■

Success for ASCON Algorithm

Authenticated encryption of information is aimed at ensuring that messages cannot be read or changed during transmission. In 2014, a research team from TU Graz's Institute of Applied Information Processing and Communications submitted its ASCON algorithm, which was developed in-house, for the high-profile, international CAESAR competition. The algorithm was tested for five years and assessed in terms of its cryptanalytic and practical security. It set such high standards of security and efficiency that the high-calibre jury selected the TU Graz encryption procedure as its primary recommendation for what are known as lightweight applications. ■

Reliable in the Face of Interference

Carlo Alberto Boano from the Institute of Technical Informatics at TU Graz and Markus Schuß run the annual Dependability Competition. This year, the challenge facing the participants was to devise a set-up that records data and sends commands reliably in an industrial, wireless multi-hop network in spite of strong radio frequency interference. 13 teams from ten countries put their ideas to the test. A scientific paper is planned. ■

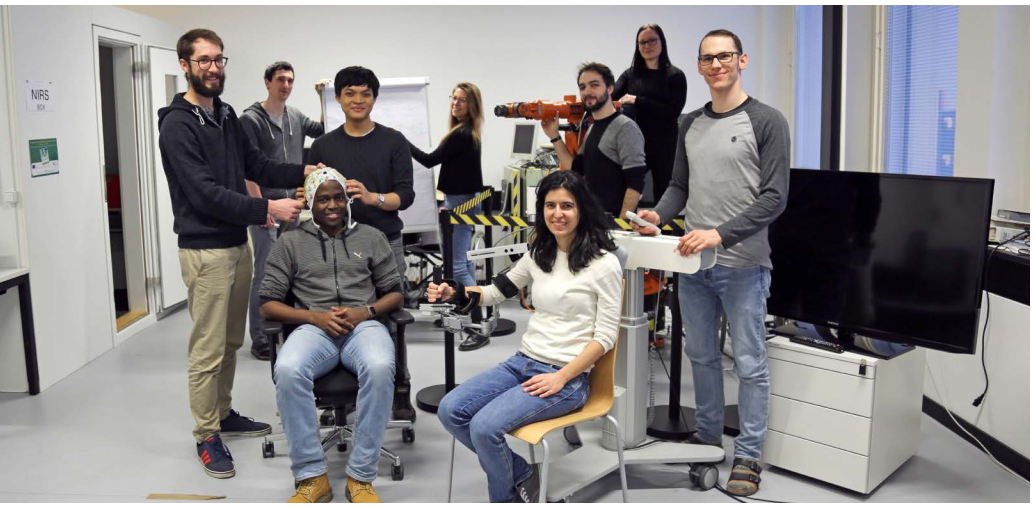
Battle of the Neuro-Assistance Systems

Live CYBATHLON events for 'pilots' with physical impairments, who compete by controlling computer avatars with their thoughts, demonstrate just how far brain-computer interface (BCI) research has come. The next CYBATHLON BCI race will take place on 17 September 2019 in the run-up to the BCI Conference in Graz.

Werner Schandor

"The hall was packed at CYBATHLON 2016 in Zurich," remembers Gernot Müller-Putz, head of TU Graz's Institute of Neural Engineering. "66 athletes from 25 different countries took part in the competition, which played out in front of a crowd of 7,500 people. It was broadcast live on Swiss TV, and a team from the Austrian national broadcaster ORF covered our delegation's participation in the event."

CYBATHLON, the world cup of technical assistance systems, was launched by ETH Zurich. The competition showcases what athletes with disabilities can achieve when assisted by prosthetics, robots or



Left: Gernot Müller-Putz is head of the Institute of Neural Engineering at TU Graz.
Source: Lunghammer – TU Graz

Right: The Graz BCI Racing Team Mirage 91 will also take part in the competition.
Source: TU Graz

neurotechnology. They compete in six disciplines, ranging from functional electrical stimulation (FES) cycling on recumbent bikes for paraplegic people, robotic prosthetic arm and prosthetic leg races, to computer game contests in which paraplegic pilots use electroencephalogram (EEG)-based BCIs to control avatars.

Spectators can follow the pilots' progress live on big screens, watching the avatars completing an obstacle course, jumping hurdles and overcoming tricky tasks before driving on again towards the finish. "At the BCI race the research teams pit their systems against each other under competitive conditions to find out who has adapted their technology to the pilots most effectively," explains Gernot Müller-Putz. "You can see straight away just how well the algorithms can interpret the EEG signals and translate them into impulses."

GRAZ: A CENTRE OF BCI EXPERTISE

September's BCI competition in Graz is a taste of things to come at the next full-scale CYBATHLON, which will take place in Zurich in 2020. It is no coincidence that the CYBATHLON BCI Series is coming to Graz, or that the city hosts one of the most important conferences on brain-computer interfaces every two years: TU Graz's BCI working group is one of Europe's leading research groups when it comes to computer-assisted interpretation of brain waves and translating them into electrical impulses for prostheses, robotic prosthetic arms and means of communication. The interdisciplinary team led by Gernot Müller-Putz has made major strides over the past few years, participating in several EU-funded research projects. A good example is its work in the field of neuroprosthesis control for the MoreGrasp project. Currently, the ERC consolidator project "Feel Your Reach" is working on the fundamentals for the future control of an entire arm.

One of the core objectives of BCI research is to enable paraplegic people to move their limbs again by means of mental control. Its beginnings in the 1970s go back to the effort to help patients whose communication is severely restricted, for example, by amyotrophic lateral sclerosis (ALS) or locked-in syndrome. The P300 communication technology was developed on the basis of EEG, with which these patients can come into contact with their environment.

New approaches in the field have focused on using BCIs in the treatment of stroke patients, as well as for non-hospital applications such as the neuro-physiological optimisation of vehicle assistance systems or helping students to learn more effectively. "We could use BCI to detect peoples' mental state. For instance, a computer system could identify when learners are tiring, and what input was required to make best use of their remaining powers of concentration," explains Gernot Müller-Putz.

A WORLD OF OPPORTUNITIES

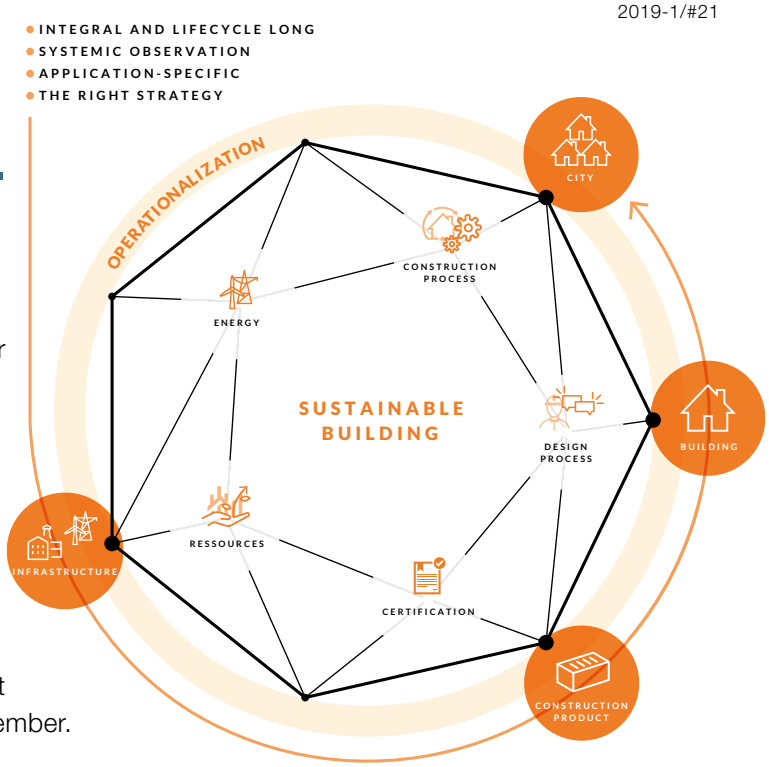
If this all sounds a bit like a brave new world to you, the TU Graz Professor begs to differ: "No, for me it sounds like new possibilities that will enrich our lives". BCI research is still focused on medical and therapeutic applications. And these will be the centre of attention at the 8th Brain-Computer Interface Conference in Graz from 16-20 September 2019, which is expected to attract over 240 scientists. 78 papers have been submitted and six keynote speakers from Germany, the UK, the Netherlands and the US will reflect the broad spectrum of disciplines covered by the field, which encompasses everything from neurophysiology and data analysis to sensory-motor systems, neuroprosthetics and the electrical stimulation of nerves.

Teams from Europe and Asia have already signed up for the CYBATHLON BCI Series event on 17 September. Gernot Müller-Putz is hoping that the cheers for the athletes will be as loud as they were at the Zurich 2016 competition. ■

Sustainable Construction – a Question of Attitude

When Alexander Passer looks down on the building sites for Graz's future Smart City from his office on the 11th floor of the Science Tower Graz, he's not really satisfied: "As soon as a building exceeds the requirements for energy certification by a fraction, everyone immediately starts talking about a green building." In the view of the professor of sustainable construction at TU Graz, much greater effort than that required to scrape above the target is needed to make building truly sustainable and climate-friendly. Models for achieving this will be the subject of discussions at the Sustainable Built Environment D-A-CH Conference 2019 to be held at TU Graz this September.

Werner Schandor



Sustainable construction is a comprehensive process that considers all aspects and incorporates all these factors into a systemic, end-to-end model. This model covers the entire life cycle of a building or urban development initiative, and is geared towards objectifiable environmental, social and cultural qualities.
Source: Alexander Passer, postdoctoral thesis, 2016

The challenges have been obvious for some time: how can we use our planet's increasingly scarce resources so as to leave our descendants a suitable basis for their existence (i.e. sustainability)? And what do we have to do to keep anthropogenic or man-made global warming to a minimum and meet the targets of the Paris Agreement? A drastic reduction in greenhouse gas emissions will be necessary. This is especially true for the construction sector, which accounts for around 40% of energy use and 50% of resource consumption worldwide.

Sustainable Built Environment D-A-CH Conference:
Transition Towards a Net Zero Carbon Built Environment
11–14 September 2019

Organiser: TU Graz, Institute of Technology and Testing of Construction Materials, Working Group Sustainable Construction
In cooperation with the Institute of Construction Management and Economics, TU Graz, the University of Natural Resources and Life Sciences, Vienna (BOKU), Karlsruhe Institute of Technology and ETH Zurich

Improving buildings' energy efficiency, and using green (construction) materials and new digital planning approaches will not be enough to cut emissions. "We need a rethink along the entire chain, from planning and construction to use and right the way to the end of the life cycle," Passer believes. "The aim is to leave behind structures that represent a form of capital, not a burden." Taking the life cycle as a whole, these increased costs can be recouped in a short time.

INTERNATIONAL RESEARCH NETWORK FOR SUSTAINABLE CONSTRUCTION

At the Sustainable Built Environment D-A-CH Conference from 11 to 14 September 2019 at TU Graz, researchers will address the question of what they can do to achieve climate goals and contribute to sustainability. Titled 'Transition Towards a Net Zero Carbon Built Environment', the conference will take place in cooperation with the BOKU Wien, Karlsruhe Institute of Technology and ETH Zurich. More than 200 presentations will cover four aspects of sustainable construction: assessment and certification, design and decision-making processes, cities and networks, and innovation and implementation. The latter is one of the conference's key focuses. Selected contributions from SBE19 in Graz will feed into the Beyond 2020 World Sustainable Built Environment Conference, which is being held in Gothenburg, Sweden. Beyond 2020 will play host to sustainability and construction experts from all over the world.

Science Tower Graz, a flagship project that opened in 2017, is proof that sustainability can be a feature of construction work. The Working Group Sustainable Construction at TU Graz provided scientific support for the project and now occupies one floor of the building. The facade of the cylindrical, 14-storey building is made of energy glass, which generates electricity from light, while concrete core activation allows for largely greenhouse-gas-free cooling and heating. The Science Tower also features an active, rotating PV shading system, smart LED lighting, urban farming zones and other innovative technologies. ■

Research Centre for CO_2-free Small Engines

Lawn mowers, chainsaws, hedge trimmers and leaf blowers: handheld motorised tools make gardening so much easier and people are increasingly using them at home. But just like cars, these devices contribute significantly to global CO_2 emissions. A consortium comprised of scientific institutes and industrial companies is now looking into this trend. Over the next four years they will carry out research into decarbonising small powertrain systems at the specially equipped Research Centre for Low Carbon Special Powertrain (RC-LowCAP). Besides the tools mentioned above, this category also covers powertrains for personal mobility vehicles (such as motorbikes, quads and powersports vehicles) and light commercial vehicles. ■

Nano-Composition

Researchers at the Institute of Experimental Physics at TU Graz have been investigating the detailed structure and thermodynamic behaviour of nanocluster structures since 2012. Very clean nanoparticles of various metals or metal oxides are produced by a technique known as “pick-up”, where helium droplets at a temperature very close to absolute zero are loaded with atoms or molecules from an evaporative source which then agglomerate to form nanoparticles inside the droplets. The team at the Institute of Experimental Physics led by head of institute Wolfgang Ernst and Andreas Hauser used this method to study vanadium oxides and their clusters. The scientists and their team achieved a breakthrough regarding the structure and thermodynamic properties of vanadium pentoxide. These results will contribute to a better understanding of the stability of vanadium oxide nanoparticles that could lead to improvements in the production of SCR catalytic converters and their application, for example in industrial plants, power stations and combustion engines. The work has just been published in the renowned journal of the Royal Society of Chemistry, Chemical Science. ■

Excessive Hygiene Driving Antibiotic Resistance

All over the world, the number of people falling victim to and dying as a result of antibiotic-resistant germs or “superbugs” is on the rise. The World Health Organisation (WHO) believes that understanding the spread of antibiotic resistance and devising countermeasures is one of the most important challenges facing the world today. In response, Gabriele Berg, head of the Institute of Environmental Biotechnology, launched an interdisciplinary collaboration as part of a research project entitled ‘Plant-associated microbial communities in indoor environment’, which has received funding from the Austrian Science Fund (FWF). The research focused on the ways in which microbial control – in other words, the scope of cleaning and hygiene measures – influences the development of resistance. Research was carried out in conjunction with Austrian partners of the Medical University of Graz under the BioTechMed-Graz cooperation, and with partners from abroad. The findings have now been published in the journal Nature Communications. ■

New Breakthroughs in Research on Super-Batteries

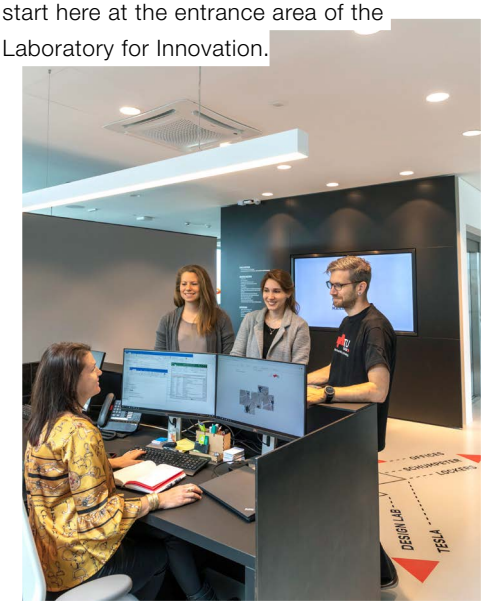
Since 2012, Stefan Freunberger of the Institute for Chemistry and Technology of Materials at TU Graz has been working on development of a new generation of batteries with enhanced performance and longer useful lives, and which are also cheaper to produce than current models. He believes that lithium-oxygen batteries have significant potential. In 2017, in the course of his work, Freunberger uncovered parallels between cell ageing in living organisms and in batteries. In both cases, highly reactive singlet oxygen is responsible for the ageing process. This form of oxygen, which has been the focus of Freunberger’s research over the past few years, is produced when lithium-oxygen batteries are charged or discharged. The Graz-based researcher has now found ways to minimise the negative effects of singlet oxygen, and his findings have been published in renowned journals Nature Communications and Angewandte Chemie. ■

doc.funds Go to CATALOX

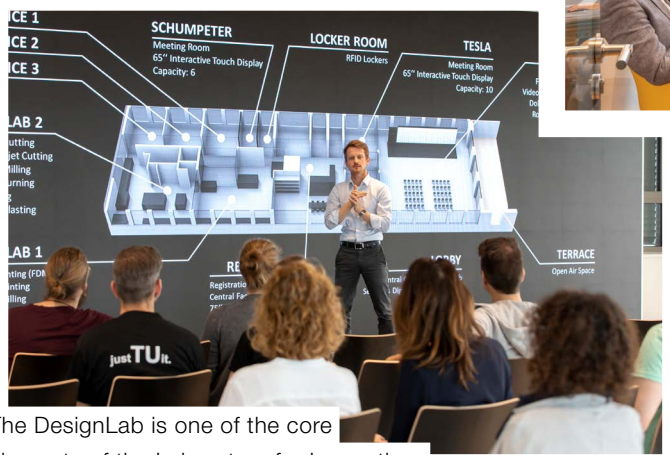
The Catalytic Mechanisms and Applications of Oxidoreductases (CATALOX) project has secured financing under the Austrian Science Fund’s (FWF) highly competitive doc.funds programme, a scheme which promotes high-quality doctoral education with a view to enhancing scientific research. CATALOX will give ten young researchers the opportunity to investigate the mechanisms and applications of the biocatalysts oxidoreductases at TU Graz’s Doctoral School of Molecular Sciences and Biotechnology. Oxidoreductases belong to the largest classification of enzymes. Due to their often high selectivity and mild reaction conditions, they have outstanding potential for use in the development of environmentally friendly biotechnological processes. The project is being coordinated by the head of TU Graz’s Institute of Molecular Biotechnology, Robert Kourist. ■

Equipped with the latest digital manufacturing technologies and appliances for the production of prototypes and innovative product designs, the Laboratory for Innovation offers everything the maker's heart desires: from cutting-edge 3D printers for FDM, STL and CFF methods, CNC 4-axis and 3-axis milling machines and appliances for laser cutting and laser engraving, to water-jet cutting, sand-blasting, circuit-board printing and vinyl cutting. Here, students and researchers engage in multidisciplinary cooperation, as do start-ups, SMEs and established industrial companies involved in joint innovation work. The public is also welcome to the innovation lab: ambitious makers can implement their ideas and designs at TU Graz every Thursday afternoon.

800 square meters of innovation start here at the entrance area of the Laboratory for Innovation.



Meeting rooms and offices provide space for planning and discussion.

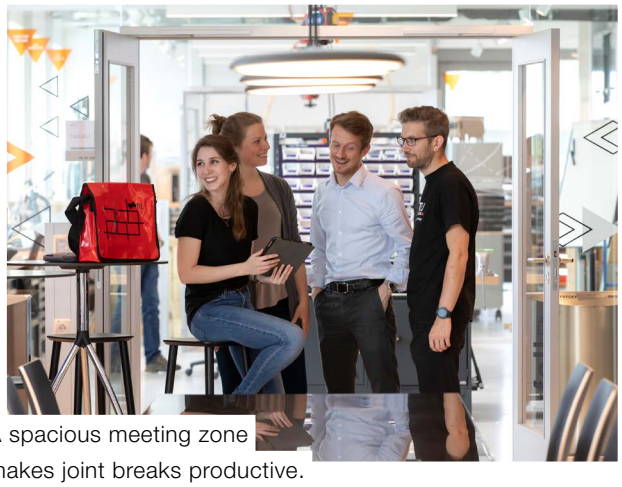


The DesignLab is one of the core elements of the Laboratory for Innovation: a multifunctional room with a 4K LED wall and much more.

The spacious FabLab is the centrepiece of the Laboratory for Innovation – equipped with everything a maker's heart desires.

The Laboratory for Innovation is an initiative of the Institute of Innovation and Industrial Management headed by Christian Ramsauer at TU Graz and is located at Inffeldgasse 11.

Everything the Maker's Heart desires: Laboratory for Innovation

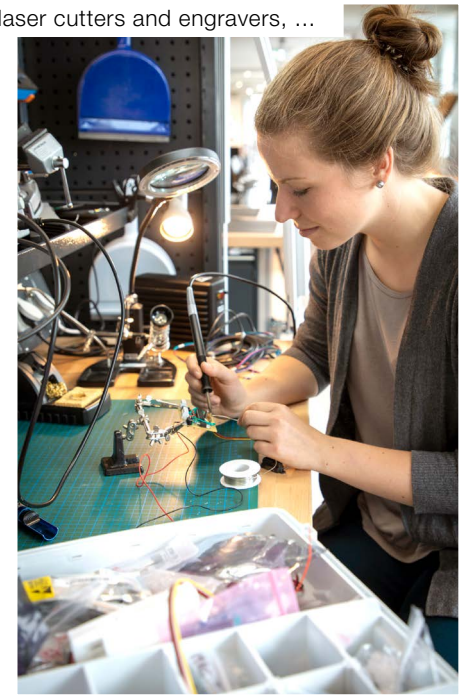


A spacious meeting zone makes joint breaks productive.

Source: Lunghammer – TU Graz

... and other types of state-of-the-art production equipment are available for users of the Laboratory for Innovation.

State-of-the-art 3D printing systems, CNC 4-axis and 3-axis milling machines, laser cutters and engravers, ...



... sand-blasting, a water-jet cutter, circuit-board printer, vinyl cutter ...

The Fascination of the Abstract

Jürgen Hartler hardly has time for swimming, his favourite pastime, because he's so busy conducting research into the mass spectrometry of lipids at the University of California (UC) San Diego – where the sea is basically right on his doorstop.

Werner Schandor

Jürgen Hartler carries out research in Graz and California.
Source: Baustädter – TU Graz

"I haven't had much time to go to the beach," explains the bioinformatics expert, who began his year-long stay at UC San Diego's Department of Pharmacology in October 2018. Hartler, who was born in southern Burgenland in Austria, chose the university "because the pharmacology department at University of California San Diego is one of the leading lights in lipid research." He is currently a visiting scholar at the Ed Dennis Lab, where LIPID MAPS originated. "This is where lipids were categorised. The lab has excellent connections to the pharmaceuticals industry and medicine, and it takes part in extensive studies."

This is a useful network for a researcher like Hartler, who has made a valuable contribution to the identification of lipids. Earlier this year, the TU Graz scientist won the German Mass Spectrometry Society's prestigious Mattauch-Herzog Award for Mass Spectrometry 2019 for developing a computer-assisted method of identifying lipids using mass spectrometry (MS).

100,000 POSSIBILITIES

There are more than 100,000 different species of lipids, which can be roughly categorised into eight categories, and subsequently into many more specific classes. The most well-known lipids are fatty acids, triglycerides, waxes as well as isoprenoids, which include steroids. Some lipids are membrane-forming and a lot of species have specific functions in membranes. Lipids are of great interest to scientists working in medicine, pharmaceuticals and the food industry. For example, researchers want to discover more about the role they play in cardiovascular disease and Alzheimer's. Food technology is another area that relies on lipid science, for activities such as analysis of cooking oils.

FROM DATA NOISE TO RELIABLE RESULTS

The fact that there are so many different types of lipids, and that they had largely evaded automated identification, appealed to Hartler's scientific instincts. "Lots of people have avoided working on lipids because analysing the data is extremely complex and takes a lot of time," he explains. "When I first started in this area, MS lipid data was still being mostly analysed manually because existing solutions weren't sufficiently reliable."

Thanks to the program developed by Jürgen Hartler and his team at TU Graz, researchers can now carry out data-driven lipid identification with a high degree of reliability. Following analysis in the mass spectrometer, previous evaluation methods frequently reported wrongly annotated species. Hartler used specific lipid signal patterns from mass spectrometry (MS^1) as well as tandem mass spectrometry (MS/MS or MS^2), a form of MS where samples in the mass spectrometer are analysed at the molecular level, and subsequent fragmentation provides information about the lipid species' structure.

LIPID DATA ANALYSER

The MS^1 and MS^2 data analysis method developed by Hartler's team offers unrivalled reliability for lipid identification and is also simple to use for different lipid classes. The lipid data analyser (LDA) software, which their research gave rise to, is very practical. It can be used with many of the different mass spectrometry systems on the market without the need for time-consuming adjustments. "We developed a flexible approach that allows for adaptions without further code implementations", says Hartler. "And our goal was to come up with a straightforward solution for mass spectrometrists, so that they can adapt the annotation of lipid spectra as easily as possible."

Jürgen Hartler took the long road to lipid identification. He studied electrical engineering at TU Graz, specialising in biomedical engineering. His dissertation, which he completed at the Institute of Genomics and Bioinformatics, involved MS analysis of proteins. Abstraction is a thread that has run through all of Hartler's research. This is probably also combined with a love of complexity, because he has chosen to investigate sphingolipids next, which occur in the cell membrane of nerve cells, for instance. "The level of complexity is even greater here," says the scientist. Hobbies such as swimming will have to play a minor role for the time being. ■

Marcus Wallenberg Prize

Gerhard Schickhofer, head of the Institute of Timber Engineering and Wood Technology at TU Graz, took the 2019 Marcus Wallenberg Prize for his pioneering research on cross-laminated timber. The award comes with prize money of around EUR 200,000.

Josef Krainer Award

Two Styrian-based researchers who already have outstanding achievements to their name in their respective disciplines have now been awarded accolades by the Province of Styria. Experimental physicist **Markus Koch** picked up the Josef Krainer Honorary Award on 18 March. Meanwhile, **Vanja Subotić's** work on heat engineering was rewarded with the Josef Krainer Award for Young Scientists.

Mattauch-Herzog Award

The German Mass Spectrometry Society presented the 2019 Mattauch-Herzog Award to **Jürgen Hartler** of TU Graz's Institute of Computational Biotechnology. He received the accolade for his "exceptional work" in a paper entitled High-Throughput Identification of Lipids in Biological Material Using Software-Aided Analysis of LC-MS/MS Data.

ICOLD Innovation Award

A team headed by **Franz Georg Pikl** of the Institute of Hydraulic Engineering and Water Resources Management won the international Innovation Award at the Congress of the International Commission on Large Dams (ICOLD).

Erwin Wenzl Prize

Presented by the Province of Upper Austria, the **Erwin Wenzl** Prize went to Peter Gangl of the Institute of Applied Mathematics for his dissertation.

Most Influential Scholar

Vice Rector **Horst Bischof** of the Institute of Computer Graphics and Vision was ranked 30th on the AMiner Most Influential Scholar List of the most-cited researchers in the field of artificial intelligence. He also took the Most Influential Paper over the Decade Award, which is presented by the Machine Vision Applications (MVA) Conference Committee, for his 2009 paper, Eye blink based fatigue detection for prevention of computer vision syndrome, written together with **Matjaž Divjak**, now a member of the University of Maribor.

Verena Special Award

The Cera Charge TM project was presented with the Verena special award at the State Awards for Innovation. In the project, TDK Electronics developed a fireproof and explosion-proof Li-ion battery together with TU Graz.

Interspeech 2019

Crossroads of Speech and Language is the title of this year's Interspeech, the annual conference of the International Speech Communication Association, taking place at Messe Congress Graz from 15-19 September. Gernot Kubin of the Institute of Signal Processing and Speech Communication at TU Graz and Zdravko Kacic of the University of Maribor will be chairing the event.

ConTEL 2019

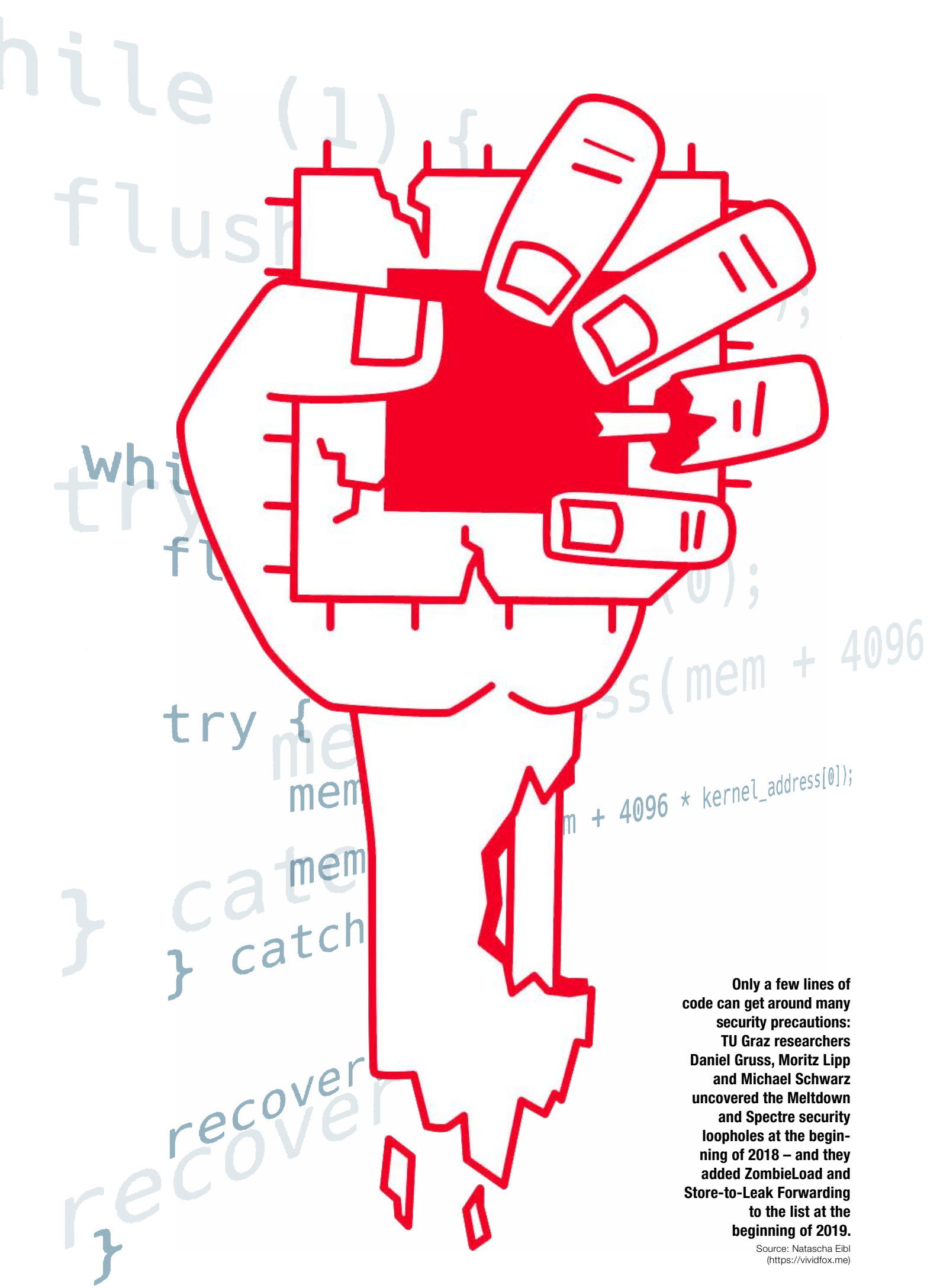
The Institute of Microwave and Photonic Engineering at TU Graz's Campus Inffeldgasse will play host to the 15th International Conference on Telecommunications (ConTEL 2019) from 3-5 July.

SBE19

The Sustainable Built Environment D-A-CH Conference 2019 (SBE19) is titled Transition Towards a Net Zero Carbon Built Environment. The conference is taking place from 11-14 September at TU Graz, which is staging the event in cooperation with ETH Zurich, the University of Natural Resources and Life Sciences, Vienna (BOKU) and Karlsruhe Institute of Technology.

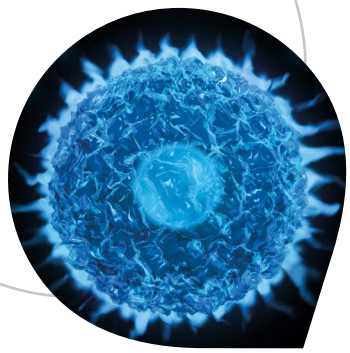
Graz Brain-Computer Interface Conference 2019

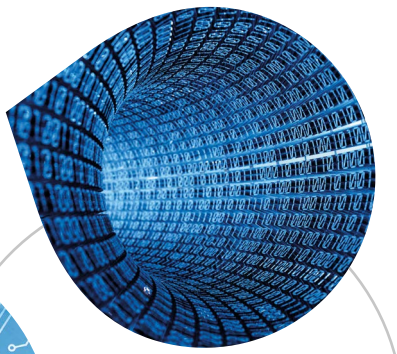
The Institute of Neural Engineering will be hosting this conference from 16–20 September. The schedule includes the 2019 Cybathlon BCI Series. The article on pages 12 and 13 provides background information.



Only a few lines of code can get around many security precautions: TU Graz researchers Daniel Gruss, Moritz Lipp and Michael Schwarz uncovered the Meltdown and Spectre security loopholes at the beginning of 2018 – and they added ZombieLoad and Store-to-Leak Forwarding to the list at the beginning of 2019.

Source: Natascha Eibl (https://vividfox.me)




Fields of Expertise

TU Graz's research activities are grouped into five strategic, forward-looking Fields of Expertise. Researchers engage in interdisciplinary cooperation and benefit from different approaches and methods, shared resources and international exchange.

Advanced Materials Science

Editorial: Peter Hadley

Radiation Damage in Microelectronics
Alicja Michalowska-Forsyth,
Varvara Bezhenova

Human & Biotechnology

Editorial: Gernot Müller-Putz

Lighting Up the Brain: LOGOS-TBI Project
Theresa Rienmüller

Information, Communication & Computing

Editorial: Kay Uwe Römer

Stochastic Optimisation in Financial and Insurance Mathematics
Stefan Thonhauser

Mobility & Production

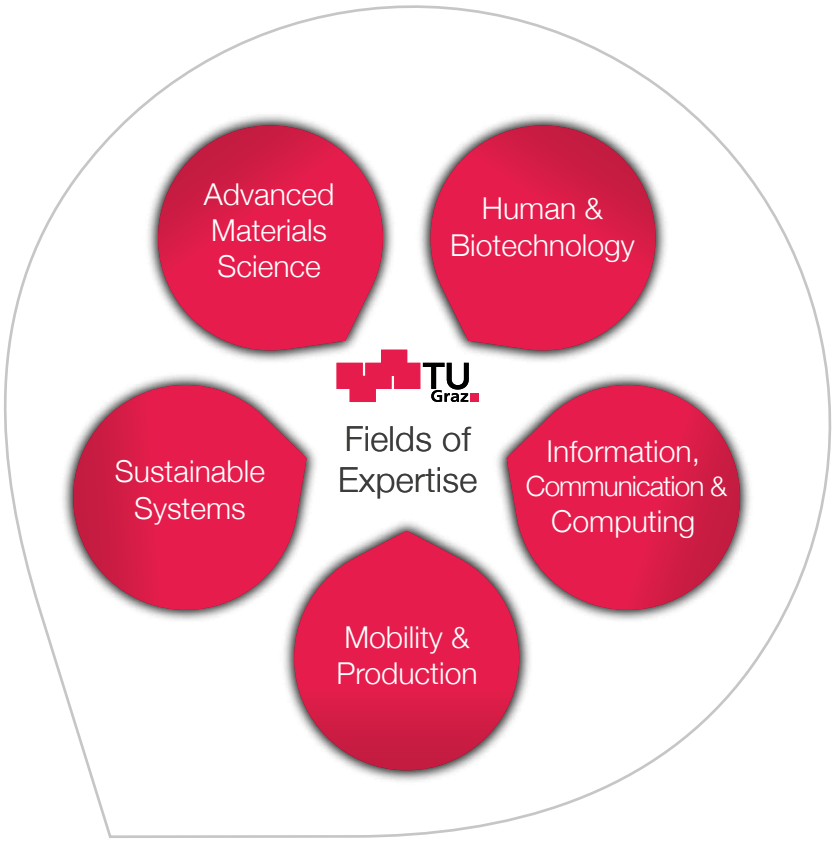
Editorial: Helmut Eichlseder

Fuel Cells – Materials and Methods for Prolonging Lifetime
Katharina Kocher,
Kurt Mayer,
Bernhard Marius,
Bernd Cermenek,
Viktor Hacker,
Sigrid Wolf

Sustainable Systems

Editorial: Urs Hirschberg

Advanced Control for Sustainable Energy Systems
Markus Gölles,
Martin Horn



TU Graz has divided its research into five innovative areas: the Fields of Expertise. Researchers in the Fields of Expertise break new ground in basic research. They take part in interdisciplinary cooperation, gain support for outstanding projects and are based in the region as well as part of international networks. They also develop key technologies for industry and commerce, and perform research in the framework of company shareholdings and partnerships.

Source: TU Graz

ADVANCED MATERIALS SCIENCE
Researchers aim to understand the smallest components in the structure and function of new materials, and develop and assemble them in special processes.

HUMAN & BIOTECHNOLOGY
Researchers develop devices and methods for medical applications and therapies, or focus on using enzymes and living microorganisms such as bacteria, fungi and yeast in technical applications.

INFORMATION, COMMUNICATION & COMPUTING
Researchers face challenges prompted by the information age, for example data security and efficient use of the ever-increasing volume of data.

MOBILITY & PRODUCTION
Researchers investigate novel vehicle technologies, new drive systems and more economical product manufacturing processes.

SUSTAINABLE SYSTEMS
Scientists focus on the complex challenges presented by a growing population and increasingly scarce natural resources.

Source: istockphoto.com

ADVANCED MATERIALS SCIENCE

Fields of Expertise TU Graz

Peter Hadley,
Advanced Materials Science
Source: Lunghammer – TU Graz

Our understanding of solids is largely based on studies of ordered materials where the atoms are arranged in straight rows. However, many engineering materials are composites with a high degree of disorder and sometimes a fractal or hierarchical structure. To be able to examine complex materials like this, a consortium of nine institutes from four TU Graz faculties and three institutes from the University of Graz and Med Uni Graz joined together to acquire a µCT instrument with the Austrian Research Promotion Agency (FFG) funding, awarded under its recent infrastructure call. This instrument uses X-rays to determine the microscopic structure and composition of a material. The machine uses a combination of X-ray imaging and X-ray diffraction. X-ray imaging involves measuring the intensity of X-rays that pass through a sample. This produces images like the ones conventionally used in hospitals. By taking X-ray images from a number of different angles, it is possible to make a 3D reconstruction of an object. This method is called computed tomography (CT). A µCT performs computed tomography with a spatial resolution in excess of one micron. X-ray diffraction can be used to determine which atoms are present in a crystal, the arrangement of the atoms, and the distances between the atoms. For instance, the double helix structure of DNA was first determined by crystallising DNA and measuring it by X-ray diffraction. Conventionally, X-ray diffraction has been performed on single crystal samples but the latest µCT devices can focus the X-rays on a small region, and determine how the atoms in that region are arranged. A similar measurement is sometimes performed using an intensely focused X-ray nanobeam in a synchrotron. Once the 3D structure of a material has been determined by µCT, a lot of computational work is still necessary to segment the different components of the material and determine how they are connected together. For instance, a porous material might consist largely of parallel channels or the channels might be twisted with many dead ends. The µCT will be maintained by a senior scientist, who will assist the institutes with programming data analysis routines and travel with them to synchrotrons when additional experiments using a nanobeam are necessary.

Alicja Michalowska-Forsyth,
Varvara Bezhenova:

Radiation Damage in Microelectronics

Reliability is a wide-ranging subject in microelectronics, covering responses to different kinds of stress as well as measures to increase devices' tolerance against them. This includes ionising radiation stress, which affects device characteristics, leading to circuit degradation. Investigating such problems, as well as irradiation campaigns with custom integrated circuits (ICs) are the day-to-day focus of the team at the Institute of Electronics.

Analog IC design is an integral part of microelectronics. Designers have a host of options when it comes to meeting specifications, they need to make decisions on trade-offs between different parameters, and also need to comply with strict requirements in terms of precision, fast timing and low noise. It becomes even more challenging when reliability issues, such as ionising radiation stress, come into play.

It is this combination that makes research into radiation-hard integrated circuit design so exciting. Ionising radiation changes the electrical characteristics of microelectronic devices. As a consequence, instruments for medical and industrial X-ray imaging, space or high-energy physics have to be qualified and potentially hardened against ionising radiation. >

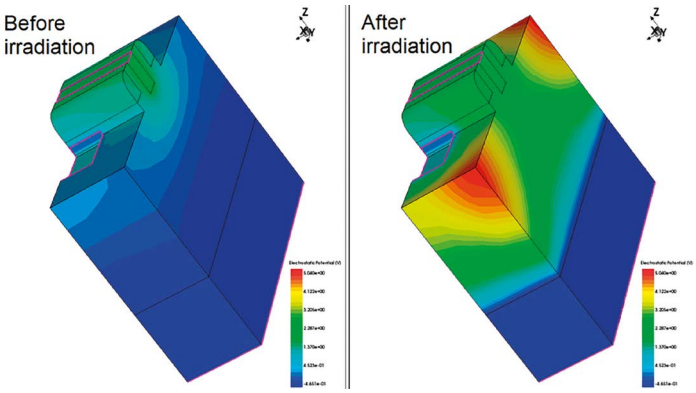


Figure 1: Simulation results: electrostatic potential of an N-type MOS transistor before and after irradiation, simulated with Sentaurus TCAD.
Source: TU Graz/Institute of Electronics

ORIGINS OF IONISATION DAMAGE

Exposing ICs to X-rays or gamma rays causes ionisation, resulting in randomly generated free charge carriers across the structure. Every IC consists of a bulk semiconductor and interleaved layers of metals and insulators. Free charge carriers in the conducting layers can be easily collected. Unless it is generated by energetic particles, the resulting current is negligibly small. In the case of insulator layers, an X-ray photon leaves behind a number of electron-hole pairs. Holes in particular have extremely low mobility, but electrons can escape the interaction region and move towards conductive layers more easily. Meanwhile, holes remain as net positive charge trapped in the insulator, producing a parasitic electric field. This effect is particularly undesirable when the insulator region is adjacent to a device, for example the gate oxide of a metal-oxide-semiconductor (MOS transistor. Even a low radiation flux can accumulate to a significant net charge after receiving a certain dose. Parasitic electric fields in the gate oxide cause the threshold voltage of an MOS transistor to shift (see Figure 1), while leakage current also increases and the intrinsic gain degrades; these are just a few of the possible effects.

In modern complementary metal-oxide-semiconductor (CMOS) ICs, the gate oxide, measured by the number of atomic layers, is so thin that the trapped oxide charge is neutralised by means of the tunnelling effect. In these modern processes, transistors are separated from each other by a much thicker insulator – this is known as shallow trench isolation (STI). After exposure to X-rays the STI is rich in trapped charge that has a strong influence on a device's characteristics. For example, a parasitic transistor is formed along the gate edge (see Figure 2), leading to off-state leakage currents.

With MOS transistors, one way to counteract this problem is to use edgeless or enclosed layouts, where the STI edge only sees the outer terminal, meaning there is no potential path for the leakage current. However, this solution cannot be used with narrow transistors; it also does not comply with the design rules of some semiconductor foundries, in particular in sub-65 nm nodes. Taking these factors into account, as well as requirements for devices other than MOS, new solutions for device geometry and the circuit topology level are urgently required to raise radiation tolerance limits.

COTOMICS AND ROBUSTIC PROJECTS

Our group at the Institute of Electronics is currently involved in several projects dealing with the radiation hardness of ICs. The precursor was the recently completed Cotomics project, which evaluated radiation tolerance and explored hardening strategies for a broad variety of devices in

Alicja Michalowska-Forsyth
is a postdoctoral researcher at the Institute of Electronics, specialising in analog integrated circuit design with a focus on harsh environments.

Source: Baustädter – TU Graz

Varvara Bezhenova
is a university project assistant at the Institute of Electronics. Her research focuses are the overall effects of ionising doses on integrated circuits, radiation hardness of integrated circuits and analogue IC design.

Source: Baustädter – TU Graz

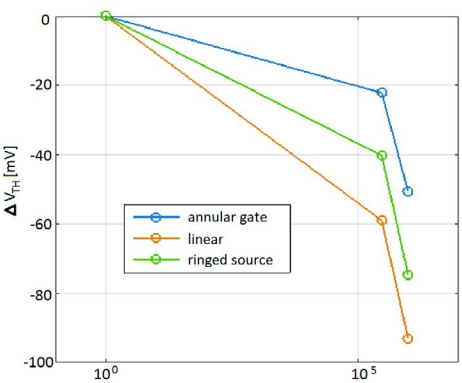


Figure 2: Experimental results: absolute threshold voltage shift of N-type MOS transistors with different layouts and same equivalent channel dimensions as a function of the total ionising dose (TID).
Source: TU Graz/Institute of Electronics

the 180 nm CMOS production process. It targeted reliability improvements in next-generation computed tomography. One of our current projects, RobustIC, is investigating the combined impact of ionising radiation, overvoltage and temperature effects, looking into new custom devices as well as circuit solutions. As a consequence of these two projects, in the last four years we have designed four integrated circuits with a huge number of devices and test circuits for radiation tolerance characterisation. So far, our results have been based on seven irradiation campaigns using a 10-200 keV X-ray tube beam (see Figure 3). For each experiment, the total ionising dose received by the circuit had to be determined at each characterisation step. We were able to calibrate the dose between three different facilities using several dosimetry techniques, in collaboration with experts from MedAustron, Seibersdorf Laboratories, CERN-EP and the Institute of Solid State Physics.

INITIAL FUNDING GRANT

Scaled CMOS processes below 65 nm are attractive for a range of sensing, signal processing and computing applications, but the effects of radiation on individual devices are still not fully understood. In 2018 our group received an initial funding grant from the Advanced Materials Science Field of Expertise to kick off research into radiation tolerance and hardening techniques in 28 nm and 40 nm technology nodes. The new SIRENS project looks beyond medical technologies to the exciting fields of space and high-energy physics instruments, where the amount of energy absorbed over a device's lifetime as a result of radiation can reach previously unexplored levels.

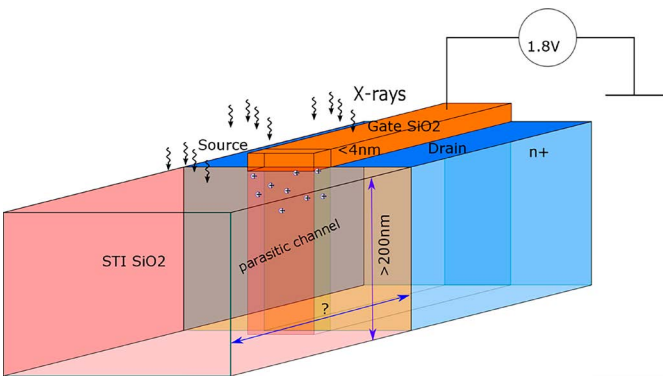


Figure 3: Formation of a radiation-induced parasitic channel by charge trapped in STI along the gate of a standard linear MOS transistor (N-type).
Source: TU Graz/ Institute of Electronics

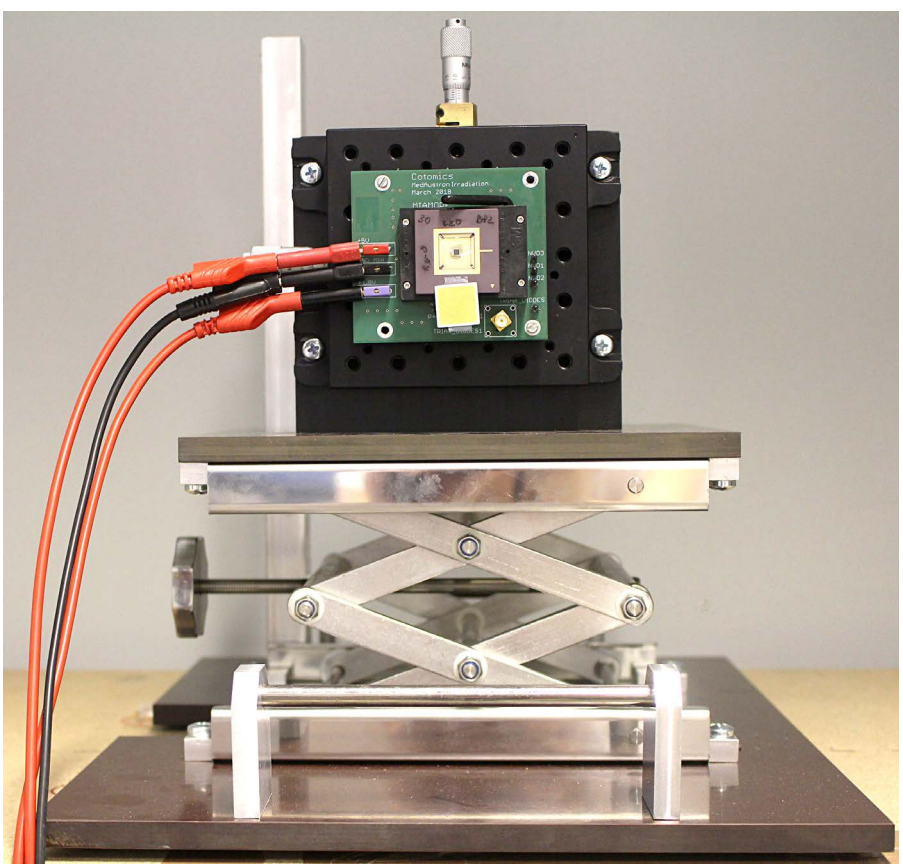


Figure 4: Exposed silicon die of the Mitigation and Modeling of Radiation Effects (MiAMoRE) IC ready for irradiation.
Source: TU Graz/Institute of Electronics

Source: fotolia.com

HUMAN & BIOTECHNOLOGY

Fields of Expertise TU Graz

Gernot Müller-Putz,
Human & Biotechnology
Source: Lunghammer – TU Graz

We would like to take a brief look back at the third Human & Biotechnology FoE Day, which took place last autumn. The aim was to give new and existing companies from the areas of research belonging to our Field of Expertise the opportunity to speak. Representatives of successful businesses talked about their careers and their companies' portfolios. We heard from Biotenzz, CNSystems, bisy e.U., Tyromotion, Innophore, CNA Diagnostics, Microinnova Engineering GmbH, g.tec, and VALIDOGEN. The range of topics covered everything from basic research to marketable products.

The next FoE Day will take place on 28 October and will once again be dedicated to science.

The new performance period will create fresh opportunities for the members of the Fields of Expertise: in addition to the tried and tested Initial Funding Programme (the 11th call for proposals is already underway), there are also grants for research and teaching infrastructure.

The professorship in Bioinformatics is currently being negotiated with the Rectorate. The goal is to establish a new institute in the field of biomedical engineering. A professorship in computational medicine is also in the pipeline and will be announced in due course. And a professorship in Biooptical Imaging and Spectroscopy is set to further strengthen the entire department.

The Austrian Science Fund (FWF) recently approved a doctoral programme entitled CATALOX - Catalytic Mechanisms and Applications of Oxidoreductases, which is being coordinated by Robert Kourist from the Institute of Molecular Biotechnology. There was strong competition for funding, with only six successful applications in the whole of Austria. The CATALOX research and training programme for doctoral candidates is scheduled to start in October 2019 and will run for four years. Ten project leaders, seven of them at TU Graz, are participating in the programme. CATALOX is a NAWI Graz project involving three other project leaders from the University of Graz.

Theresa Rienmüller:

Lighting Up the Brain: LOGOS-TBI Project

Jointly funded by the Austrian Science Fund (FWF) and the Austrian Academy of Sciences (ÖAW) over the next four years, the LOGOS-TBI project was launched at the Medical University of Graz and TU Graz in May 2019. In this project, neuronal cells will be stimulated using light-activated organic semiconductor implants. Electrical brain stimulation is aimed at promoting neuronal network formation and enhancing regeneration and neuroprotection after traumatic brain injury (TBI). This interdisciplinary research project brings together specialists in neuroscience (M. Ücal), structural biology (K. Kornmüller), electrophysiology (S. Scherübel) and biomedical engineering (T. Rienmüller).

Theresa Rienmüller
is deputy head of the Institute of Health Care Engineering with European Testing Center of Medical Devices.
She and her working group focus on computational and experimental physiology.

Source: Jakob Leiner – TU Graz/HCE

TRAUMATIC BRAIN INJURY (TBI)

TBI is a major cause of death and disability, particularly among young adults. The costs of patient care place a burden on both families and the public health system. Moreover, years of disability leave TBI survivors dependent on assistance

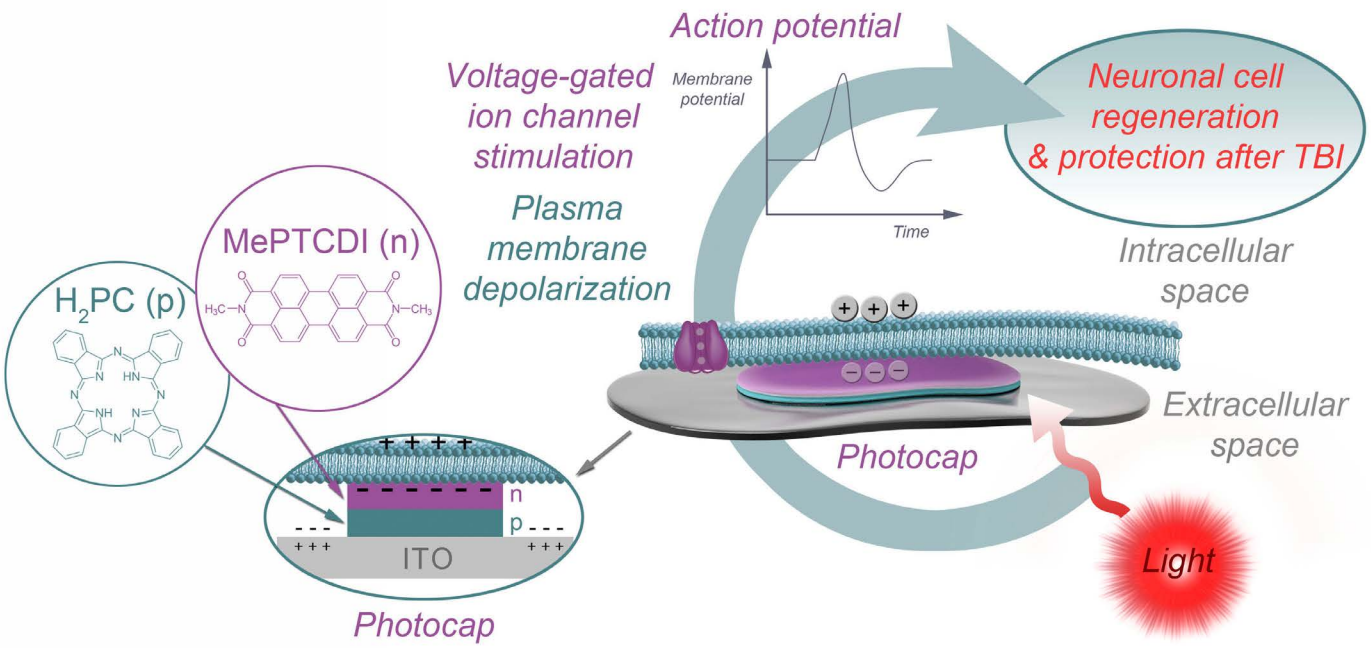


Figure 1: The basic idea behind stimulation using photocaps.
Source: Karin Kornmüller

for everyday activities. TBI is associated with pathologies at the molecular, physiological and structural level, which impact neuronal circuitry, communication and synchronisation within neuronal networks. Glial scar tissue forms a physical barrier that prevents axonal sprouting and the rebuilding of lost synaptic connections within the injured area. Persistent inflammation continues to cause chronic and progressive neurodegeneration years after TBI. However, with the exception of physiotherapy, there are currently no long-lasting treatments that mitigate the functional deficits resulting from TBI.

NEUROSTIMULATION AS A TREATMENT FOR DISABILITY

Recent advances in the understanding of neural connectivity have turned the focus on exogenous stimulation as a means to induce plasticity and neuromodulation for functional recovery. For example, transcranial magnetic stimulation (TMS) was introduced to increase overall excitability. But the method's main drawback is its simultaneous activation of many different neuronal populations and, in turn, modulation of both facilitatory and inhibitory connections. In contrast, direct cortical stimulation (DCS) enables more precise stimulation by directly accessing the target structures. The disadvantages of DCS include extensive wiring and the implantation of electrodes with limited biocompatibility into a patient's body. Light-driven neural activation, an emerging field with a broad range of applications – from functional assessment of neuronal systems to therapy aimed at addressing neural impairments – is seen as a promising alternative approach. Common light-based neural activation methods are founded on genetic and chemical approaches, and on the use of near-infrared (NIR) light. A completely novel concept for minimally invasive neural stimulation based on photoactive surfaces delivers high temporal and spatial resolution without the need for genetic modification.

ORGANIC PIGMENT PHOTOCAPACITORS (PHOTOCAPS)

The basic idea behind stimulation using photocaps is shown in Figure 1. The attached part of the cell membrane is separated from the top layer of the photocap by a thin layer of electrolyte, and the free part is in contact with the bath. Upon illumination, the top-layer of the photocap becomes negatively charged, resulting in localised displacement currents across the photocap/electrolyte interface and a profile of extracellular voltage in the area of cell adhesion. As a consequence, the attached plasma membrane is depolarised and voltage-gated ion channels are activated, triggering cellular action potentials. The photocaps recently developed by an international partner of the LOGOS-TBI team (Glowacki et al., Linköping University) are easy to produce, stable and non-toxic, and enable electrical stimulation of neurons with safe light intensities, without the need for external wiring. They can be produced in thicknesses three orders of magnitude >

lower than their silicon-based counterparts. Taken together, these features make photocaps the ideal candidate when it comes to studying mitigation of injury-induced deficits in neural communication by means of neuronal stimulation.

APPROACH

We hypothesise that stimulation of neuronal cells using light-activated photocaps promotes neuronal network formation and consequently enhances regeneration and neuroprotection after TBI.

To test this hypothesis, we developed an interdisciplinary research programme that brings together specialists from the fields of neuroscience, structural biology, electrophysiology and biomedical engineering (see Figure 2). Cultured cells (Figure 3 shows a hippocampal slice culture placed on a multi-electrode array) are an invaluable tool for developing optimal stimulation parameters before shifting attention to healthy and injured brain tissue. We will investigate the optimal time window after TBI in which stimulation yields the most extensive regenerative results.

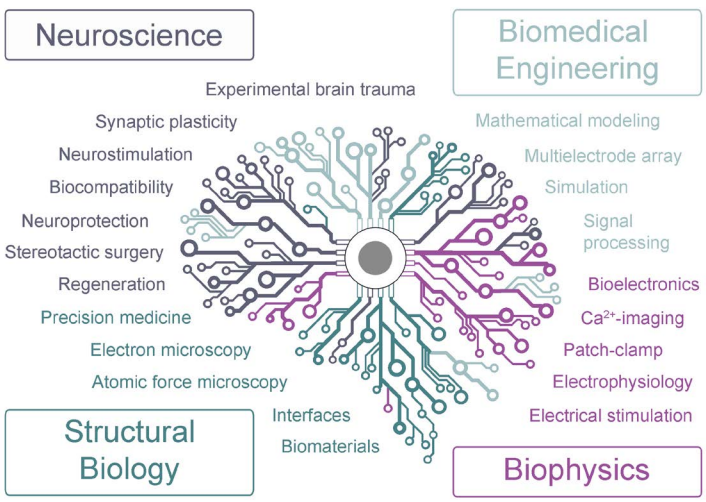


Figure 2: Research is being carried out in an interdisciplinary programme that brings together researchers specialising in neuroscience, structural biology, electrophysiology and biomedical engineering.
Source: Karin Kornmüller

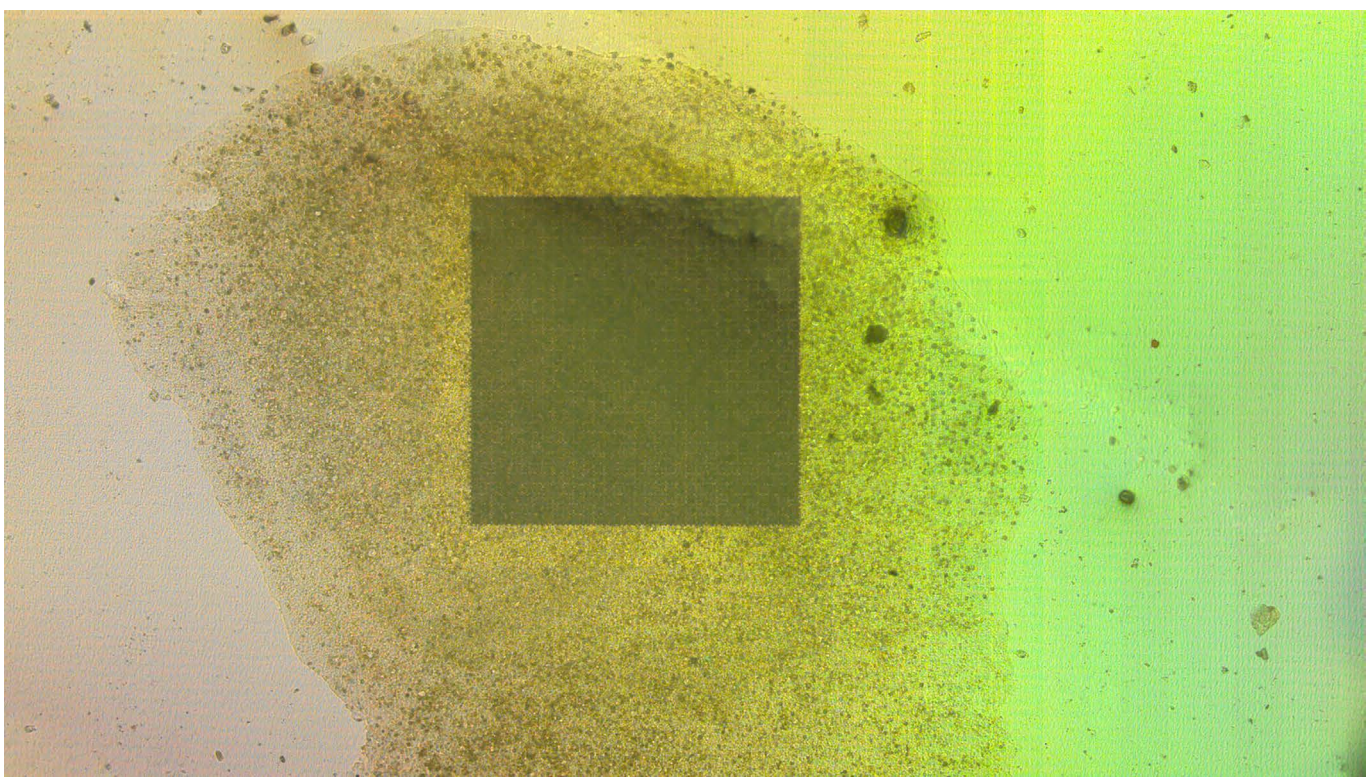


Figure 3. A hippocampal slice culture placed on a high resolution multi-electrode array with more than 4,000 recording sites and an interelectrode distance of 32 micrometres.
Source: TU Graz/HCE

Source: istockphoto.com

INFORMATION, COMMUNICATION & COMPUTING

Fields of Expertise TU Graz

Kay Uwe Römer, Information, Communication & Computing

Source: Lunghammer – TU Graz

TU Graz's Information, Communication & Computing Field of Expertise is currently undergoing massive expansion. Silicon Austria Labs, which focuses on electronic-based systems, is establishing its headquarters at TU Graz and will increase its Graz-based staff to 200, and to 500 in Austria overall in the next few years. The new SGS cybersecurity research and certification centre will be established at Campus Inffeldgasse and named Cybersecurity Campus Graz. It will focus on security and the Internet of Things, and eventually employ 400 people. As a result of the new university financing scheme, the base funding of the Faculties of Mathematics, Physics and Geodesy; Computer Science and Biomedical Engineering; and Electrical and Information Engineering will grow by an average of some 15%. This translates into roughly another 100 new ICC research staff. But where will we find the high-quality researchers to fill all these positions? There is already enormous competition for ICC graduates in the Graz area due to the density of high-tech industry here. Demographic trends indicate that student numbers will decrease rather than increase over the next few years, and many universities (including TU Graz) have experienced a decline in numbers in some ICC subjects recently. Due to the intense focus on digitalisation in developed countries, it will also not be easy to attract talent from these countries to Graz. There is certainly a lot of talent in places such as Iran and India; however, there is also a great deal of bureaucracy involved in getting these people to Graz. The formal paperwork required for a PhD student from such countries can easily take between six and ten months to complete, based on my personal experience. The result is that many candidates lose patience and go elsewhere. I would welcome any clever ideas for solving this human resource problem – feel free to drop me an e-mail.

You can read more about ICC in this edition of TU Graz research, which has a fresh new design, in the contribution by Stefan Thonhauser from the Institute of Statistics in which he presents his research on financial and insurance mathematics. I wish you an enjoyable read!

Stefan Thonhauser:

Stochastic Optimisation in Financial and Insurance Mathematics

Stochastic models are now indispensable for answering practical questions on finance and insurance. Their use needs to be based on a careful model validation process and an awareness of model limitations. In risk management, being able to react to negative trends is essential. Resulting questions can be directly linked to stochastic optimisation problems.

BACKGROUND

Financial and insurance mathematics is playing a prominent role in current probability theory. Its contributions are twofold: the analysis of practical problems is leading to deep theoretical findings, and results, which had been considered to be purely of a theoretical nature, are also feeding into applications.

In research and the application of research findings, a distinction needs to be drawn between various aspects – or fundamental problems. One group of questions deals with the correct pricing of financial claims. In finance, the notion of a fair price broadly speaking dictates that a financial market should remain free of arbitrage after the introduction of a new product. Trading opportunities which lead to riskless profits should not arise. In insurance, however, the correct price of some newly insured risk should maintain the financial stability of an insurer. >

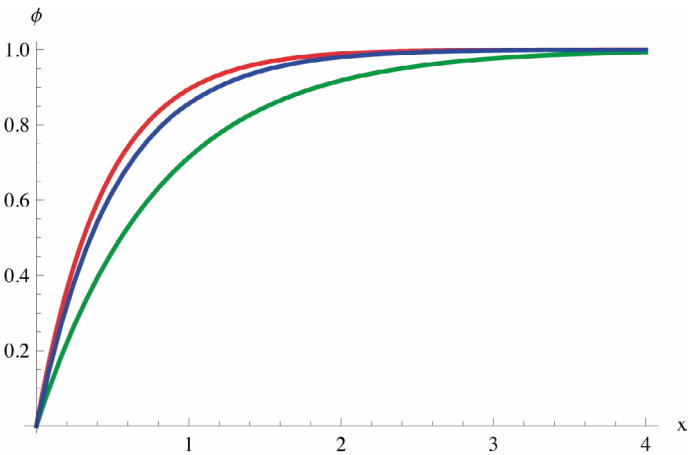


Figure 1
Source: Thonhauser

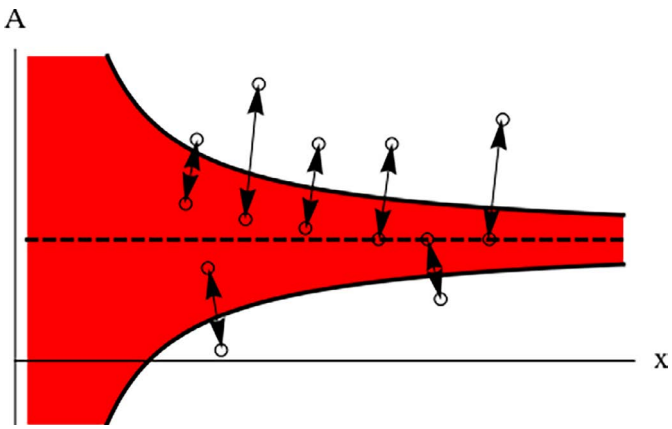


Figure 2
Source: Thonhauser

Stefan Thonhauser
is an associate professor
at the Institute of Statistics.

Source: Baustädter – TU Graz

The second class of problems puts the focus on portfolio and risk management. Typical problems in this context are concerned with the identification of investment strategies which maximise profit measuring functionals, or, conversely, minimisation of risk measures.

One aspect that both types of problem have in common is that underlying objects are modelled by probabilistic quantities. For example, in finance, prices of traded assets such as stocks, currencies or commodities are modelled as stochastic processes. However, in insurance it is crucial to describe claim events which are of a different nature in probabilistic terms.

I will outline two topics that I am currently investigating below.

RISK MINIMISING INVESTMENT

The chosen starting point is the situation of an economic agent (for instance an insurer) who is exposed to some fundamental risk which creates random fluctuations in its income stream. The resultant wealth generated needs to be invested in a financial market which is represented by a risky and a non-risky asset, for the sake of simplicity. The assets generate a low but deterministic and a higher but random interest return. Consequently, the division of wealth is under the control of the agent, who aims to minimize her shortfall probability, i.e. minimising the probability of having a negative wealth position at one point in time.

In typical portfolio problems, random fluctuations are modelled as Brownian motions and adaptions of the investment positions can be continuously implemented. To make the investment control more realistic, transaction costs are introduced into the model with the decisive effect that trading activities are limited to a discrete set of points in time. Optimal timing of interventions and optimal post-intervention positions for the two assets therefore need to be determined. The resulting stochastic optimisation problem is categorised as an impulse control problem. Its solution can be linked to a set of quasi-variational inequalities which involve a heat-equation type partial differential equation.

The theoretical and numerical results produced by this problem produce interesting phenomena. Firstly, they show that assuming an optimal additional risky position can be beneficial. This

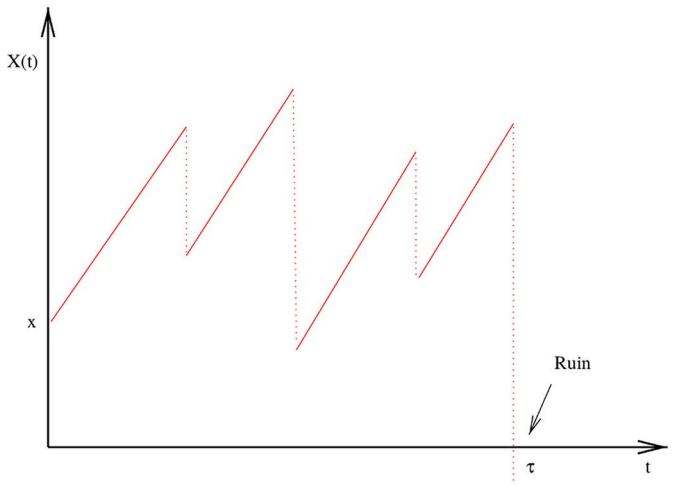


Figure 3
Source: Thonhauser and Preischl

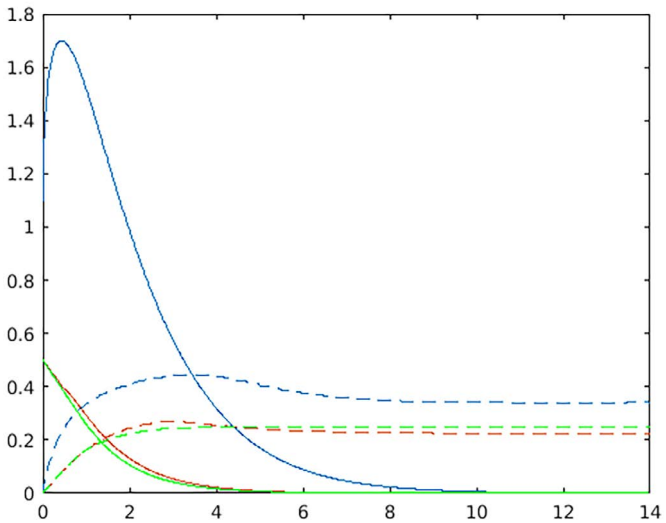


Figure 4
Source: Thonhauser and Preischl

is demonstrated in Figure 1 in terms of survival probabilities (one minus the shortfall probability) where the red line corresponds to the case of fictitious continuous adaptions, the blue one to optimal impulses and the green curve to a purely non-risky investment. Secondly, the optimal strategy is a function of the total wealth position 'x' and the risky investment position 'A' (see Figure 2). The ideal continuous investment position is shown by the dotted line for reference. The strategy consists of jumps back to the red area whenever the (wealth/investment) position is too far from the ideal position. Here 'too far' is part of the problem's solution and can be calculated by solving a free boundary value problem.

OPTIMAL RISK SHARING

This problem deals with the construction of optimal reinsurance models for the minimisation of risk measures. Such models are risk sharing mechanisms between an insurer and a reinsurer – for a deterministic price the reinsurer assumes parts of claim payments.

The underlying model specifies the insurer's surplus process by means of a continuous premium component and a jump process corresponding to claims, in general a piecewise-deterministic Markov process. Figure 3 illustrates a typical sample path. In mathematical terms, reinsurance changes the probability distribution of claims and the control problem focuses on its optimal choice. Fairly general penalty functions for the deficit can be considered as a risk minimisation measure. Solving the resulting problem relies on theoretical arguments which need to be supplemented by numerical results.

Figure 4 shows an iteratively determined numerical solution. The unbroken lines correspond to the expected penalty as a function of the initial surplus (the minimum in green), and the dotted lines represent the optimal risk sharing proportion which is also a function of the surplus.

MOBILITY & PRODUCTION

Fields of Expertise TU Graz

Source: istockphoto.com/fotolia.com

Helmut Eichlseder, Mobility & Production
Source: Lunghammer – TU Graz

One of the key questions relating to the future of mobility is how to determine the right propulsion technology. Since the answer to this question naturally also represents a decisive framework condition for the production of drive systems, the Mobility & Production Field of Expertise at TU Graz creates a valuable synergy in this regard.

The essential requirements for propulsion technologies are that, instead of fossil fuels, they are based on sustainable energy – in the medium term at least – and that they have no significant negative impact on ambient levels of pollution. In principle, this can be achieved by means of electricity using battery electric drives, hydrogen using fuel cells, as well as e-fuels and renewable fuels using internal combustion engines. Since each of these approaches has advantages and disadvantages, the choice of the right technology depends on the specific application. Within the Mobility & Production Field of Expertise, research is carried out in all of the areas mentioned above, some of which has already been presented in this journal.

At TU Graz, research into hydrogen and fuel cells is also firmly established in several institutes and in the HyCentA hydrogen research centre. The following article presents the extensive research work carried out at the Institute of Chemical Engineering and Environmental Technology on the characterisation and optimisation of fuel cells, and describes recently completed research projects and ongoing dissertations which have a special focus on questions concerning the ageing mechanisms of fuel cells.

Katharina Kocher, Kurt Mayer, Bernhard Marius, Bernd Cermenek, Viktor Hacker, Sigrid Wolf:

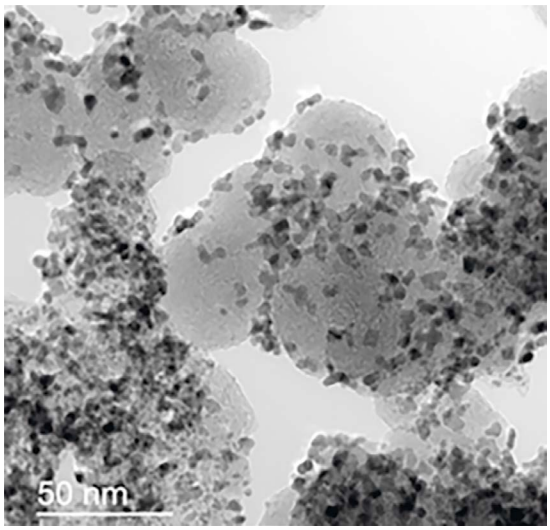
Fuel Cells – Materials and Methods for Prolonging Lifetime

Finding the optimal combination of high performance and durability is a key factor in the realisation of future sustainable energy production systems. The research at the Institute of Chemical Engineering and Environmental Technology focusses on the development of highly innovative materials and efficient operation strategies for fuel cells.

New technologies for emission-free energy conversion are needed in the face of the tug of war between environmental protection and the temptations of the consumer world – especially when it comes to electrical and entertainment technology and transport. Fuel cells enable sustainable electrical power generation for mobile, portable and stationary applications. In the case of transport applications, consumers expect the same ranges and speed of refuelling as they get from conventional mid-size vehicles. Long-lasting, active and stable catalyst systems and innovative operation strategies with very low performance losses are required to guarantee the successful commercialisation of fuel cell systems.

CATALYSIS IN FUEL CELLS

By combining hydrogen and atmospheric oxygen, chemical energy is directly converted to electrical energy via an electrochemical redox reaction. The materials currently used for catalysis, carbon and platinum, reach extremely high reaction rates for the hydrogen oxidation reaction at the anode and the oxygen reduction reaction at the cathode; kinetically ingenious but thermodynamically instable and too costly over the long term.



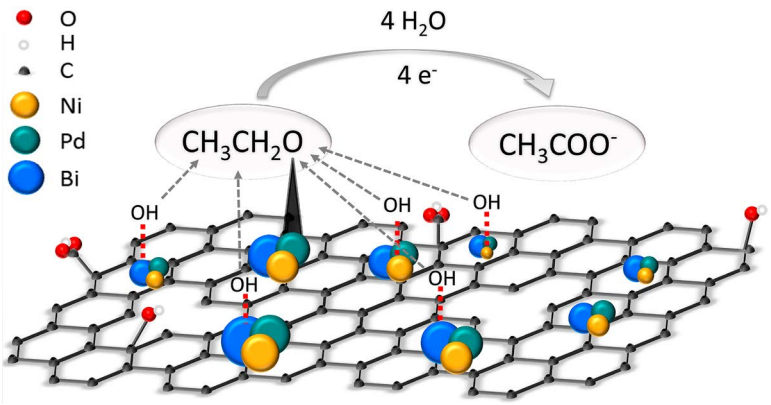


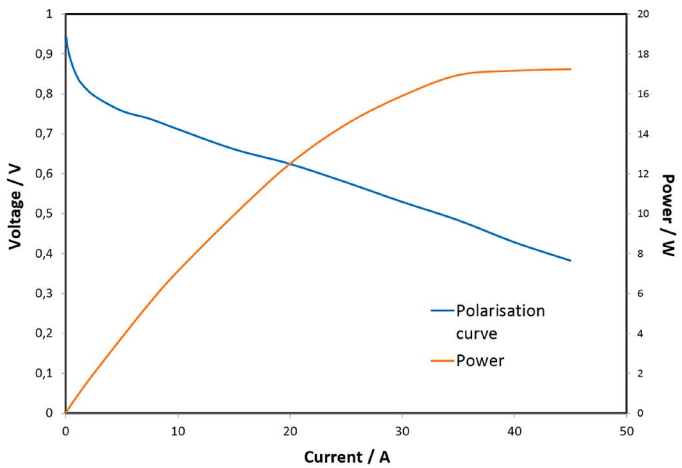
Figure 1: Schematic illustration of the ternary catalyst system and TEM image of platinum distributed on carbon.
Source: Intistute of Chemical Engineering and Environmental Technology

New approaches to chemical functionalisation of the catalysts with conducting polymers simultaneously result in the desired increase of mass activity and the stabilisation of the catalysts. In such a catalyst system, reactive platinum nanoparticles are embedded in a polymer layer which selectively coats the carbon support. The polymer film protects the catalyst against the corrosive environment in the fuel cell, while the polymer structure changes electronic properties of the components, enhancing the reaction rates for catalysis.

Alternative methods to boost reaction rates and stability are the modification of the carrier material and the establishment of alloys in optimal atomic compositions. Graphene has proven to be a promising carrier material, especially because of its unique structural properties. Innovative ternary catalyst systems based on palladium, nickel and bismuth, with a significant increase in mass activity, have been synthesised for direct ethanol fuel cells.

New catalysts are primarily characterised ex-situ, i.e. outside the normal operating fuel cell. A few micrograms of the prepared catalyst ink are placed on a rotating disk electrode and the mass activity and stability are analysed in half-cell measurements. If the catalyst shows promising characteristics, electrodes are manufactured and tested in-situ for performance and lifetime analysis in fuel cells. The development of new catalysts for energy conversion processes, in which multiple electrons are transferred, are particularly challenging. Disadvantageous intermediate steps and products occurring during the catalysis must be avoided, and material availability, durability, high mass activity and good scalability of the production methods are crucial parameters which have to be observed during catalyst synthesis. >

The Fuel Cell Research Group at the Institute of Chemical Engineering and Environmental Technology.
Source: Lunghammer – TU Graz



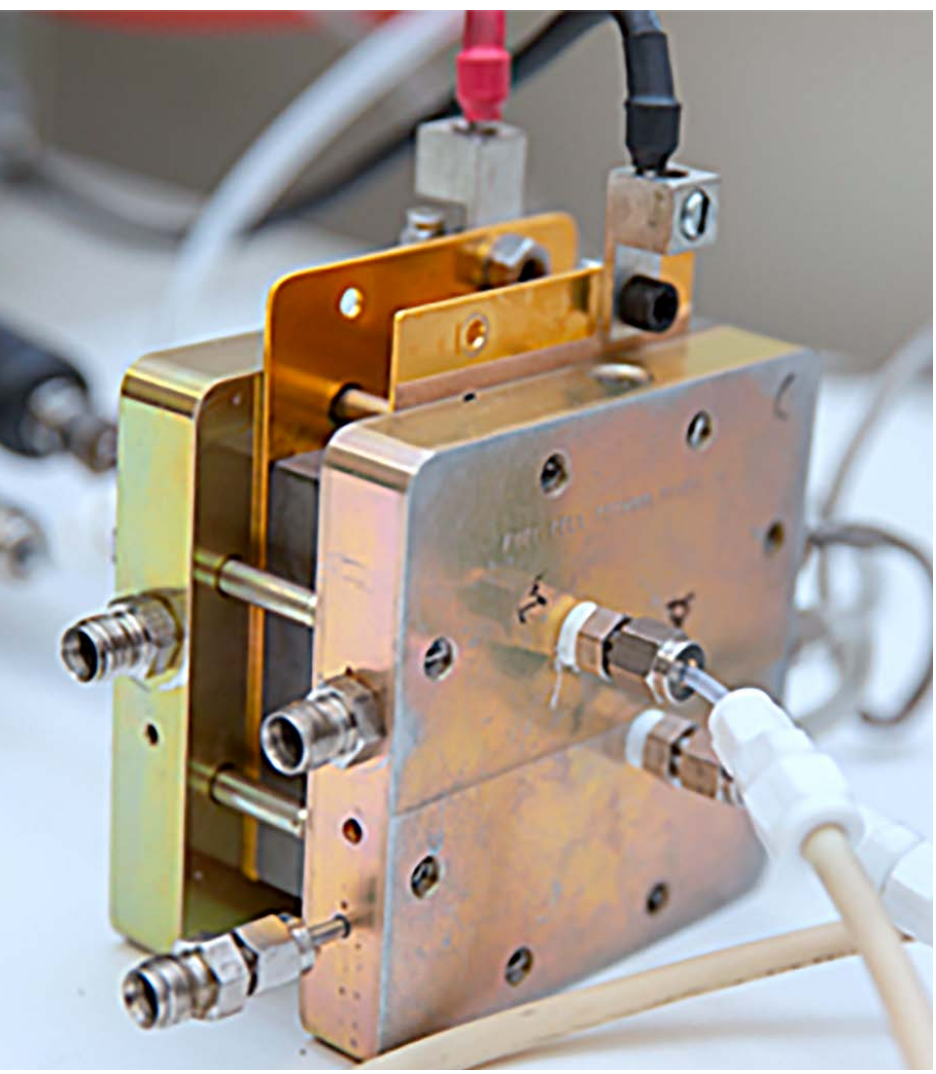


Figure 2: Polarisation and power curve of a 25cm² PEM fuel cell operated with hydrogen and air.
Source: Intistute of Chemical Engineering and Environmental Technology

DEGRADATION OF FUEL CELLS

For mobility applications, a lifetime of 5-10 thousand operating hours must be reached in order to achieve market success. Degradation phenomena which occur during real operation are the limiting factors standing in the way of reaching this target. The rapid current variations under dynamic operating conditions, like in a car, lead to mechanical and chemical degradation of materials due to fluctuations in humidity (water management), voltage, temperature and gas distribution, which eventually result in fuel cell conversion efficiencies which are too low.

The development of satisfactory operating strategies requires an understanding of the fundamental processes in the fuel cell, the electrodes, the membrane, the gas diffusion layers, as well as an understanding of the effects of different operating parameters on local performance. Using carefully designed accelerated stress tests (ASTs), the cell is operated under high load conditions to speed up degradation effects such as membrane thinning, carbon corrosion and platinum agglomeration.

During the experiments, the fuel cells are monitored using electrochemical methods including cyclic voltammetry (CV), electrochemical impedance spectroscopy (EIS) and determination of voltage drop using polarisation curves to specify catalyst plus membrane degradation, current plus voltage characteristics, and performance losses. Structural changes to the electrodes and the membrane are identified by means of electron microscopy. Changes in chemical compositions are investigated using X-ray analysis.

In-situ online monitoring techniques enable new and deeper insights into the degradation mechanisms by means of the visualisation of several performance

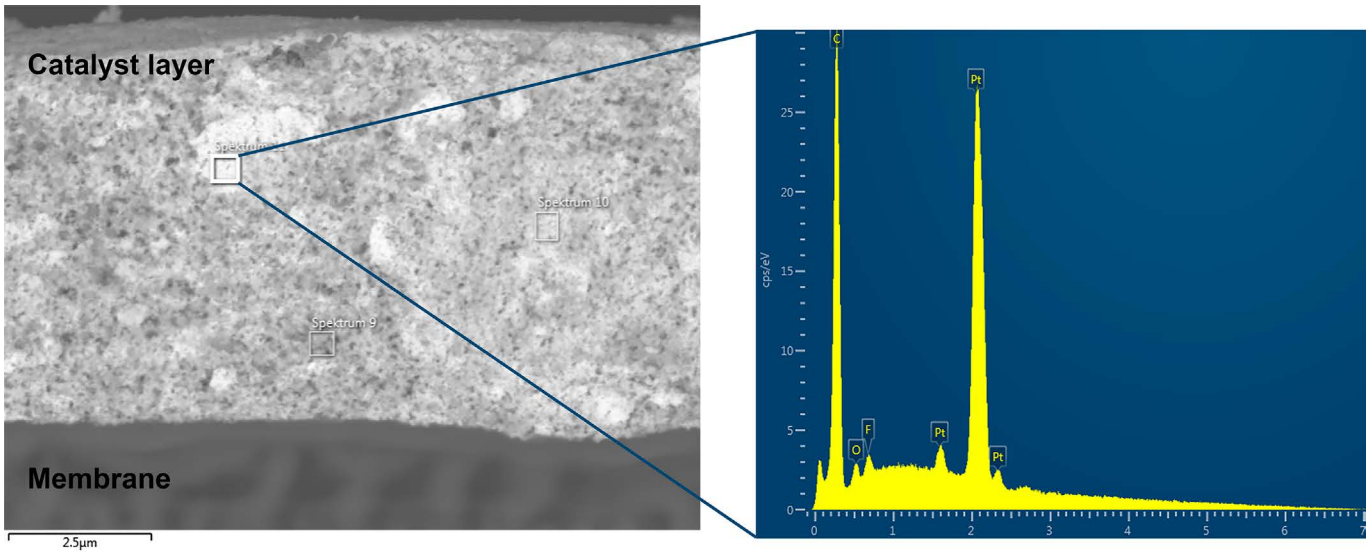
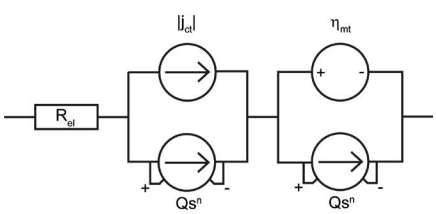


Figure 3: SEM image of an electrode layer, identifying platinum agglomeration in specific areas with EDX for elemental composition analysis.
Source: Intistute of Chemical Engineering and Environmental Technology

parameters during the stress tests. Based on the available data from CV, EIS and polarisation curves, a dynamic large signal equivalent circuit (dLSEC) has been developed. With this new diagnostic tool, fast identification and interpretation of performance losses is now possible and the transient behaviour of a fuel cell under certain harmful operating conditions can be simulated. In addition to the simulation, the total harmonic distortion (THD) is used as an important online monitoring method during cell operation to identify harmful operating conditions which occur. The THD uses a superimposed alternating current signal, which becomes distorted if the local operating point moves into the non-linear region of the polarisation curve. These online monitoring techniques have proven to be a valuable tool for enhancing operating strategies for low temperature fuel cells.



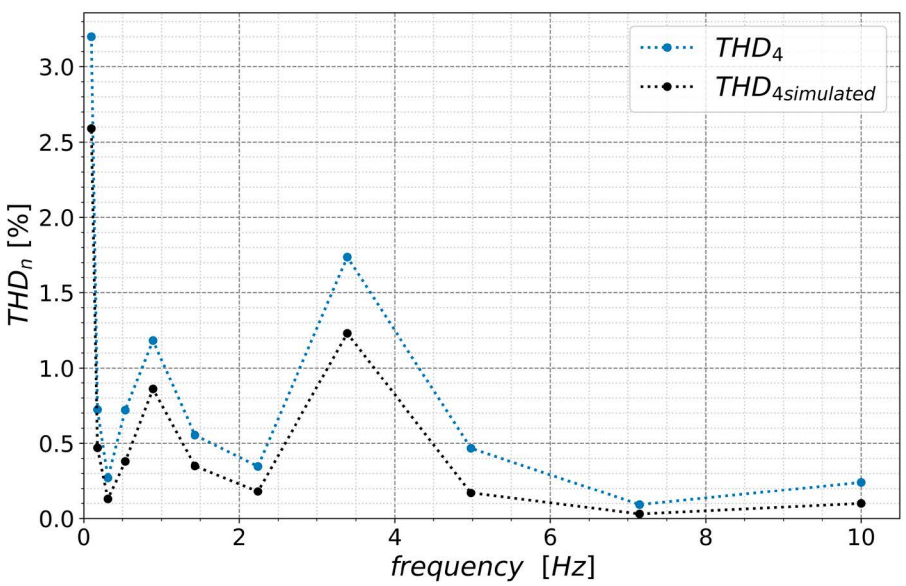


Figure 4: (Top) example of a dLSEC that is used for fitting data: R_{el} simulates the voltage loss; the parallel circuits describe charge transfer losses and mass transport losses. (Bottom) THD peaks at characteristic frequencies in the non-linear region of the polarisation curve.
Source: Intistute of Chemical Engineering and Environmental Technology

SUSTAINABLE SYSTEMS

Fields of Expertise TU Graz

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Urs Leonhard Hirschberg, Sustainable Systems

Source: Lunghammer – TU Graz

In my column in the last issue of this publication, I referred to an urgent public appeal by the Intergovernmental Panel for Climate Change (IPCC): the necessity to drastically reduce greenhouse gas emissions by 45% by 2030 and to zero by 2050, in order to limit global warming to 1.5 degrees Celsius. I pointed out that science and technology can make a long-term contribution to reaching this goal. In fact, the IPCC typically adds to its reports that "research and development are making unexpectedly good progress". But of course, it has not been nearly enough.

The notion that "Technology will save us?" (note the question mark) is the tag line for a lecture series currently under way, which is organised by sustainability4u, an initiative jointly sponsored by all four Graz universities. It aims to question the widespread faith in technological solutions and to look at the ethical questions that are linked to technological advances. Just like last year, when the focus was on the 17 Sustainable Development Goals (SDGs), this year's series is proving a success. It is attracting many students from all the universities, and the talks are being followed by lively debates with the speakers.

If anything, the lectures are making it very clear that it is not enough to look to science and technology to sort things out for us. After all, the problems we have created on this planet have been associated with technological advances. They have enabled us to claim the dubious honour of having impacted the planet we live on as no other species has ever done before us. We are now living in the Anthropocene epoch. Mankind has succeeded in raising CO_2 levels in the atmosphere to over 400ppm – an all-time high – and thereby profoundly changing the climate. But not only that, we have also polluted land and oceans in an unprecedented fashion, and caused the fastest rate of extinctions for millions of years. Insects are currently experiencing an apocalypse, as Thomas Schmickl declared when he gave the first lecture of the series. Meanwhile, as Gottfried Kirchengast pointed out in the third lecture, Austria is not doing nearly enough to curb greenhouse gas emissions. After a fall between 2005 and 2014, overall levels have been rising again in recent years. Austria's traffic-related CO_2 emissions per capita are now 60% above the EU average.

So who will save us? It is clear that it will have to be a joint effort, but with science and technology very much playing their part. Informing the public and creating greater awareness, while keeping the discussions rational, is in some ways just as important as working on new technical solutions. The lecture series has set out to make a contribution to this. And it is not the only initiative of this kind. TU Graz Sustainability Week, which aims to raise awareness of the 17 SDGs, will take place from 3-9 June.

TU Graz is, of course, a technical university, and we are very proud of this. And no one here is naive enough to assume that technology is the simple cure-all. We still believe, however, that we can contribute to solving these urgent problems. The next seed funding for projects carried out by junior researchers in the Sustainable Systems Field of Expertise is currently underway. This is what we need: young, critical minds with new ideas, who understand the systemic nature of our problems, and who want to humbly contribute to solving them.

Markus Gölles,
Martin Horn:

Advanced Control for Sustainable Energy Systems

The growth in renewable energy technologies will render future energy systems more complex and volatile. So advanced control strategies are required to ensure their optimal operation. For this reason, the Bioenergy 2020+ competence centre established a working group focusing on automation and control in close cooperation with the Institute of Automation and Control at TU Graz.

Model-based control strategies for different renewable energy technologies, such as biomass combustion and solar thermal systems, as well as strategies for their optimal interaction will be developed in the course of the cooperation. A key part of the research focuses on developing control-oriented mathematical models for the respective processes. This means that the models reproduce the main dynamic characteristics of the processes sufficiently well but still serve as a suitable basis for controller design. >

Figure 1: Biomass gasification CHP plant in Senden, Germany.
Source: Schneider-photography

JOINT RESEARCH PROJECTS

In recent years a number of joint research projects have been carried out. Numerous master's and doctoral theses have been written in the course of the research projects, leading to a number of scientific publications in renowned journals and presentations at high-profile conferences.

A good example of the collaborative research performed in recent years focused on the model-based control of a biomass gasification combined heat and power (CHP) plant that uses dual fluidised bed biomass steam gasification. The research project is outlined below.

The possibility of simultaneously producing sustainable heat and power means this technology is essential for implementing sustainable energy systems. However, it is currently facing financial challenges due to the high price of raw materials (such as wood chips) and low prices for products (like electricity and heat). In order to maintain, carry out research on and enhance this key technology on an industrial scale, its economic efficiency needs to be increased. So the project investigated various options for improving interaction between the different processes by means of advanced control.

The project was completed in summer 2018 with the successful evaluation of the developed control strategies at an industrial-scale biomass gasification CHP plant in Senden, Germany, owned by the company Blue Energy Syngas (see Figure 1). The main result is an innovative control strategy based on the joint control of an essential process variable, the pressure at the inlet of the gas engines producing the electricity, with two actuators each operating in different frequency ranges.

The evaluation of the innovative control concept revealed that the amount of product gas required, and thus the requisite amount of fuel, could be reduced by 12% in partial load operation while maintaining the same level of electricity production (see Figure 2). At full load, the reduction was estimated at around 7%. Since fuel accounts for a large proportion of the plant's operating costs, these costs could be significantly reduced by means of this particular control engineering measure.

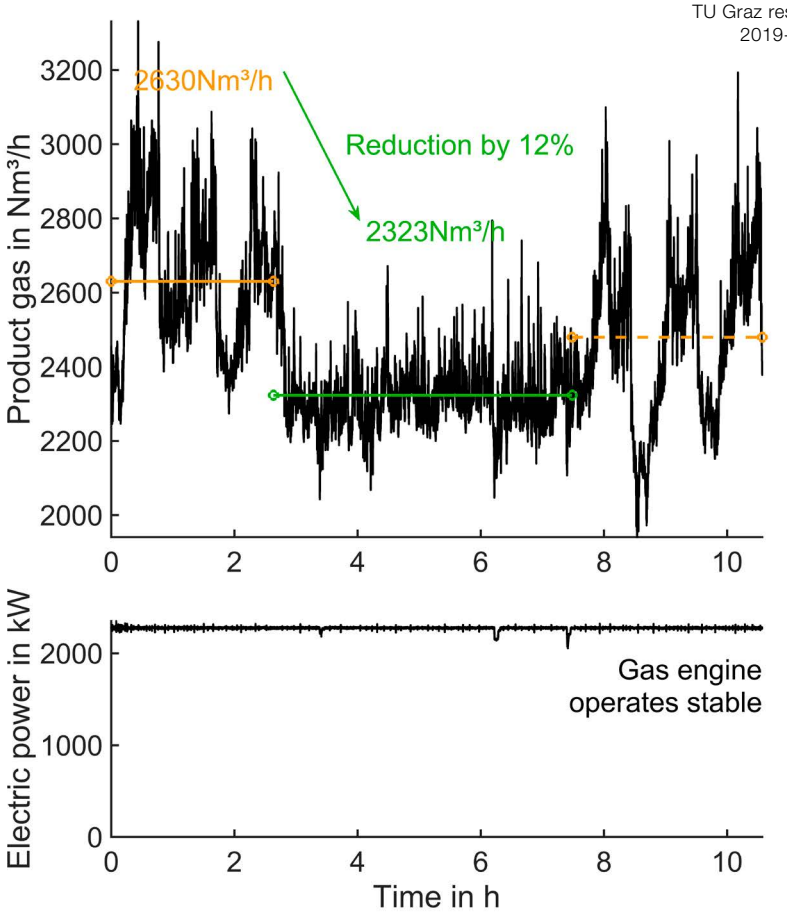

Figure 2: Significant reduction in the amount of fuel required for the same level of electricity production.
Source: Bioenergy2020+

Martin Horn
is head of the Institute of Automation and Control at TU Graz.

Source: Baustädter – TU Graz

Markus Gölles
is Area Manager for Automation and Control at the Bioenergy 2020+ competence centre.

Source: Baustädter – TU Graz

The project was funded by the Austrian Research Promotion Agency (FFG) as part of the NATS BRIDGE Early Stage programme. Other project partners included the Institute of Chemical, Environmental and Bioscience Engineering at TU Wien and the company Repotec.

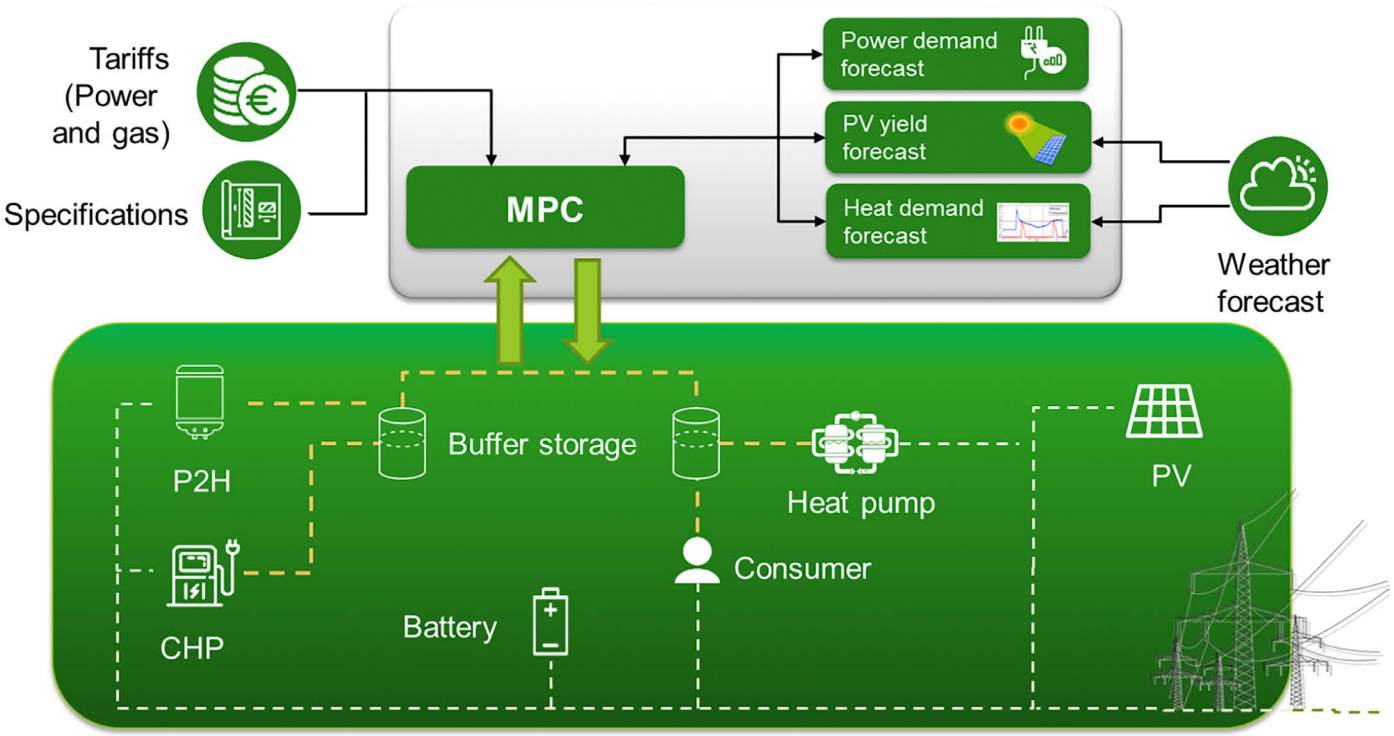

Figure 3: Energy management system for cross-sectoral energy systems (microgrids).
Source: Bioenergy2020+

Apart from the work on the control of different renewable energy technologies, there is a strong focus on the interaction of these technologies at the systemic level, since the shift towards a renewable energy and resource system can only be achieved by means of an appropriate combination of different technologies. This is mainly because of the volatility of many renewable energy technologies: their output is nor controllable, or only partly controllable, and mainly depends on environmental conditions (e.g. wind or sunlight). For this reason, different technologies have to be combined in an appropriate, typically more decentralized way to fulfil all the needs of final consumers. However, the resulting cross-sectoral energy systems, often referred to as microgrids, are becoming more complex and currently control methods are not yet capable of operating such complex systems reliably and efficiently.

In recent years, several joint research projects on the optimal control of microgrids have been carried out. Essentially, the approaches pursued are based on the concept of model predictive control (MPC). This approach uses simple mathematical models describing the behavior of different energy technologies and weather forecast data, as well as the tariffs for different consumables (e.g. natural gas, biomass, etc.) to predict the optimal future operating strategy for the different technologies and forms of energy storage. MPC continuously calculates (e.g. every 15 minutes) the optimal actuating signals for a forecast horizon (e.g. 48 hours) with the aim of minimising a defined cost function (e.g. primary energy use). The first interval of the calculated manipulated variables is then applied to the system and the MPC calculation starts anew, with updates to both the initial state and the different forecasts used. In this context, the development of suitable methods for forecasting the yield of the prevalent volatile energy sources (e.g. photovoltaic systems) and consumers' future demand for electricity and heat is particularly important. On the one hand these methods should be general and adaptive and on the other they should be as simple as possible so that they can be implemented without excessive effort.

Since the optimal interaction of different renewable energy systems is one of the major challenges of the move towards a renewable energy and resource system, the two partners are also trying to combine their specific research results to create a more general and modular framework for the optimal, predictive control of microgrids. This will take the form of modular energy management system for cross-sectoral energy systems which is designed to support the practical application of research findings (see Figure 3).

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